

Mosby's[®] Radiation Therapy

Study Guide and Exam Review

SECOND EDITION

Edited by

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Elsevier
3251 Riverport Lane
St. Louis, Missouri 63043

MOSBY'S RADIATION THERAPY STUDY GUIDE AND EXAM
REVIEW, SECOND EDITION
ISBN: 978-0-443-12592-8

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Printed in India

Last digit is the print number: 9 8 7 6 5 4 3 2 1





Dedication

To my husband, Rick, for your support and encouragement,
and my children, Reia and Malcolm, for your understanding
during those long hours at the computer.

To my parents, for your encouragement and cultivation of my faith.

To my colleagues, for your support of this project and influence on my
professional life.

To every radiation therapy student who has passion and determination
to make a difference in the lives of every patient encountered.

This second edition is dedicated to my teacher and mentor, the
late Elva Dawson, EdD, R.T.(T).

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Preface

Content and Organization

Mosby's Radiation Therapy Study Guide and Exam Review is intended to be a comprehensive study guide and review of radiation therapy curriculum content and the traditional core competencies for the radiation therapist. The guide is divided by subject area. The first seven chapters are subject-concentrated so that students may use them to reinforce notes following lecture or to prepare for subject-related examinations. The final chapter is intended to show readers how curriculum content is applied in clinical situations and should allow students to see how all curriculum content areas are used in everyday practice.

Each chapter contains the following material:

- **Focus questions** , which should give students a glimpse into the highlights of the subject matter. Students and faculty may use focus questions as a means of testing knowledge in the subject area *before* reading through the chapter.
- **Review material** , which is presented using bulleted high-point phrases and detailed illustrations, including drawings, diagrams, radiographic images, and tables, when appropriate.
- **Reference textbooks for suggested reading** , which are texts that are available and used by many programs in radiation therapy, radiation oncology, oncology nursing, and medical physics. The hope is that the user will have access to at least one text on the list to explore theories and find illustrations and justification for the published correct answers.
- **Review exercises** , which are designed to engage the student in active review of the material. There are fill-in-the-blank, complete-the-table, true/false correctives, matching, diagramming, labeling,

and other active-learning exercises among traditional multiple choice–type questions.

ANCILLARIES

The study guide is also available for purchase in electronic format for convenience of use in any setting where the internet is available. Faculty with access to the electronic study guide may use focus questions or end-of-chapter activities during class time for content review.

Online Mock Examinations

To supplement the study guide, online mock examinations are available through Elsevier's Evolve website at <http://evolve.elsevier.com/Levy/radiationtherapy/>. The online mock examinations feature a bank of more than 700 multiple-choice questions in topic areas relating to the core competencies for the radiation therapist. The exam questions may be used for study or exam preparation.

Study Mode

In study mode, students can choose to view questions from all topic areas or select specific area(s) in which they would like to concentrate. During study mode, the user will be provided immediate feedback after answering each question.

Exam Mode

When a student elects to take a mock examination, they will be administered a 200-question test, with questions randomly selected from the question bank. The random selection of questions will provide the student with access to multiple comprehensive examination opportunities while minimizing the chances of seeing repeat questions. At the end of the mock examination, the student and/or faculty will be able to review results and become cognizant of areas needing further study or areas of relative proficiency.

Because some radiation therapy programs require program exit examinations, the mock examinations accompanying the study guide will

provide programs with an exit examination tool and insight into content area strengths and weaknesses per cohort, across cohorts, or for individual students. These examinations may also be used periodically by students and faculty as developmental assessments. For example, a student or program may begin taking mock examinations by the mid-point of the curriculum and then take examinations periodically thereafter, to assess improved and increased understanding of content.

How to Use

The maximum benefits of this study guide and online examinations can be realized when student and faculty implement use starting at the beginning of the academic program. By using the guide from the beginning, content areas may be reinforced gradually. The table of contents is expanded such that students and faculty can selectively review material as curriculum content delivery order prescribed by individual programs. By the end of an academic program, students may use previously completed activities to help prepare for comprehensive exit examinations and to prepare for certifying examinations.

Acknowledgments

I would like to thank all of the radiation therapy professionals who contributed to this project. To Lisa Bartenhagen, radiation therapy professional advocate and program director, for committing to helping with this project during a very demanding period in her professional and personal life. To Robert Laureckas, medical physicist, for committing to helping with this project while meeting the demands of a full-time family leader and medical physicist. To Delores J. Whiteing, radiation therapist and educator, for being courageous in committing to a project such as this that required her to step into an area she had reservations about. To Nishele Dyan Lenards, dosimetrist and educator, for not hesitating in committing to helping with this project in the midst of the most demanding program director duties. To Waylon Malmay, radiation therapist and educator, for taking the leap into teaching and mentoring students in whatever opportunities presented.

To the late Elva Dawson, EdD, RT(T), whom I am so grateful to have met decades ago. Her influence and encouragement are invaluable. Her daily work in this profession impacted so many. Her memory will forever be imprinted on my heart.

Very special thanks to Jinia Dasgupta and Meg Benson, for their guidance, patience, and flexibility. Thanks also to the other Elsevier staff members who contributed to the publication of this work.

Table of Contents

Cover image

Title page

Copyright

Dedication

Contributors

Preface

Acknowledgments

Table of Contents

CHAPTER 1 Overview of Cancer, Imaging, and Management Modalities

Focus questions

Definitions and terminology

Carcinogenesis

Detection and diagnosis

Management modalities

Management modality overview

Review Exercises

For questions 21 to 26, circle the word(s) that would correctly complete the sentence.

The following are true/false corrective statements. If the statement is true, place a T on the line. If the statement is false, place an F on the line and correct the statement so

that it becomes true without changing the intent of the statement.

Think about it.

Bibliography

CHAPTER 2 Radiation Therapy Physics

Focus questions

Atomic Physics

Electromagnetic Spectrum

Particle Interactions and X-Ray Production

Photon Interactions

Radiation Intensity and Beam Quality

Radioactivity and Nuclear Transformation

Review Exercises

Bibliography

CHAPTER 3 Radiation Biology

Focus questions

Radiation Biology Overview

Interaction of Radiation and Matter

Cellular Response

Cellular Radioresponse Factors

Cells

Systemic Response to Radiation

Tissue Response

Whole Body System Response

Acute Radiation Syndromes

Embryo and Fetus

Four Rs of Radiobiology and Time/Dose Considerations

Review Exercises

Circle the Correct Word

Think About It

Bibliography

CHAPTER 4 Radiation Protection and Safety

Focus questions

General Objectives of Radiation Protection

NCRP Dose Limit Recommendations

Minimizing Patient Exposure

MRI Screening

Radiation Protection and Safety Organizations

Units Of Exposure and Methods of Detection

Work Areas

Radioactive Sources

Review exercises

Think About It

The Following Are True/False Corrective Statements. Put T on the Line if the Statement Is True. If the Statement Is False, Place an F on the Line, Then Make the Statement Correct Without Changing the Intent of the Statement

Write the Letter C for Cosmic, T for Terrestrial, or I for Internal Next to the Statement That Refers to the Appropriate Component of Natural Background Radiation

Think About It

Bibliography

CHAPTER 5 Radiation Therapy Equipment and Quality Assurance

Focus questions

Therapy Equipment Evolution

The Linear Accelerator (LINAC)

Other Particle Accelerators

Tomotherapy

Brachytherapy Equipment

CT Simulators

Digital Imagers for Field Verification

Stereotactic Radiation Therapy Devices

Treatment Accessories

Treatment Planning and Record and Verify (R and V)
Systems

Review Exercises

Think About It

Matching

Below Are 13 Components of the Linear Accelerator. In
the Statements That Follow, Indicate Which Components
Are Used. Some May Be Used More Than Once

Write T for True and F for False for the Following:

Bibliography

CHAPTER 6 Treatment Planning

Focus questions

General Simulation Practices

XYZ Coordinate System

Lasers Used for Localization

Positioning, Positioning Aids, and Immobilization Devices

CT Simulation

Computerized Treatment Planning

Interpreting the Treatment Plan

Monitor Unit Calculations

Review Exercises

Bibliography

CHAPTER 7 Oncology Patient Care

Focus Questions

Ethical and Legal Aspects

Interpersonal Communication

Assessment of Acute Side Effects

Acute Chemotherapy-Related Side Effects

Management of Acute Side Effects

Ergonomics and Monitoring

Managing Medical Emergencies

Infection Control

Drug administration

Review Exercises

Bibliography

CHAPTER 8 Clinical Applications in Radiation Therapy

Focus Questions

Head and Neck Cancers

Head and neck review exercises

Lung

Lung review exercises

Alimentary canal: esophagus, stomach, small bowel,
colon, anus

Alimentary canal section review exercises

Pancreas, liver, and gallbladder

Pancreas, liver, and gallbladder section review exercises

Breast

Breast review exercises

Gynecologic tumors

Gynecologic review exercises

Male genital

Male genital review exercises

Urinary

Urinary section review exercises

Central nervous system: brain, spinal cord, pituitary

Central nervous system review exercises

Skin Cancer

Skin cancer section review exercises

Leukemia

Leukemia review exercises

Lymphoma

Lymphoma review exercises

Pediatrics

Pediatric review exercises

Sarcomas: primary bone and soft tissue
Primary Bone and Soft Tissue Sarcoma review exercise
Sarcomas: Primary bone and soft tissue review exercises
Palliative care
Palliative care review exercises
Bibliography

Answer Key

Index

CHAPTER 1

Overview of Cancer, Imaging, and Management Modalities

Delores J. Whiteing

Focus questions

- What are some epidemiologic factors associated with cancer?
- What is carcinogenesis?
- What are some etiologic factors associated with cancer?
- How might you differentiate, compare, and contrast benign and malignant tumor cell populations?
- What are the various roles in cancer management served by surgery, chemotherapy, and radiation therapy?
- Describe the basic principles of surgical oncology.
- Describe the basic principles of chemotherapy.
- What are some examples of biologic response modifiers?
- Describe the basic principles of radiation therapy.
- Compare and contrast various staging and grading systems.
- Define morbidity and mortality.
- Which types of cancers show the highest mortality and incidence rates in the United States?

Definitions and terminology

-

Oncology is the study of a large variety of diseases that behave in a similar way with lethal potential; it is the study of neoplastic disease.

- A

tumor is a neoplasm composed of cells with abnormal proliferation capacity.

- Tumors may be classified as

benign or

malignant .

- Malignant tumors are referred to as

cancers .

- Hippocrates, a Greek physician who lived in the fourth century BCE, was the first to identify a group of diseases that appeared to manifest as a central mass with extensions similar to the anatomy of a crab. He named the disease “karkinos,” the Greek word meaning crab (see

[Figure 1.1](#)). Today we accept the crab as the symbol for the zodiac sign Cancer.

- Hippocrates and physicians who followed him also observed that this disease had the tendency to spread to distant locations in the body. The means by which the disease spread was not completely understood at the time.

- It is understood now that cancer has the ability to spread through three main routes: local extension, lymphatics, and blood.
- When cancer has spread outside of the original location to distant locations in the body, the phenomenon is known as

metastasis .

- The study of cancer as it is distributed in a given population is known as

epidemiology . Epidemiologic studies help reveal patterns of

incidence . Populations may be divided by race, gender, common social habits, occupation, geographical location, age, religion, or marital status, among others.

- The study of cancer causes and risk factors is known as

etiology . Etiologic factors include smoking, asbestos exposure, arsenic exposure, ultraviolet radiation, and nickel compounds, among many others.

- Epidemiologic and etiologic studies have resulted in recommendations for cancer screenings by agencies such as the American Cancer Society.
- Continued study and research means that screening recommendations may change over time.

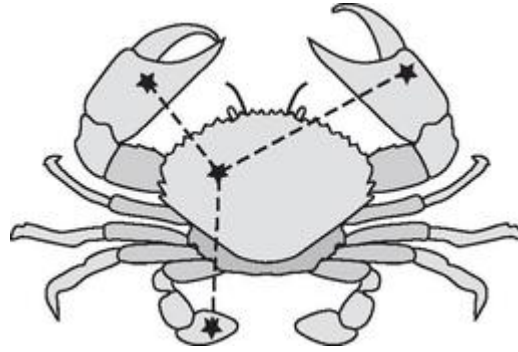


FIG. 1.1 Sketch of the crab.

Carcinogenesis

- Cancer-causing agents are known as *carcinogens* . The multistage process that occurs following exposure to a carcinogen leading to malignancy is termed *carcinogenesis* .
- Development of a tumor likely requires two or more mutations in the stem cells of the tissue of origin, but expression of the mutation as a tumor depends on how the cell population proliferates and a number of host factors.
- Carcinogens may be categorized as chemical factors, physical factors, viral agents, or genetic factors.
- There are known chemicals that increase the likelihood of developing a cancer, such as soot, tar, nickel compounds, asbestos, arsenic, and benzene.
- Some viruses have been proven to cause transformation of normal cells by attaching to the cells' DNA or RNA, therefore leading to multiplied mutations, eventually forming a tumor (see

[Figure 1.2](#)).

- All mammalian cells contain genes known as

proto-oncogenes, oncogenes, and

antioncogenes (tumor suppressor genes).

- Proto-oncogenes are responsible for controlling cellular proliferation.
- Proto-oncogenes can be transformed into oncogenes when activated by the presence of certain viruses or chemical agents.
- When oncogenes cannot be combated by antioncogenes, or negated and eliminated by the body's other immune system components, the oncogenes can take control of proliferation and manifest as a malignancy.
- Ionizing radiation is an example of an extensively studied carcinogen. Cigarette smoke is another.
- Being exposed to a carcinogen does not guarantee the manifestation of a cancer; hyperplasia, metaplasia, or anaplasia may be the result of carcinogen exposure.
- Whether a cancerous condition manifests is influenced by many things including immune status, inherited and intrinsic factors that increase the risk for developing cancer, and the total time over which exposure has occurred.
- Most cancers are not inherited. Those cancers attributable to extrinsic factors are classified as sporadic. Inherited cancers are classified as familial. Familial cancers are a result of a genetic translocation, loss of chromosomes, or amplification of genes causing genetic instability.
- Sporadic cancers typically are caused by multiple outside factors. These cancers are likely the result of a change in cell genes following multiple encounters with a carcinogenic agent.
- Familial cancers show up in families who share a common environment and/or genetic abnormality that is passed down through generations. The mother's side tends to be most influential. Familial cancers tend to have an early age of onset; tumors may be multifocal/bilateral, multiple family members are often affected and each family member has a high risk of multiple primary cancers in their lifetime.

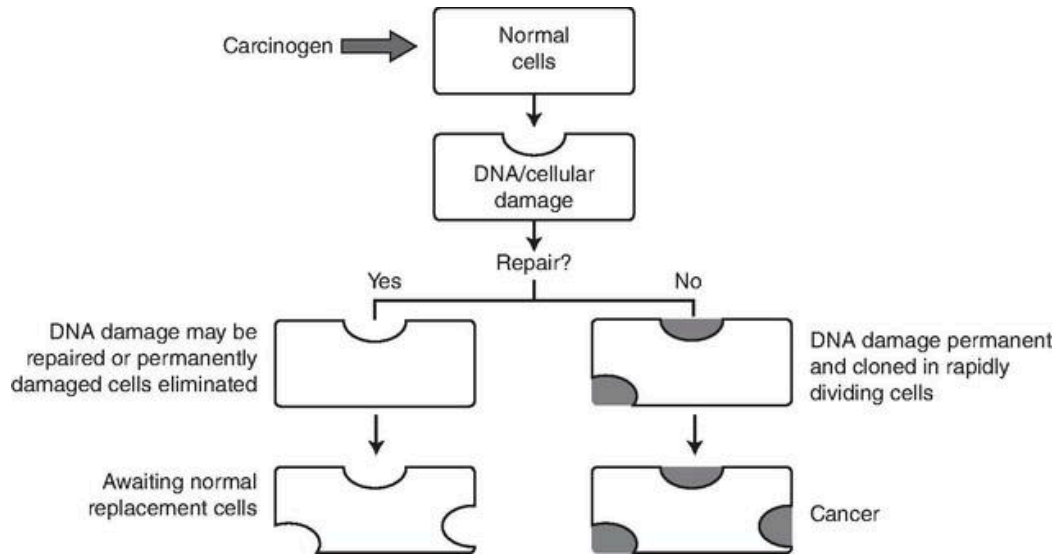


FIG. 1.2 Carcinogenesis process diagram.

Detection and diagnosis

- Taking a medical history is the initial step toward the diagnoses of cancers.
- The medical history should include documentation of:
 1. Chief complaint and main symptoms
 2. Details of known or present illnesses
 3. Review of all body systems
 4. Medical history
 5. Social history
 6. Family history
 7. Work history
- Reliance on early symptom reporting is the foundation of cancer detection and subsequent management.
- Physical examination is also critical in diagnosing cancer.
- The examiner should check the status of the skin, lymph nodes, oral cavity, breast, testis, perineum, and central nervous system.

The American Cancer Society publishes 7 Warning Signs of Cancer signified by the acronym CAUTION.

C change in bowel habits

A a sore that will not heal

U unusual bleeding or discharge

T thickening or lump

I indigestion or difficulty swallowing

O obvious change in a wart or mole

N nagging, persistent cough

The next critical step toward accurate diagnosis is to obtain a cell sample.

- A

biopsy is the removal of tissue or cells for microscopic evaluation.

- There are several types of biopsy procedures including:

1. Collection of body secretions such as sputum or urine
2. Scraping or curettage of tissue surfaces
3. Aspiration of fluid as from the chest, abdomen, fluid-filled mass, or other body cavity with a small bore needle (fine needle aspiration [FNA])
4. Core needle sampling in which a larger bore needle can actually “punch out” a bit of tissue from a mass
5. Dermal punch is similar to core needle; however, a special instrument is used to remove a plug of tissue
6. Scalpel incision or excision; incision refers to cutting into a mass, whereas excision refers to the total removal of a mass with a margin of gross normal tissue
7. Direct biopsy or endoscopy uses special flexible, fiber optic instruments directed into a body lumen with an instrument on the end for tissue sampling
8. Open surgery is a formal surgical procedure performed under general anesthesia that allows the surgical oncologist to visualize the tumor and surrounding tissues

- leading to an opportunity to perform a total excision of the tumor and any areas appearing positive for disease
- To help determine the proper management strategy and to give caregivers an idea about the prognosis of the patient, tumors may be classified and sorted by:

- a. Biologic behavior—benign versus malignant, slow-growing versus aggressive
- b. Anatomic site—breast, prostate, pancreas
- c. Tissue origin—epithelial, connective, reticuloendothelial
- d. Differentiation—how well the cells can carry out the normal functions of cells of this origin; how well the cells exhibit normal physical characteristics; also known as the tumor grade

Differentiation is divided into four categories: well differentiated, moderately well differentiated, poorly differentiated, and undifferentiated or anaplastic

Degree of differentiation is determined only by examination of cells obtained through biopsy under a microscope

Cancer cells that have the most characteristics of the original cell are well and moderately well differentiated

Cells in which the original cell is barely or not distinguishable are poorly differentiated or undifferentiated

- e. Stage—the extent of disease; whether there is only local involvement or involvement of distant tissues (metastasis)
- Cancerous tumors originating in epithelial tissues are referred to as

carcinomas .

- Epithelial tissues line, cover, or are glandular. Cell types that form epithelial tissues include basal cells, squamous cells, and transitional cells.

ADENO + CARCINOMA = adenocarcinoma; cancerous tumor of glandular epithelium.

- Cancerous tumors originating in connective tissues are referred to as

sarcomas .

- Connective or mesenchymal tissues provide our bodies with support and comprise our blood tissues. Cell types that form these tissues are osseous, muscular, fatty, cartilaginous, and vascular.

OSTEO + SARCOMA = osteosarcoma; cancerous tumor of the bone

- The suffix -OMA may be combined with other root words to indicate benign growths in various tissues.

LIP + OMA = lipoma; benign tumor of fatty tissue

- There are exceptions to the root + suffix rule such as:

LYMPHOMA = malignancy originating in the lymphatic system

LEUKEMIA = malignancy originating in the blood, specifically the white blood cells

GLIOMA = malignancy originating in the central nervous system

- There are many organizations responsible for staging system recommendations.
- The American Joint Committee for Cancer Staging (AJCC), the International Union Against Cancer (IUCC), the Pediatric Oncology Group (POG), the World Health Organization (WHO), the International Federation of Gynecology and

Obstetrics (FIGO) are a few organizations with well-known recommendations for certain cancers.

- The stage of disease may be assessed clinically or pathologically.
- Clinical staging requires the use of the practitioner's senses.

What is seen, felt, or heard on physical examination can provide enough information for clinical staging.

- Pathologic staging requires the use of imaging and histologic study. Imaging studies such as CT, MRI, or positron emission tomography (PET) and tissue sampling provide information for pathologic staging (see

Table 1.1 ,

Figures 1.3 –

1.5).

- The most widely used and internationally accepted staging system is the TNM system.
- The TNM system describes the

tumor 's size, circumference, depth of invasion, or mobility status.

The involvement of lymph

nodes , their size, and mobility are also evaluated. Finally, the presence of distant

metastasis is assessed as well.

- Each category may be assigned a numerical value. Typically, the values are 0 to 4. Once each category has been assigned a value, then multiple combinations may be placed in stage groups indicated by Roman numerals (see

Table 1.2).

- Whenever the value “X” is assigned to one of the categories, that indicates that the status could not be accessed and has to be documented as “status unknown.”

Table 1.1

SMALL CELL LUNG CANCER, TYPICAL IMAGING ON PRESENTATION

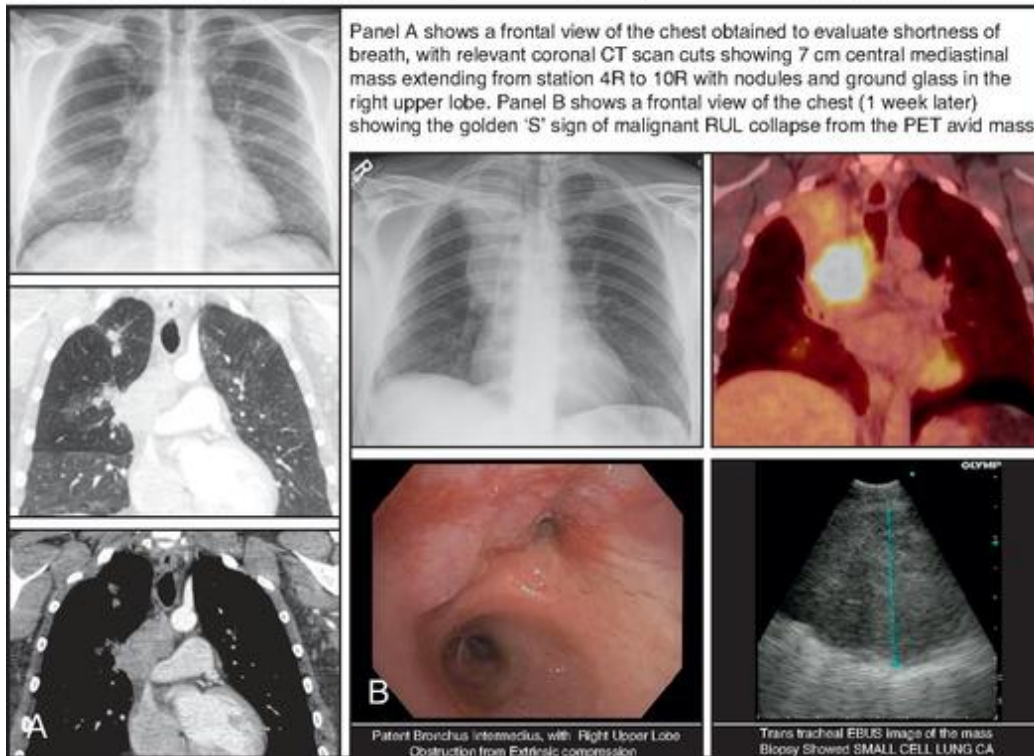


FIG. 1.3 (A) Chest x-ray, computed tomography (CT) scan, and positron emission tomography (PET) imaging showing the classic radiographic presentation of small cell lung carcinoma. (B) Bronchoscopic image showing submucosal disease and extrinsic compression of the right upper lobe (RUL) by tumor, with transtracheal endobronchial ultrasound (EBUS) image of the mass (just prior to biopsy). Landsberg J.

Manual for Pulmonary and Critical Care Medicine, 2018, Fig. 9.19: (A) Chest x-ray, CT scan, and PET imaging showing the classic radiographic presentation of small cell lung carcinoma. (B) Bronchoscopic image showing submucosal disease and extrinsic compression of the RUL by tumor, with transtracheal EBUS image of the mass (just prior to biopsy). Image Identifier: pii:B9780323399524000093/f09-19ab-9780323399524.

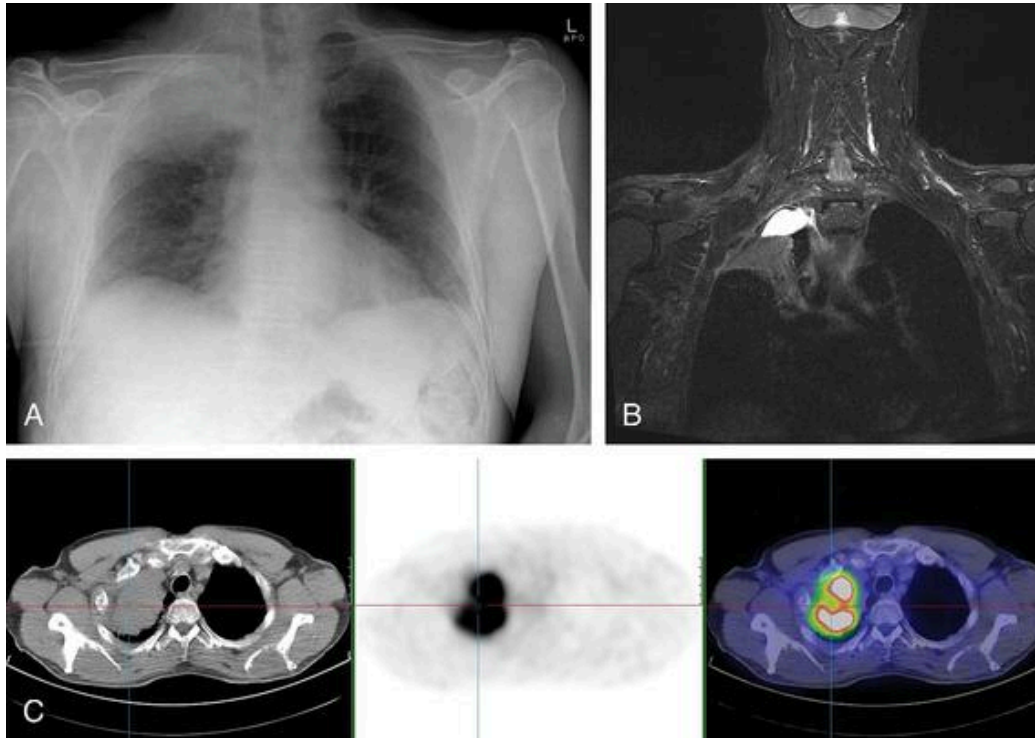


FIG. 1.4 (A) Preoperative chest x-ray demonstrates a right apical lung tumor. (B) Coronal short tau inversion recovery (STIR) magnetic resonance imaging following induction chemoradiation demonstrates right apical lung tumor in a patient with T1 nerve root involvement. (C) Axial CT scan (left), axial positron emission tomography (PET) scan (center), coregistered CT and PET images (right) demonstrating right apical lung tumor. *The Wrist and Hand: Pain Medicine: A Case-Based Learning Series* , 2023, Fig. 3.19: (A) Preoperative chest x-ray demonstrates a right apical lung tumor. (B) Coronal STIR magnetic resonance imaging following induction chemoradiation demonstrates right apical lung tumor in a patient with T1 nerve root involvement. (C) Axial CT scan (left), axial PET scan (center), coregistered CT and PET images (right) demonstrating right apical lung tumor. Image Identifier: pii:B9780323834537000033/f03-19-9780323834537.

(From Davis GA, Knight SR. Pancoast tumors.

Neurosurg Clin North Am . 2008;19(4):545–557 [Fig. 1].

<https://doi.org/10.1016/j.nec.2008.07.002> ,

<http://www.sciencedirect.com/science/article/pii/S1042368008000314>
.)

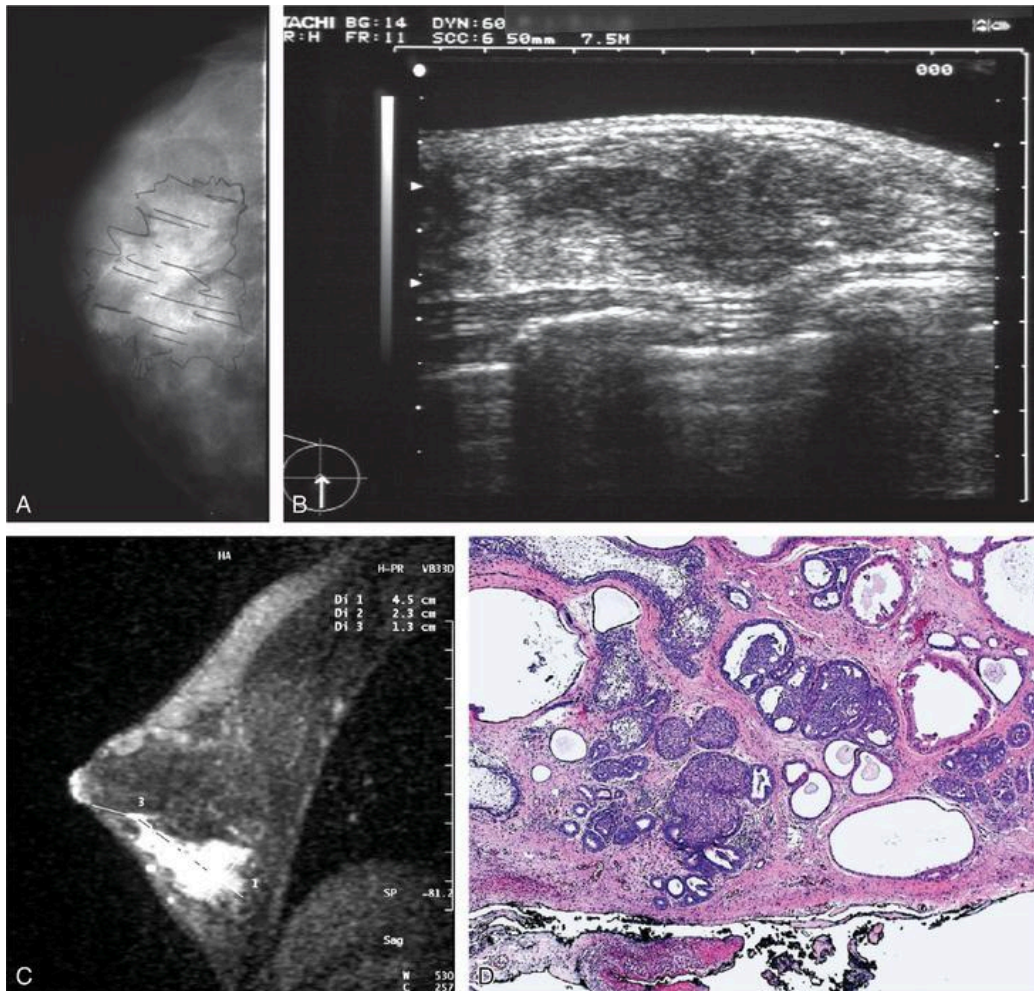


FIG. 1.5 (A) Mammography of the right breast of a 42-year-old woman showing a large multilobular tumor. Note the associated microcalcification. (B) Ultrasound with cystic change. (C) MRI scan demonstrating intense enhancement. (D) Low-power view demonstrating the histological features of fibrocystic change and extensive ductal hyperplasia. *Breast Pathology*, Third Edition, 2024, Chapter 18: Fibrocystic Change and Usual Epithelial Hyperplasia of Ductal Type Fibrocystic Change, Fig. 18.26: Juvenile papillomatosis. (A) Mammography of the right breast of a 42-year-old woman showing a large multilobular tumor. Note the associated microcalcification. (B) Ultrasound with cystic change. (C) MRI scan demonstrating intense enhancement. (D) Low-power view demonstrating the histological features of fibrocystic change and extensive ductal hyperplasia. ISBN: 978-0-323-79522-7. Image Identifier: pii:B9780323795227000187/f18-26-9780323795227.

Table 1.2

Stage Grouping Sample			
Stage I	Stage II	Stage III	Stage IV
T1 N0 M0	T2 N1 M0	T3 N2 M0	T4 N3 M1

Management modalities

- The three main cancer management modalities include surgery, chemotherapy, and radiation therapy.
- Immunotherapy is another cancer management modality; although not used as widely as the main three, its use may become more prevalent as we continue studying the mechanisms for carcinogenesis, remission, and recurrent disease.
- The specialized areas of medical practice that apply these modalities are known as surgical oncology, medical oncology, and radiation oncology.

Angiogenesis

- The growth success of a tumor is governed by a complex interplay between the cells of the tumor and surrounding tissue
 - A powerful example of this interplay is the process of tumor angiogenesis (also known as tumor neovascularization).
- Tumor growth depends on access the tumor has to oxygen and nutrients as well as its ability to remove carbon dioxide and metabolic waste.
- Growing tumors require direct access to the circulatory system.
- Tumor access to the circulatory systems is secured through angiogenesis, whereby the tumor cells encourage the ingrowth of capillaries and larger vessels from neighboring normal tissue.

- Tumor cells then recruit these vessels through the freeing or release of angiogenic factors, which results in the proliferation of endothelial growth factor and unquestionably, tissue growth factor- β .

Surgery

- Surgery is a local approach used to diagnose or aid in disease staging, palliate symptoms, curatively manage, or as an adjunct (complementary) to other cancer management modalities.
- Before surgery, radiation therapy or chemotherapy may be given to increase the likelihood of a complete resection. This is often referred to as neoadjuvant therapy.
- Surgery may also be used following cancer therapy for rehabilitation, restoring of normal organ function, or cosmetic restoration.
- Surgical diagnosis is achieved through tissue sampling. Some biopsies may be performed in the surgical suite with the aid of specialized imaging modes such as ultrasound or fluoroscopy.
- Nonoperative staging is desired and essential before a curative surgical procedure is planned; however, surgical lymph node dissections have been helpful in staging certain cancers, such as breast cancer and those of the head/neck region.
- Historically, surgical staging laparoscopies were performed for systemic cancers such as lymphoma; today, the advances in medical imaging have made invasive procedures such as this unnecessary.
- Surgery may be used to debulk or decrease the size of a tumor before other management modalities are attempted.
- Large tumors may be difficult to totally excise when they may be invading neighboring tissue, wrapped around a neighboring organ, or in an anatomic region where it may be difficult to excise without compromising the quality of the postsurgical life for the patient.

- Surgical treatment is optimally used as curative therapy, where the goal is for the patient to be pronounced cancer-free or in remission after surgery.
- Cancers that are easily cured with surgery are small and localized with no evidence of distant metastasis.
- The role of surgery may also be prophylactic; an example may be a bilateral mastectomy for a patient with diagnosed breast cancer in one breast, who is at an increased risk for developing cancer in the opposite breast.
- The surgical oncologist has to be knowledgeable of all cancer types, patterns of spread, various staging and grading systems, and be proficient in surgical technique suitable for cancer detection and/or eradication of disease.
- Since surgery is a local approach, the anticipated side effects are local.
- Once a patient has been determined as a suitable candidate for surgery, he or she should be educated on possible postsurgical complications such as pain, swelling, infections, limited or altered function, lengthy rehabilitation, or recovery and cosmetic consequences.
- Not all patients are surgical candidates; Patients with preexisting medical conditions may have an unacceptable increase in surgical risk.
- Risks associated with surgery include adverse reactions to anesthesia, infection, and potential loss of function.

Chemotherapy

- Chemotherapy is the use of anticancer drugs (cytotoxic drugs) or hormonal agents to cure, palliate, maintain remission, or as a prophylactic measure.
- Chemotherapy is a systemic treatment (killing cells of the primary tumor and those that may be circulating through the body).

- Some chemotherapy drugs can enhance the effects of radiation by increasing cellular sensitivity.
- Chemotherapy is prescribed and supervised by a medical oncologist.
- Chemotherapy administration methods depend on the types of drugs prescribed.
- Chemotherapy may also be used as an adjunct to other cancer management modalities.
- In most cases, chemotherapy is administered intravenously or orally. Its use is a systemic approach to managing cancer.
- There are a few cytotoxic drugs that may be applied topically or administered locally.
- The effectiveness of cytotoxic drug therapy is influenced by the tumor cell burden, the growth rate of the tumor, the vascular supply, the patterns of cell division, and the concentration of the drug made available to malignant cells.
- Cancer cells have the ability to proliferate considerably and do not die after programmed number of cell divisions as normal cells do.
- There are five phases of the cell cycle: G₀, G₁, S, G₂, and M.
- Cytotoxic drugs may be grouped into two broad categories: phase-specific and non-phase-specific.
- Phase-specific drugs are most effective during certain stages of cell division. For these drugs to work, the tumor cells must be dividing. As cell division occurs, in many malignant populations every 4 to 6 hours, it is desirable that phase-specific drugs be available during multiple cell dividing cycles. The longer the drug is in the system, the better chance for death of malignant cells. These drugs are the ones you may observe being administered over a long period (i.e., a few days of continuous infusion).
- Non-phase-specific drugs are effective at any stage of cell division and may be effective on tumor cell populations that are no longer dividing or are sparsely dividing. These drugs are the ones you may observe administered as a bolus injection or taken orally.
- Cells are most sensitive to radiation during G₂ and M phases of the cell cycle.

- Cells that are rapidly dividing are more sensitive to the effects of radiation and chemotherapy.
- Further, cytotoxic drugs may be divided into classes such as (see

Figure 1.6):

Alkylating agents
 Antitumor antibiotics
 Antimetabolites
 Plant alkaloids
 Nitrosoureas

- Although hormonal agents and biologic response modifiers (BRMs) in the management of cancer are also administered under the care of a medical oncologist, these agents have a different action than the cytotoxic groups.
- The cytotoxics are intended to act as a poison to malignant cells.
- Hormones are administered to counteract the body's response to the presence of certain types of cancers.
- Biologic response modifiers are administered to induce or enhance the body's natural response to the presence of disease or physiologic imbalance.

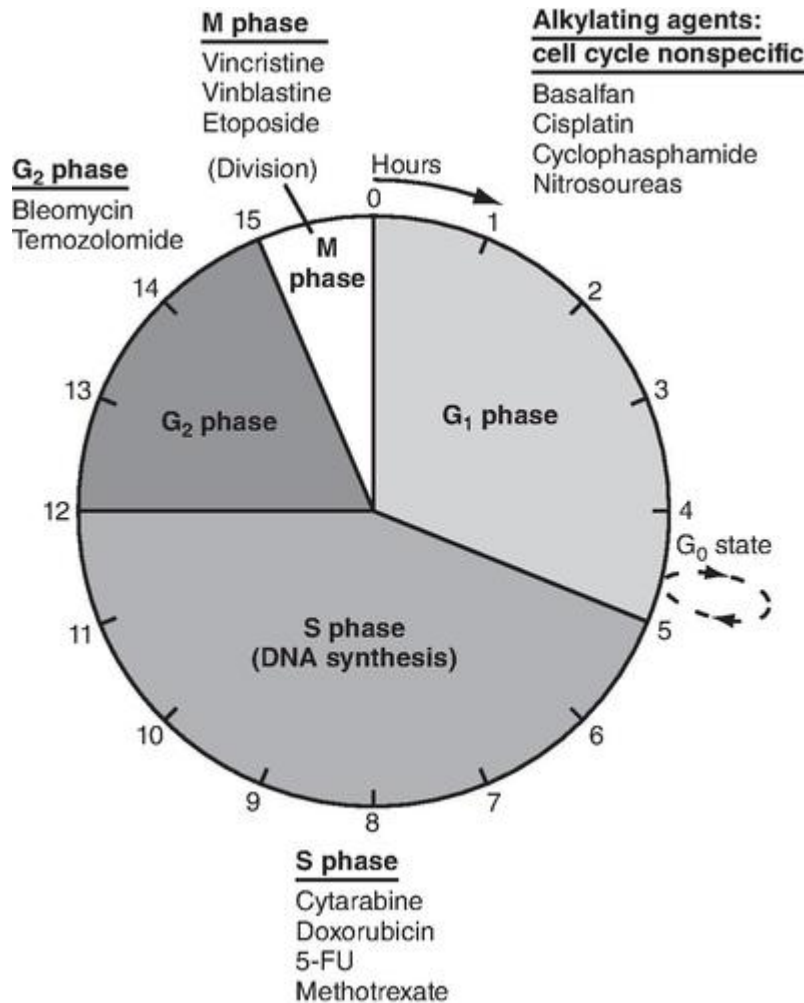


FIG. 1.6 Cell cycle and cytotoxic targets of common antineoplastic agents.

Examples: Certain breast cancers nurtured by the presence of estrogen may be stunted by the administration of an antiestrogen, such as tamoxifen.

Central nervous system cancers may cause increased swelling in the cranium. An anti-inflammatory, such as dexamethasone, could decrease swelling.

Monoclonal antibodies may be harvested from cancer infected animals and given to the cancer patient to induce an antigen–antibody complex reaction so that the patient may fight the disease.

- Some chemotherapy agents sensitize the cancerous tissues to other cancer therapy such as radiation. They are called

radiosensitizers .

- Some chemical agents protect the normal tissues from other therapy such as radiation. They are called

radioprotectors .

- Radiosensitizers and radioprotectors have limited duration, so it is important to administer radiation in a timely manner after these drugs are administered.
- Single drugs may be administered, but most often drugs are used in combination to improve effectiveness.
- Past

clinical trials, the known biologic behavior of the cancer, its vascular supply, and spread pattern strongly influence the use of chemotherapy as a management strategy.

- In instances where there is no evidence of systemic disease, but there is a strong possibility of systemic disease in the future, as past case studies have proven, the prophylactic use of chemotherapy is warranted.
- When chemotherapy is administered systemically, the side effects manifest systemically.
- Cytotoxic drugs are not only toxic to malignant cells but to normal cells as well. The number of surviving cells decreases as the cycles of therapy progress, but regrowth may start if therapy is prematurely stopped (see

Figure 1.7).

- Administers and handlers of chemotherapy agent containers should take care not to expose skin or eyes to drugs.
- Some common side effects across chemotherapy cytotoxic agent classes are myelosuppression, nausea, vomiting, alopecia, skin rashes, diarrhea, renal disease, and cardiomyopathy.
- All chemotherapy agents do not have the same side effects.

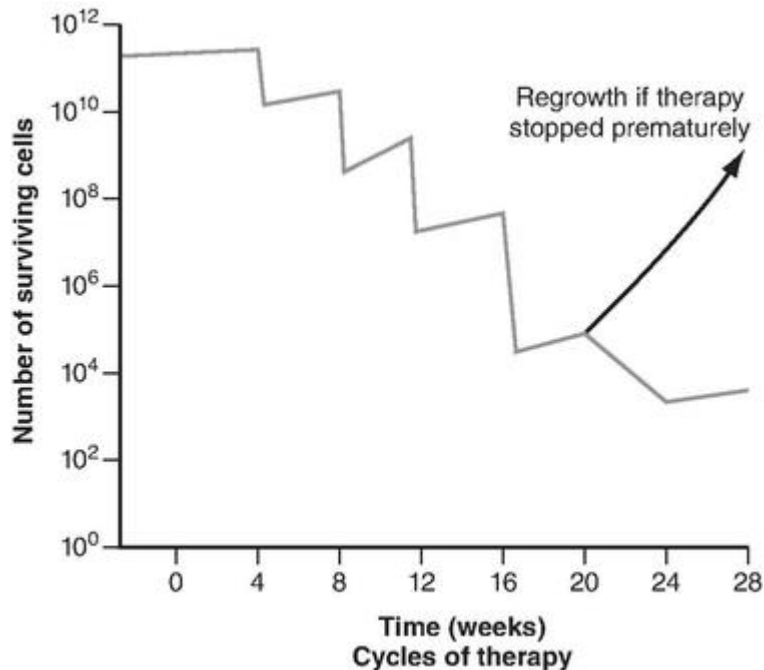


FIG. 1.7 Cell survival curve for cytotoxic chemotherapy administration.

Radiation Therapy

- Radiation therapy, like surgery, is a local approach to cancer management.
- Radiation therapy is further limited to areas in which a curative dose may be delivered without harming critical structures.
- Patients with tumors that are diffuse throughout the body are not candidates for radiation therapy.
- Radiation may be used to cure, palliate, maintain remission, or for prophylaxis.
- Benefits of radiation therapy include preservation of function and better cosmetic results.
- The effectiveness of radiation is similar to that of chemotherapy and is influenced by the tumor cell burden, the sensitivity of both the cancerous and normal tissues to radiation, the cumulative dose given, the type of radiation applied, and the patterns of cell division and the vascular supply.

- Patients with tumors that are diffuse throughout the body are not candidates for radiation therapy.
- The law of Bergonie and Tribondeau describes the most radiosensitive cells as ones that rapidly divide, divide often, have a long mitotic future, and are undifferentiated.
- Tumors with a larger cell burden tend to have necrotic, slow-dividing cells at the core. Necrotic, slow-dividing cells have decreased radiosensitivity.
- Reaching lethal doses for the tumor while sparing normal tissue from damaging doses is challenging.
- The

Therapeutic ratio diagram is a measure of potential success with radiation (see

[Figure 1.8](#)).

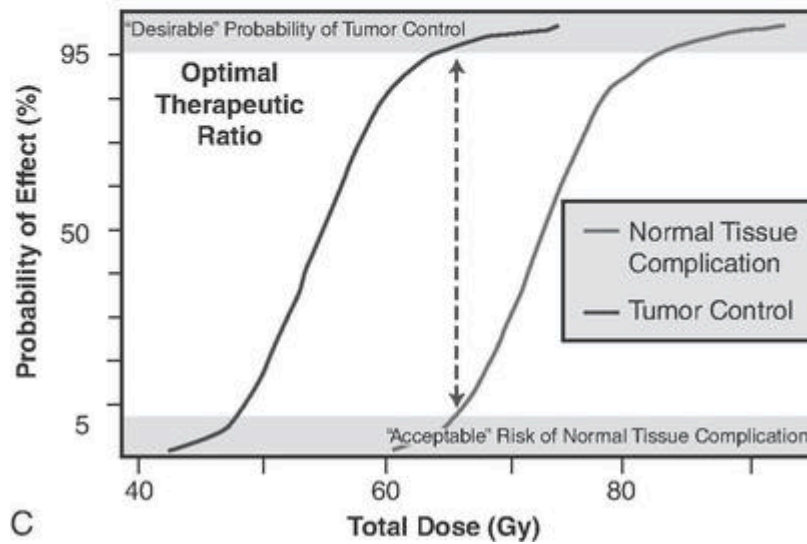
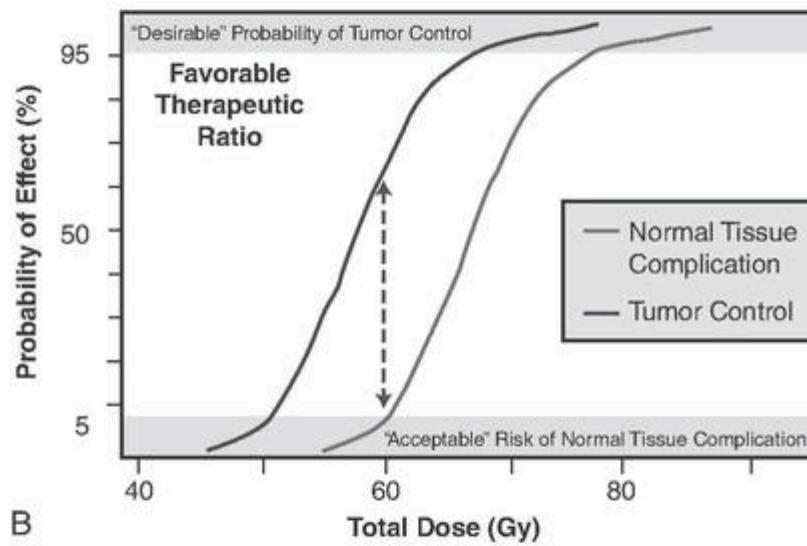
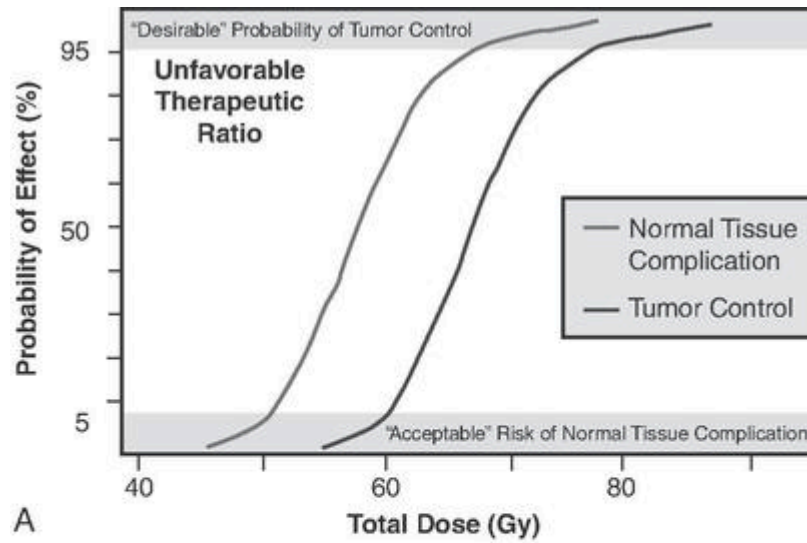


FIG. 1.8 Therapeutic ratio diagrams. (A) Poor therapeutic ratio; (B) good therapeutic ratio; (C) optimal therapeutic ratio.

$$\text{Therapeutic ratio} = \frac{\text{Normal Tissue Tolerance Dose (NTTD)}}{\text{Tumor Lethal Dose (TLD)}}$$

- When the ratio is 1.0 or greater, the potential for success is favorable.
- Strategies such as fractionation and complex treatment planning assist in making a favorable therapeutic ratio easier to achieve.
- Adverse long-term side effects of radiation are minimized by careful treatment planning and the use of appropriate fractionation schedules.
- Certain types of radiation are more lethal to tissues than others.
- When conditions are conducive, adequate doses of radiation can lead to cell death in the local area targeted.
- When tumors are localized and confined, radiation can be focused over the tumor and local areas of anticipated cancer spread, with the expectation of complete eradication of disease.
- In instances where the tumor is large and there is proven distant metastasis, radiation may also be administered to shrink the tumor to relieve symptoms due to compression or obstruction.
- Radiation therapy may also be used as an adjunct to surgery and or chemotherapy to “sterilize” any areas of possible disease spread.
- Radiation therapy is a local approach, so side effects remain local.
- Patients undergoing radiation therapy must be made aware of anticipated side effects as indicated by the region irradiated.
- Radiation side effects may include hair loss in the area, local redness and swelling, nausea, and vomiting when irradiating the abdomen and possibly diarrhea when irradiating the bowel.

- The radiation oncologist must be knowledgeable of the various cancer types, their sensitivities/resistance to radiation, proven dose and fractionation protocols, tolerance doses of normal tissues, and the biologic behavior of certain types of cancers and their spread patterns.
- Some radiation oncologists may specialize in certain age-related cancers or certain cancers of anatomic regions.
- Newer radiation therapy techniques of adaptive therapy, conformal therapy, image-guided radiation therapy, intensity-modulated radiation therapy, stereotactic radiosurgery, and proton treatments take advantage of the advances in diagnostic medical imaging and are able to almost “paint the tumor” with radiation, which greatly spares the normal tissues.

Brachytherapy

- Brachytherapy, or “short-distance therapy,” uses radioactive materials.
 - Examples: cesium-137 (^{137}Cs), iridium-192 (^{192}Ir), palladium-103 (^{103}Pd), cesium-131 (^{131}Cs), or iodine-125 (^{125}I).
- Brachytherapy provides a high dose to a small area, which spares normal surrounding tissue.
- Radioactive sources can be placed next to or directly into the tumor.
- Brachytherapy is accomplished by using a multitude of techniques, including interstitial, intracavitary, and oral applications.
- Interstitial (in-tissue) implant, radioactive sources are placed directly into the tumor. The sources may remain in place permanently, or they may be removed once the prescribed dose has been delivered.
- Interluminal brachytherapy is used when the radioactive material is placed within a body tube such as the esophagus or bronchial tree.

- Radiopharmaceuticals, known as radioactive drugs, can be delivered by mouth or by vein.
- Intracavitary implants are performed by placing the radioactive material in a body cavity.
- Energy of the radioactive sources is low, a high energy is delivered to the tumor, with the nearby normal tissues receiving a very small dose.

Immunotherapy

- Immunotherapy, or the use of BRMs, is a systemic approach like chemotherapy.
- BRMs include proteins, such as interferon, capable of attacking cancer cells, monoclonal antibodies, vaccines, and natural killer B and T cells.
- The goal of immunotherapy is to use the body's natural defense mechanisms to control malignancy.
- It has been substantiated that certain cancers occur as a result of the body's inability to naturally defend itself against disease. At some point, the body may lose its ability to differentiate between self and nonself and allows malignant, nonself cells to thrive and eventually take control of the host.
- Immunotherapy is often reserved for use in the end stages of malignancy, as much more research needs to occur while the main three modalities continue to perfect their effectiveness against the majority of cancers.
- Interferon is a protein that is naturally produced by the body, but when it seems production has failed, it may be produced technologically and administered to the cancer patient. T and B cells may be donated by compatible donors, and monoclonal antibodies are lymphocyte clones produced in animals such as mice.
- Before any drug therapy is initiated, the medical oncologist must consider the biology of the disease, the pharmacology of the

- drug(s), the effectiveness of drugs as proven in clinical trials, and the clinical condition of the patient.
- Moreover, medical oncologists must be a knowledgeable internist so that they are familiar with signs of possible complications and side effects that may occur in any body system.

Management modality overview

- Cancer management modalities are often used together to improve the potential for remission, limit side effects, and to improve patient prognosis.
- When modalities are used complementary to each other, the supporting modality is known as

adjuvant therapy, meaning “in addition to.” For example, when radiation therapy is used in conjunction with chemotherapy and/or surgery.

- The modality intended to initiate remission is known as

neoadjuvant therapy.

- The determination whether to use modalities at the same time or one after the other has to be justified by clinical trials and outcomes recorded in tumor registries.
- When modalities are used together, one after another, the term

concomitant may be used.

- When modalities are used together at the same time, the term

concurrent may be used.

- The surgical oncologist, medical oncologist, and radiation oncologist have to work together closely to design the optimal treatment plan for every patient.

- The management goals must be clearly defined, all alternatives must be presented and all expected side effects and expected outcomes should be disclosed to the patient so that they may make the ultimate decision regarding the management of their disease.

Review Exercises

1. Use the table to compare and contrast benign and malignant tumor cell populations.

Benign Tumors	Malignant Tumors

2. List and describe five different methods of tissue sampling/biopsy.
3. Match the terms and descriptions.

Adenocarcinoma A. Malignant tumor occurring in striated muscle

Myeloma B. Malignant tumor occurring in bone

Leukemia C. Malignant tumor originating in the central nervous system

Osteosarcoma D. Abnormal proliferation occurring in the bone marrow

Rhabdomyosarcoma E. Malignant tumor of glandular epithelium

Glioma F. Abnormal proliferation occurring in the bone marrow, especially the white blood cells

4. Complete the chemotherapy table.

Phase-specific Cytotoxic Drugs	Phase-Nonspecific Cytotoxic Drugs
	Effective on nondividing cells
One such class would be antimetabolites	
	Examples are nitrogen mustard, Cytosan
Toxicities include myelosuppression, anorexia, nausea	

5. Compare and contrast hyperplasia, metaplasia, and anaplasia.

6. Mortality rates are based on the number of persons per population.

- a. 1,000,000
- b. 1000
- c. 100,000
- d. 50

7. Any substance or agent that produces or incites cancer is called:

- a. Carcinosis
- b. Carcinogen
- c. Mutant
- d. Carcinoid

8. The seven warning signs of cancer include all of the following except:

- a. Thickening or lump
- b. Nagging cough
- c. Pain
- d. Change in bowel habits

9. The TNM staging system evaluates:
- a. The size and extent of the tumor
 - b. Whether the primary tumor has metastasized
 - c. The grade of the tumor
 - d. a, b
 - e. a, b, c
10. Malignant neoplasms that originate in lymphoreticular tissues are called:
- a. Sarcomas
 - b. Lymphosarcomas
 - c. Lymphomas
 - d. Lymphoreticulomas
11. When more than one cancer modality is used simultaneously, it is known as:
- a. Concurrent therapy
 - b. Concomitant therapy
 - c. Systemic therapy
 - d. Immunotherapy
12. The class of cytotoxic agents that has the potential to burn the skin of the one administering is:
- a. Alkylating agents
 - b. Antimetabolites
 - c. Plant alkaloids
 - d. Hormones
13. The cancer warning sign most likely indicating colon/rectal cancer would be:
- a. Pain
 - b. A sore that will not heal
 - c. A change in a wart or mole
 - d. Change in bowel habits
14. Which of the following cytotoxic drugs may produce heart failure?

- a. Methotrexate
- b. Actinomycin-D
- c. Adriamycin
- d. Bleomycin

15. A tumor classified as T3, N2, M0 is likely a stage:

- a. I
- b. II
- c. III
- d. IV
- e. V

16. The tissue of a malignant carcinoma is:

- a. Epithelial
- b. Cartilaginous
- c. Skeletal
- d. Neural

17. The method used to establish definite malignancy is:

- a. Radiologic imaging
- b. Hematologic study
- c. Histopathologic screening
- d. Clinical staging

18. A cancerous tumor composed of glandular tissue would be called a/n:

- a. Neurilemoma
- b. Adenocarcinoma
- c. Epithelioma

d. Chondrosarcoma

19. A malignant tumor of striated muscle would be called a/n:

a. Leiomyoma

b. Fibrosarcoma

c. Epithelioma

d. Rhabdomyosarcoma

20. A surgical procedure in which an incision is made through the abdominal wall to examine lymph nodes and establish the extent of disease is called a/n:

a. Incisional biopsy

b. Laparoscopy

c. Mastectomy

d. Radical excision

For questions 21 to 26, circle the word(s) that would correctly complete the sentence.

21. The highest incidence of malignancy for adult males in the United States occurs in the (prostate, liver, colon). The highest incidence of malignancy for adult females in the United States occurs in the (liver, breast, colon).

22. The process by which tumors are induced by certain chemical or physical agents is called (carcinosis, carcinogenesis, carcinitis).

23. (Hair loss, weight loss, myelosuppression) is the most common side effect associated with cytotoxic drugs.

24. Most cancers are (sporadic, familial).

25. The removal of cells by scraping is called (FNA, total excision, curettage).

26. The (stage, grade, histology) of a tumor is an evaluation of the degree of cellular differentiation.
27. According to Bergonie and Tribondeau, factors that may influence the sensitivity of a group of cells to ionizing radiation are:

1. Mitotic activity
2. Time of cell division
3. Cellular differentiation
4. Length of mitotic activity

- a. 1, 2
- b. 2, 3
- c. 1, 3, 4
- d. 1, 2, 3, and 4

28. Cancer management modalities such as radiation and chemotherapy work by interfering with or modifying DNA synthesis. This synthesis occurs in the phase of cell division.

- a. S
- b. M
- c. G0
- d. G1

29. Mr. Jones and Mr. Smith have larynx tumors. Mr. Jones' tumor is classified as T2 and Mr. Smith's as T4. What difference(s) would you expect to see in these tumors?

30. Palliation is:

- a. To treat for cure
- b. Treatment for the relief of symptoms
- c. The skin color indicative of low oxygen flow
- d. Treatment to prevent the manifestation of disease

The following are true/false corrective statements. If the statement is true, place a T on the line. If the statement is false, place an F on the line and correct the statement so that it becomes true without changing the intent of the statement.

31. _____ One of the characteristics of benign tumors is that they are never fatal.
32. _____ A patient being treated with radiation to the abdomen will experience epilation of the scalp.
33. _____ The term for transmission of disease from one original site to one or more sites elsewhere in the body is metastasis.
34. _____ Oncogenes are also known as tumor-suppressor genes.
35. _____ In general, children have the highest incidence of cancer.
36. _____ Surgery is never used prophylactically.
37. Which of the following is not a possible side effect of cytotoxic drugs?
 - a. Nausea
 - b. Cardiac toxicity
 - c. Myelosuppression
 - d. Alopecia
 - e. None of the above
38. Factors considered in chemotherapy drug selection include which of the following?
 1. Histology
 2. Tumor location
 3. Rate of drug absorption

4. Tumor resistance to the drug(s)

- a. 1, 2
- b. 1, 3
- c. 2, 3, 4
- d. 1, 2, 3, 4

39. The oldest cancer management modality is:

- a. Chemotherapy
- b. Radiation therapy
- c. Surgery
- d. Immunotherapy

40. All of the following are characteristic of malignant tumors except:

- a. Blood vessel invasion
- b. Rapid growth
- c. Encapsulation
- d. Metastatic

41. One unique characteristic of substitute ureas is:

- a. They may burn the skin on contact
- b. They can cross the blood–brain barrier
- c. They are the most expensive class
- d. They are exclusively used for metastatic disease

42. The cancer warning sign most likely indicating breast cancer would be:

- a. Pain
- b. A sore that will not heal
- c. A lump or thickening
- d. Change in bowel habits

43. The incidence of cancer in a given area may be affected by:

- a. Race
- b. Environmental exposures
- c. Cultural practices
- d. All of the above

44. An imaging technique used to detect lung cancer would be:

- a. Ultrasound
- b. Routine radiography
- c. Lymphangiography
- d. Venography

45. A tumor marker for the detection of germ cell tumors is:

- a. Prostate Specific Antigen (PSA)
- b. Carcinoembryonic Antigen (CEA)
- c. Prostatic Acid Phosphatase (PAP)
- d. Beta-Human Chorionic Gonadotropin (Beta HCG)

46. The American Cancer Society recommends ____ for men beginning at the age of 45.

- a. Annual PAP smear
- b. Manual testicular examination
- c. Colonoscopy
- d. Annual chest x-ray

47. Prophylactic therapy is intended to:

- a. Relieve pain
- b. Heal or stall ulceration, fungation, or fracture
- c. Improve the quality of life
- d. Sterilize areas of microscopic disease

48. Curative therapy is intended to:

- a. Relieve pain
- b. Heal or stall ulceration, fungation, or fracture
- c. Totally eradicate disease
- d. Counteract the presence of hormones

Think about it.

49. If the administration of cytotoxic drugs poisons both malignant and healthy cells, how are we able to continue using this modality

- to treat cancer and return the cancer patient to a healthy state?
50. Systemic chemotherapy and local radiation similarly rely on adequate vascular supply. What is the significance of vasculature and the effectiveness of both therapy modalities?
51. Cure rates for early-stage carcinoma of the cervix, glottic larynx, and basal cell carcinoma of the skin are the same whether radiation or surgery is used for management. If this is so, why would radiation therapy become the treatment of choice for most?
52. Fractionation of radiation doses allow for:
- a. Repair of normal tissue
 - b. Decrease in the oxygen concentration of the cells
 - c. Efficient use of high voltage equipment
 - d. Depletion of circulating blood cells
53. Which of the following treatment modalities, if used alone, would best treat a patient with metastatic disease?
- a. Surgery
 - b. Radiation therapy
 - c. Chemotherapy
 - d. Hormone therapy
54. Actinomycin D is a/an:
- a. Alkylating agent
 - b. Antitumor antibiotic
 - c. Antiemetic
 - d. Hormonal agent
55. The ____ of a tumor is an evaluation of the degree of differentiation.
- a. Grade
 - b. Stage
 - c. Extent
 - d. Histology

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CHAPTER 2

Radiation Therapy Physics

Robert P. Laureckas

Focus questions

- How does radiation interact with matter?
- Where does radiation exist in the universe?
- What are the characteristics of electromagnetic radiation?
- How does an x-ray photon differ from a microwave photon?
- What are the influences on types of radiation interactions?
- Distinguish electron interactions from photon interactions.
- What happens during radioactive decay?
- What is radioactivity?
- Are photon interactions different from particulate radiation interactions?
- Can we predict the interaction of radiation with the atom?
- How are x-rays produced?
- How do x-rays and naturally occurring radiations differ?
- What is the importance of understanding radiation interactions with matter for the radiation therapist?

Atomic Physics

- Radiation is the propagation of energy in matter, and radiation physics is the study of its interactions with it.
- All matter in its smallest form is composed of atoms.
- There are several models for the composition of the atom.
- Rutherford's atomic model introduced the concept of a nucleus that consisted of protons and neutrons and the vast majority of the atom's mass.
- Bohr's atomic model is used often and demonstrates electrons orbiting the nucleus at discrete energy levels or "shells" similar to how planets orbit the sun (

Figure 2.1).

- Atoms have a maximum number of required electrons in each shell.
- $2n$

^{2} is the formula used to find the maximum number of electrons in a shell. N represents the shell number or quantum number. Each shell, beginning with the inner shell, is assigned a letter, K, L, M, N or quantum number 1, 2, 3, 4, and so on.

- The mass of atoms is expressed in terms of atomic mass units (amu) or atomic weight; $1 \text{ amu} = 1.66 \times 10$

$^{-27} \text{ kg}$.

- The mass in grams numerically equal to the atomic weight is the gram atomic weight.
- According to Avogadro's law, every gram atomic weight of an element contains the same number of atoms.
- The number of atoms per gram is given by Avogadro's number/atomic weight; Avogadro's number is accepted as 6.0228×10

- Atoms are represented by the formula



A .

- The X is the chemical symbol, Z is the atomic number (the number of protons or electrons), A is the atomic mass (the sum of protons and neutrons).
- Neutrons have no charge and protons have a positive charge; they have the ability to transition between positive and neutral charge; the nucleus is positively charged.
- Both neutrons and protons have a substantial mass as compared with orbiting electrons; protons are about 1800 times more massive than electrons and neutrons are slightly heavier than protons.
- The orbiting electrons may be stripped from the atom to go on to interact with other atoms or particles. The mass, charge, and linear energy transfer (LET) of some key particles is provided in

Table 2.1 .

- With electrons orbiting carrying a negative charge, they are bound to the atom by the attraction of their negative charges to positive charges in the nucleus; this attraction is known as electrostatic force.
- The closer the electrons are to the nucleus, the more tightly bound they are to the nucleus.
- The stability of the atoms in an element is determined by a balance of positive and negative charges and evenly paired electrons.
- An atom is electrically neutral or said to be in its ground state when it has as many positive charges as negative charges and has evenly paired electrons.
- An encounter with radiation can manipulate any of the atom's components.

- Electrons can be stripped from the atom and interact with other atoms or positively charged particles.
- Neutrons may also be stripped from the atom but will not interact with electrons due to their neutral charge. They may, however, interact with other particles.
- Protons can be stripped and will likely interact with electrons or neutrons.
- Any encounter that would cause an electron to be raised to a higher electron shell or made to vibrate in place, would lead to an energy emission known as excitation (

Figure 2.2).

- Any interaction with the atom that would cause an electron to be totally removed from the atom is known as ionization (

Figure 2.3).

- Once an atom is ionized, it is no longer stable. Rather, it has charge. If an atom captures an electron then it is called a negative ion. If it loses an electron, then it is called a positive ion.
- Great energy has to be expended to raise electrons to a higher shell. The closer the electrons are to the nucleus, the stronger the binding energy, or electrostatic force.
- As electrons are held tight to the nucleus by energy and have energy at rest in the shell, any change in the status of an otherwise resting electron causes an energy loss or redistribution of energy.
- If the incoming or interacting energy of an atomic particle, or energy bundle, has at least 124 electron volts of energy and a wavelength shorter than 10

10^{-6} cm, it has the greatest potential to be ionizing.

- Energy ranges commonly used in radiation therapy are 100 keV to 250 MeV.
- The kilo electron volt (keV) is 10

- ³ electron volts or 1000 electron volts.
- The mega electron volt (MeV) is 10⁶ or 1,000,000 electron volts.

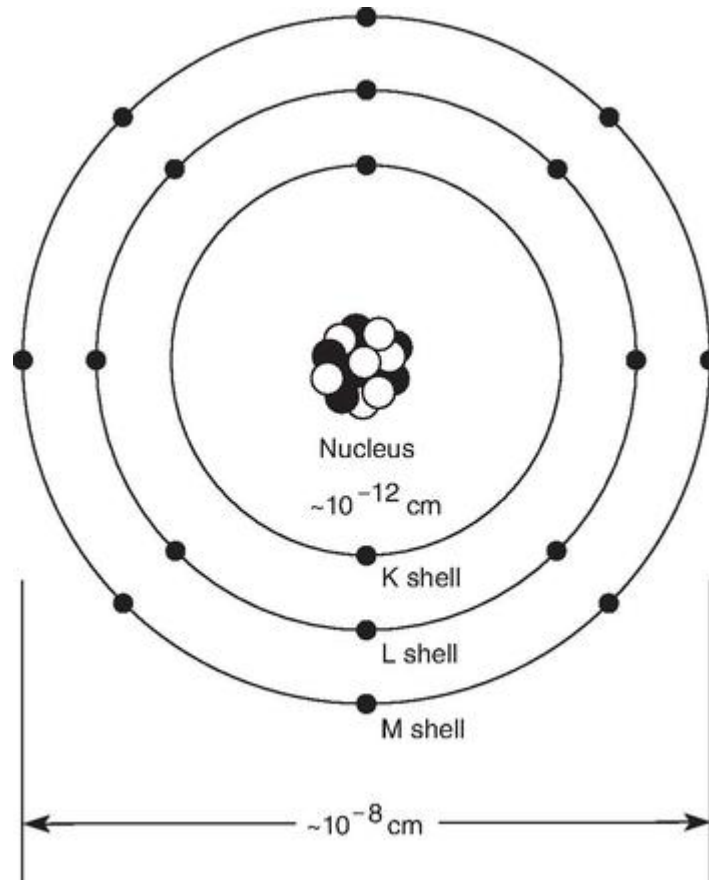


FIG. 2.1 Bohr's model of the atom.

TABLE 2.1

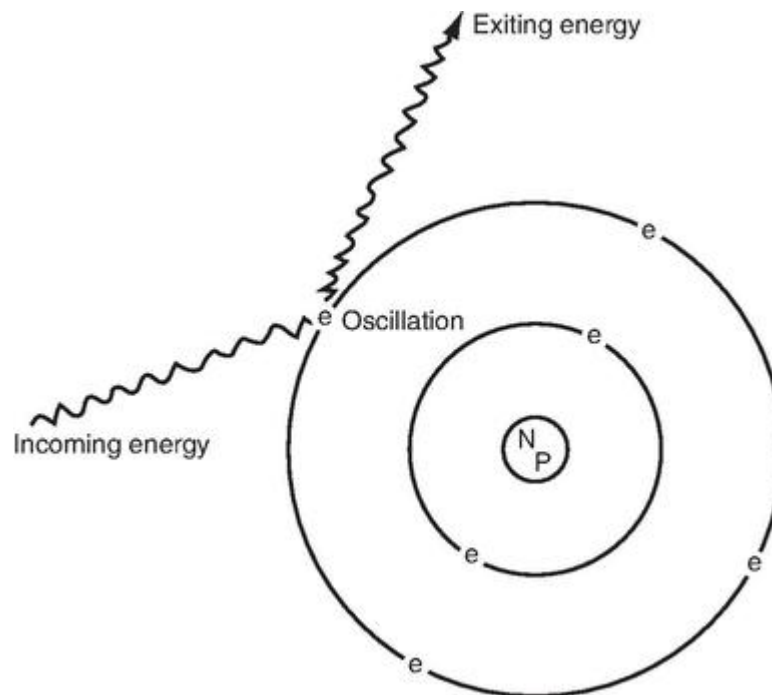


FIG. 2.2 Excitation occurs when an electron is raised to a higher shell or made to vibrate.

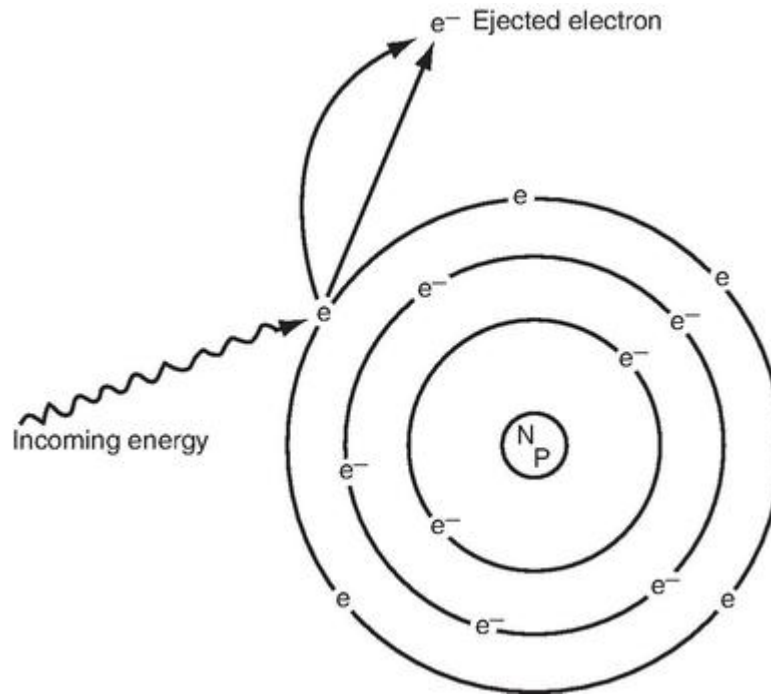


FIG. 2.3 Ionization occurs when an electron is ejected from the atom.

Electromagnetic Spectrum

- Ionizing radiation is in the family of electromagnetic radiation.
- All radiation in the electromagnetic spectrum are photons, or bundles of energy, that travel in straight lines, have velocity as the speed of light, and have wavelength and frequency.
- Radiation in the electromagnetic spectrum includes visible light, heat, radio, microwaves, ultraviolet rays, gamma rays, and x-rays (

Figure 2.4).

- These photons are called electromagnetic because they exhibit similar characteristics as electric and magnetic fields (oscillating wave patterns, frequency, wavelength, energy, and velocity).
- Frequency is measured in cycles per second using the unit Hertz.
- Wavelength is measured in meters using the unit Angstrom.
- Energy is measured in joules or expressed in electron volts (eV).

- Radiation in the electromagnetic spectrum used in radiation therapy includes gamma and x-radiation; x-rays and gamma rays are found at the upper end of the spectrum with short wavelengths, high frequency, and high energies.
- X-rays and gamma rays are ionizing.
- X-rays and gamma rays only differ by where they originate.
- Gamma rays are a result of natural nuclear decay; x-rays have to be created and are a result of interaction or deceleration of electrons with the atoms of a target material.
- Positrons (positively charged electrons), electrons, protons, neutrons, alpha particles, and pi mesons are examples of other radiation known as particulates.
- Particulates may also be ionizing; electrons, protons, neutrons, and alpha particles may be used in radiation therapy.
- Positrons only exist in motion and are used in imaging, such as positron emission tomography (PET).
- Particulates like protons and electrons are directly ionizing. Gamma rays, x-rays, and neutrons are indirectly ionizing.
- Wavelength, frequency, and the speed of light are related according to the formula:

$$C = \lambda \nu$$

where C = speed of light, λ = wavelength, ν = frequency

- The speed of light is constant at 3×10

⁸ m/sec in vacuum.

- The kinetic energy of an electromagnetic radiation is related to wavelength according to the formula:

$$E(\text{KeV}) = \frac{12.4}{\lambda}$$

- Kinetic energy is related to frequency according to the formula:

$$E = h\nu$$

where h = Planck's constant (6.626×10^{-34} joules/second)

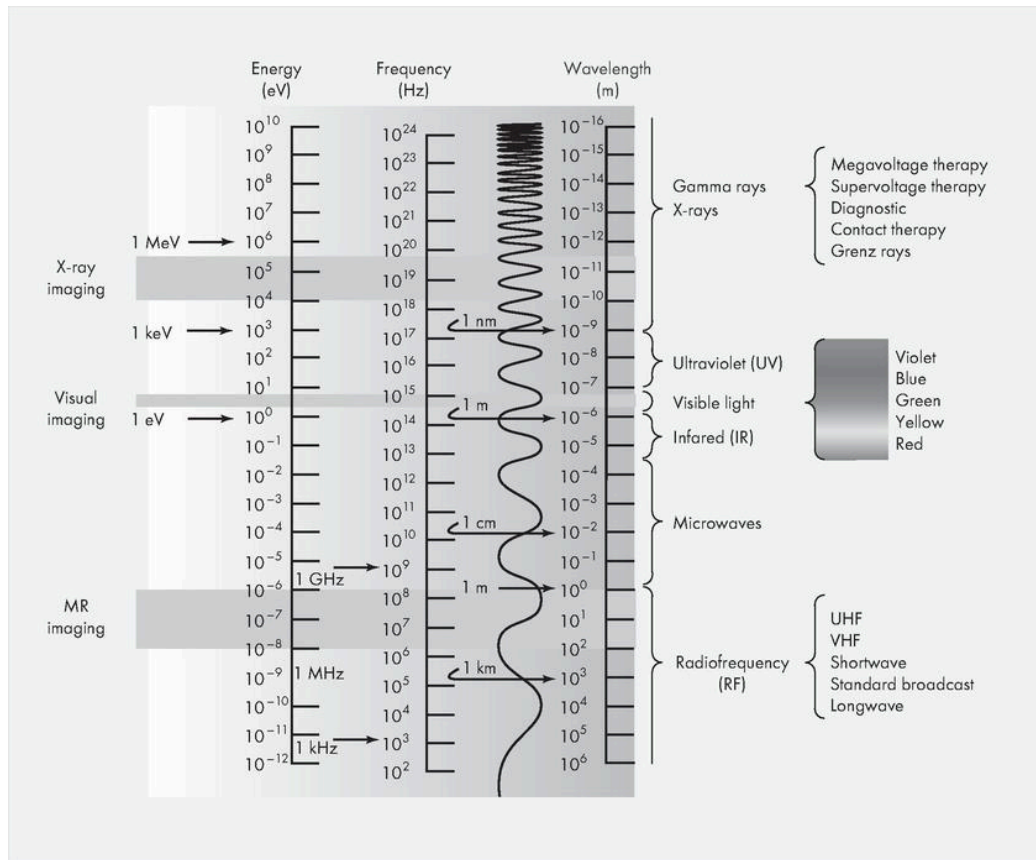


FIG. 2.4 The electromagnetic spectrum.

Particle Interactions and X-Ray Production

- The physical characteristics of heavy particles such as protons, neutrons, alpha particles (2 neutrons + 2 protons), or deuterons (1 neutron + 1 proton) allow them to penetrate and deposit energy at short range.
- The heavy particles have a high LET.
- The energy deposit increases to a maximum and produces a denser ionization near the end of its path. This ionization region is called a Bragg peak (

Figure 2.5).

- The rate of energy loss by a charged particle is proportional to the square of the particle charge.
- Electrons are commonly used charged particles in radiation therapy. Electrons have a low mass and distribute energy in a finite range in an absorber. The electron's low mass allows it to have a low LET and therefore does not show the same distribution pattern as Bragg's peak.
- There are two types of electron interactions with matter. They are collision and radiative.
- Collision interactions involve electrons interacting with orbiting electrons in matter and transferring momentum and energy. Examples of such interactions are excitation and ionization.
- Radiative collisions occur when energy from the electrons is lost in the form of bremsstrahlung radiation.
- When an inner shell electron is ionized from the atom, a vacancy in the energy shell results. This vacancy may be filled with an orbiting electron in an outer energy shell. Any energy loss may exit the atom in the form of a photon.
- Orbiting electrons have a resting energy and a binding energy.
- The binding energy of an inner shell electron is large; the binding energy of an outer shell electron is small.
- The potential energy difference between where the ionized orbiting electron used to be and the electron filling the vacancy will be the resulting energy of the exiting photon.
- The exiting photon is in the form of characteristic x-rays (

Figure 2.6).

- If the electron encountering the atom does not interact with an orbiting electron but is drawn to the positive charge in the nucleus, its velocity is slowed and its direction changes.
- The change in velocity causes a loss in the kinetic energy of the incoming electron; the energy loss exits the atom in the form of bremsstrahlung radiation (

Figure 2.7).

- When x-rays are produced, both characteristic and bremsstrahlung radiation are emitted from the target atoms.
- X-ray production requires a high voltage source, cathode, anode, glass envelope, and vacuum (

Figure 2.8).

- The deceleration of electrons as they encounter the atoms of the target causes both x-ray and heat emission.
- In diagnostic tubes about 99% of the electron energy is converted to heat, whereas only 1% is converted to x-ray.
- During megavoltage x-ray production, a higher proportion of electron energy is converted to photons.
- The proportion is influenced by the atomic number of the target and maximum energy of the electrons in MeV.
- The following equation may be used to figure the converted energy to photons:

$$F = 3.5 \times 10$$

$$^{-4} (Z) (E)$$

F = fraction of the incident electron energy converted to photons

Z = atomic number of the target

E = maximum energy of electrons in MeV

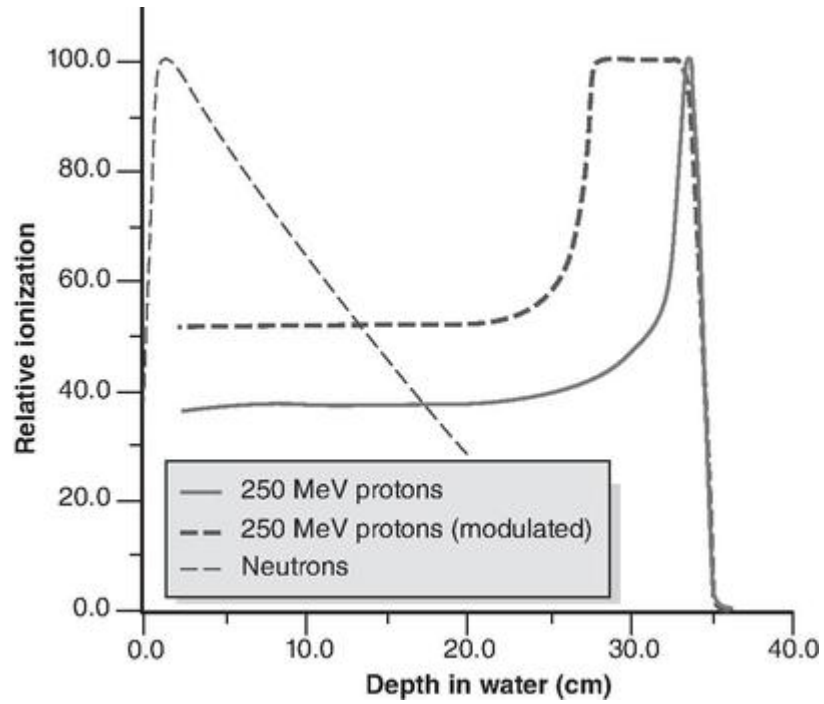


FIG. 2.5 Examples of Bragg peaks.

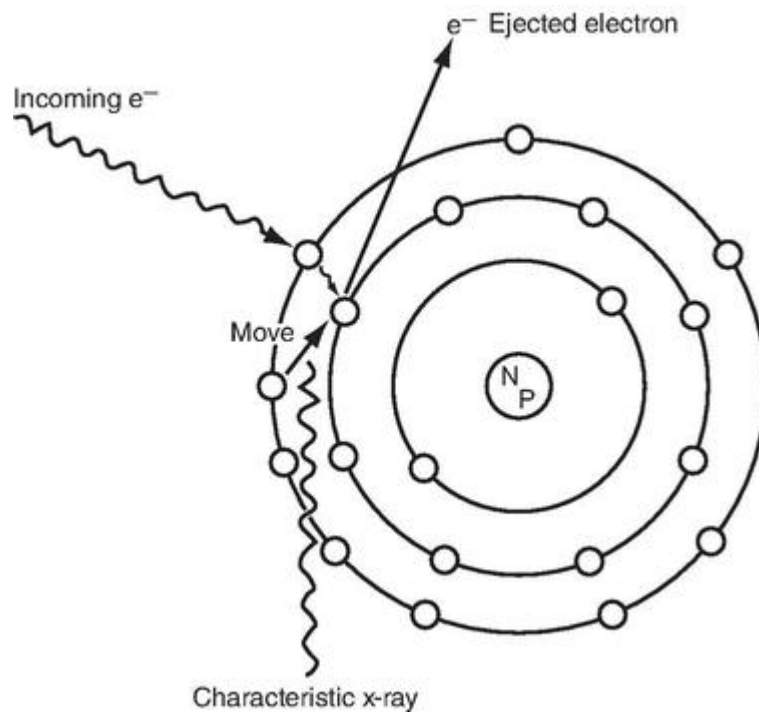


FIG. 2.6 Characteristic x-ray production.

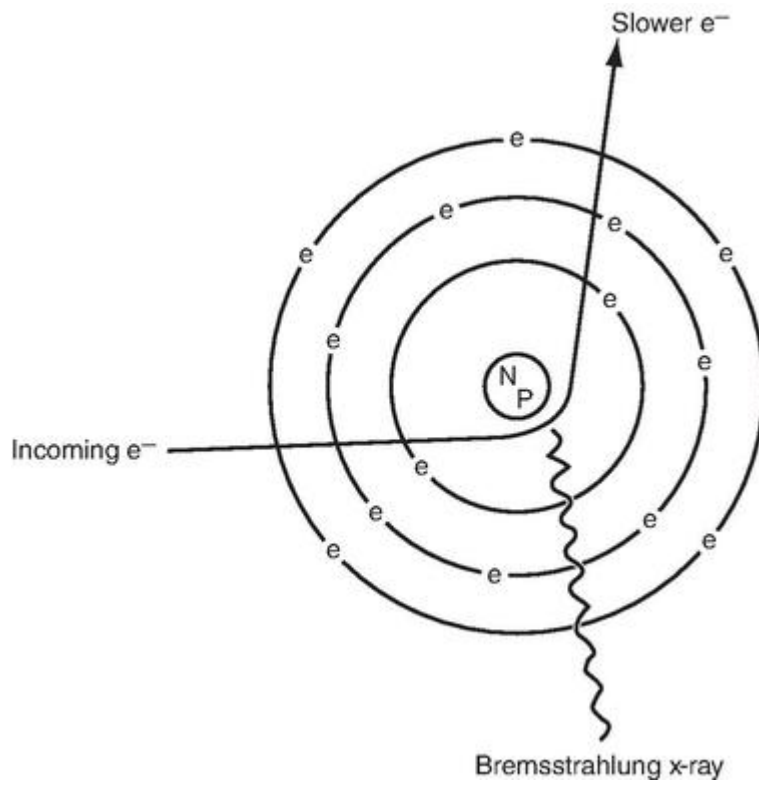


FIG. 2.7 Bremsstrahlung x-ray production.

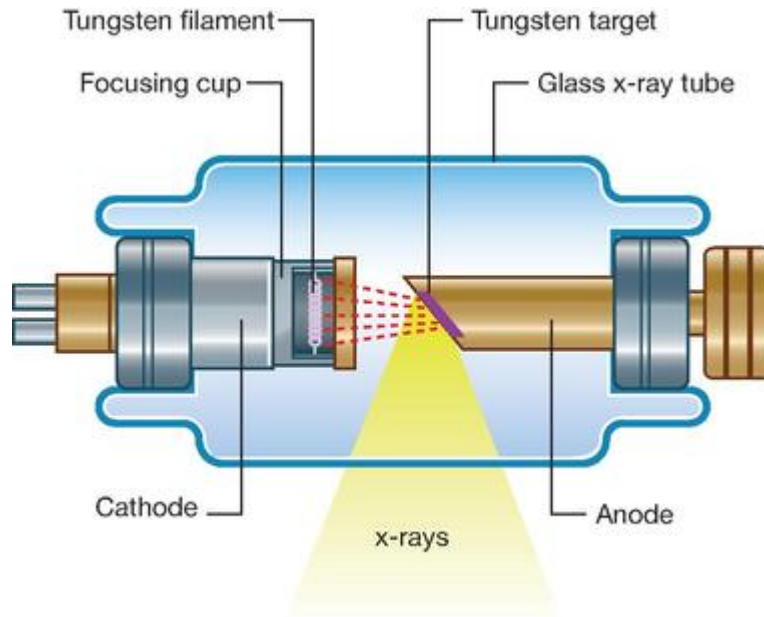


FIG. 2.8 The basic x-ray tube.

(From: Drake RL, Vogl W, Mitchell AWM, Horn A.

Gray's Basic Anatomy . Third edition. Elsevier; 2023. Ch 1: The Body, Fig. 1.2: Cathode ray tube for the production of X-rays. ISBN: 978032383442-1.)

Photon Interactions

- There are three major types of photon interactions with matter. They are:
 - a. Photoelectric effect
 - b. Compton effect
 - c. Pair production
- Photoelectric effect occurs when a photon ejects one of the orbiting electrons. The entire energy of the photon is first absorbed by the atom and then transferred to the atomic electron. This happens in the innermost shells. The ejected electron is called a photoelectron. When a vacancy occurs, another electron from another energy shell drops in to fill the space, and energy emitted is in the form of characteristic x-rays or Auger electrons. The probability of this

interaction increases when the incident photon is in the low kilovoltage range and the interacting material has a high atomic number.

- Compton effect occurs when a high energy photon (>150 KeV) interacts with an electron as though it were a free electron. This happens in the outer shells. The encountered electron receives some energy from the photon and is emitted at an angle from the atom. The photon, with reduced energy, is also scattered at an angle. There could be a direct hit where the electron will move out and forward and the photon will travel backward. The higher the energy, the greater the probability of this type of interaction. The Compton effect is independent of atomic number of the interacting material.
- Pair production occurs when the photon energy is greater than 1.02 MeV. The photon interacts with the electromagnetic field of the nucleus and gives up all its energy in the process of creating a pair of particles consisting of an electron and a positron. The particles are emitted in the forward direction; probability of this type of interaction increases with atomic number.

Figure 2.9 illustrates each of the three major photon interactions.

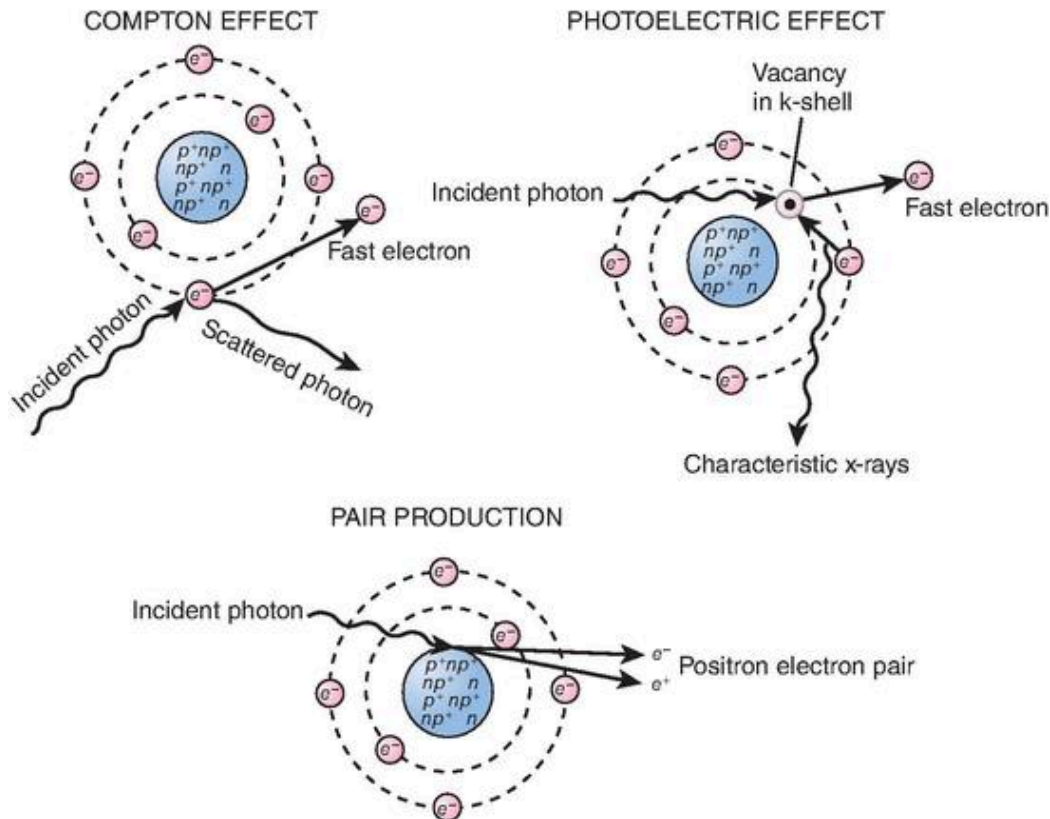


FIG. 2.9 Illustration of the three major photon interactions.

(From: Radiation Oncology: Rationale, Technique, Results, NINTH EDITION, 2010, FIGURE 1-1: The first step in the absorption of a photon of x-rays or gamma rays is the conversion of the energy of the photon into the kinetic energy of an electron, or electron-positron pair. At higher energies, when the energy of the incident photon greatly exceeds the binding energy of the planetary electrons in the atoms of the absorber, the Compton process dominates. The photon interacts with the electron in a classic "billiard-ball collision." Part of the photon energy is given to the electron as kinetic energy, while the photon is deflected and has reduced energy. At lower energies, when the binding energy of the planetary electrons of the atoms of the absorber is not small compared with the photon energy, the photoelectric effect is most important. The photon disappears completely as it interacts with a bound electron. The electron is ejected with kinetic energy equal to the photon energy, less the energy required to overcome the electron bond. The vacancy caused by the removal of the electron must be filled by an electron dropping from an outer orbit, giving rise to a photon of characteristic radiation. At sufficiently high photon energies, the photon may interact with the powerful nuclear forces to produce an electron-positron pair. The first 1.02 MeV of photon energy is used to create the rest mass of the pair, and the remainder is distributed equally between them as kinetic

Radiation Intensity and Beam Quality

-

Intensity is defined as the amount of energy present per unit of time per unit of area perpendicular to the beam direction.

- Beam quality refers to the energy of the beam expressed in electron volts or the absorbing potential or penetrating power of the beam expressed in half-value layers (HVL) of material.
- Intensity of the beam is reduced by two effects: beam divergence and attenuation.
- Beam divergence is an expression of the scattering of photons away from the original point source.
- An area at a certain distance from the source (distance 1) would have an amount of photons passing through it (intensity 1). At a greater distance (distance 2), the same amount of photons would be scattered apart further and result in a less intense beam (intensity 2) (

Figure 2.10).

- The

inverse square law governs the principle of divergence and demonstrates that the intensity of the beam is inversely proportional to the square of the distance from the original point source:

$$I_1(D_1)^2 = I_2(D_2)^2$$

- Beam

attenuation is the removal of energy from the beam.

- When a photon or particulate beam passes through matter, some energy is removed from the beam as a result of absorption and scattering; the energy that is removed or absorbed by the material is said to be attenuated.
- The number of photons passing perpendicular through an area of 1 square meter may be referred to as photon fluence.
- The energy passing perpendicularly through an area of 1 square meter would be called energy fluence.
- Some photons or particles are unaffected by the attenuator and pass through; the photons or particles passing through are referred to as

transmission .

$$\text{Transmission} = \frac{I}{I_0}$$

I

I_0 = original intensity

I = final intensity

- Some photons are totally absorbed; some may be partially absorbed and exit the material with reduced energy and changed direction.
- Photons that are totally or partially absorbed in tissue contribute to the absorbed dose.

Figure 2.11 illustrates attenuation, fluence, and transmission.

- Refer to

Figure 2.11 and consider the following:

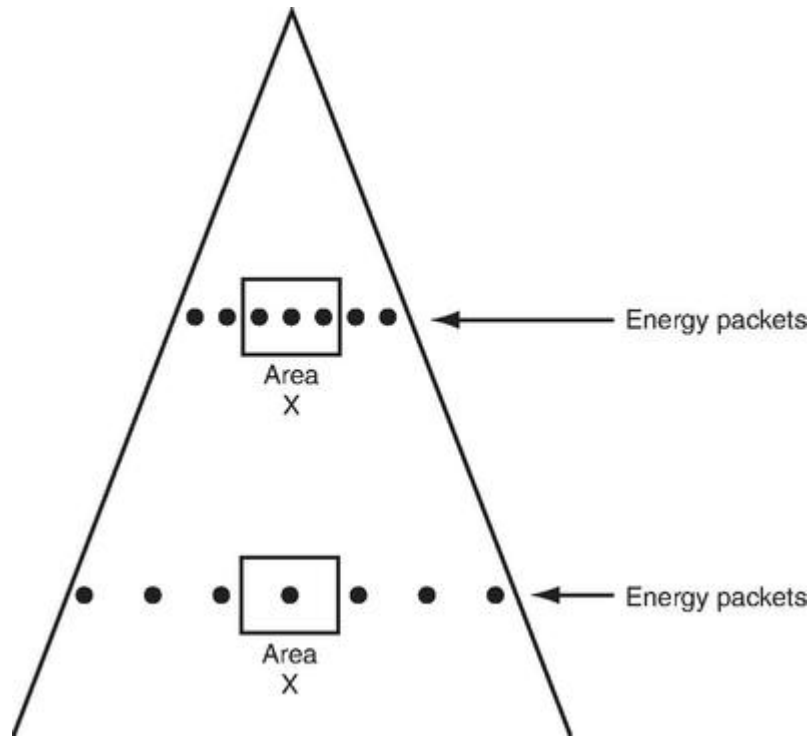


FIG. 2.10 Illustration of beam divergence.

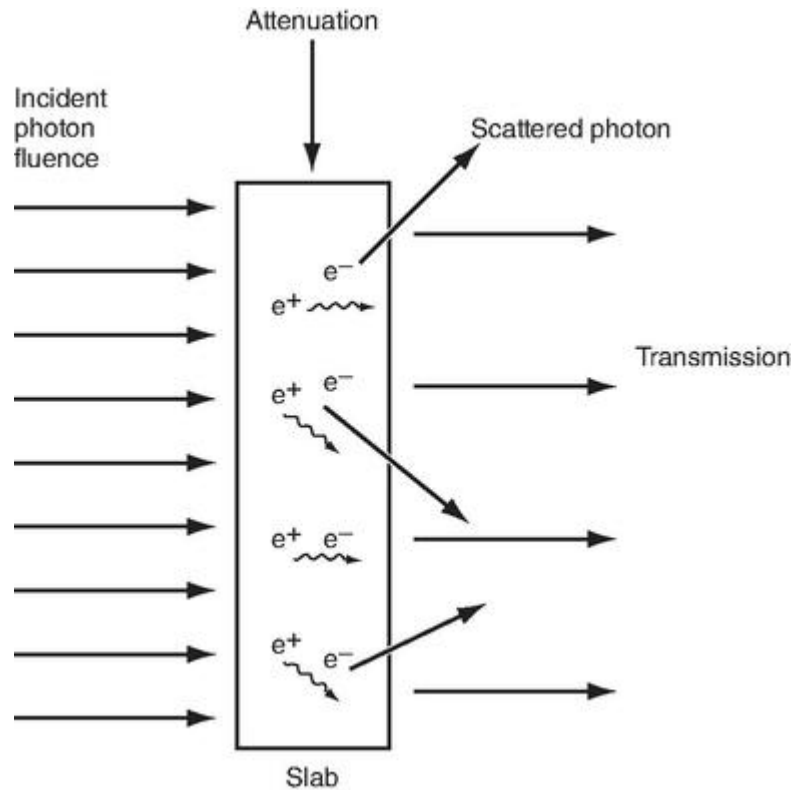


FIG. 2.11 Photon fluence, attenuation, and transmission illustration.

If N

N_0 is the number of photons incident on a slab of material (photon fluence) and it encounters a thickness of material (t) to absorb some energy, the following mathematical equation could help us solve for the number of photons transmitted.

$$N = N_0 e^{-\mu t}$$

μ = linear attenuation coefficient

The energy attenuated or transmitted is influenced by the incident beam energy and the type of material it passes through.

- The amount of material that would reduce the incident photon fluence to half its original value would be called its half-value thickness (HVT) or HVL.
- The HVT and linear attenuation coefficient are related by the formula:

$$\mu = \frac{\ln 2}{\text{HVT}}$$

μ = linear attenuation coefficient

- As the material thickness increases, the intensity of the attenuated beam decreases.
- If we use a photon source with only one energy, the attenuation of the beam follows the relationship:

I

=

I₀e

(

–

μ

t

)

$$I = I_0 e^{(-\mu t)}$$

- The meaning of the equation is that each millimeter of thickness added to an absorber reduces the beam intensity by a constant percent.
- In low energy x-ray tubes, filters may be used as absorbers to harden the beam.
- Beam hardening refers to the phenomenon where the effective energy of the beam increases as it passes through the filter: the filter absorbs the low energy rays and allows the higher energy rays to be transmitted. Because the hardened beam has more high-energy rays, the amount of material needed to decrease the original

intensity by subsequent increments of 50% actually decreases due to beam hardening.

- 2 HVLs is not exactly HVL(2), due to beam hardening.
- HVT or HVL can be used to express the beam quality in lower energy beams.
- HVL is also used in the design of beam shielding blocks; the acceptable transmission of shielding blocks is approximately 3% or 5 HVLs of material.
- HVL is not used to specify beam energy for high energy photon or electron beams. Rather, an equivalent energy is used to characterize high energy beams used in radiation therapy.
- In radiation therapy, the beam energy is expressed in eV (KeV for imaging and MeV for therapy).
- The energy specified refers to the maximum energy in the spectrum of energies exiting.

Radioactivity and Nuclear Transformation

- Atoms represented by the formula



^A are called nuclides. When elementary particles of the stable atom are manipulated, they become unstable elements grouped by radionuclide families of isotopes, isotones, isobars, or isomers (

[Table 2.2](#)).

- Radioactivity was discovered by Henri Becquerel in 1896 while exploring the naturally irradiative element, uranium.
- At around the same time, similar irradiative characteristics were found in radium by Marie and Pierre Curie.
- Radioactive decay, or disintegration, is a phenomenon in which radiation is emitted by the nucleus in the form of particles or electromagnetic radiation as an unstable element attempts to become stable again.
- On the periodic table of elements, the elements with atomic numbers higher than 82 tend to be unstable and are at some point attempting to become stable; as they are emitting particles or electromagnetic radiation, we refer to them as radioactive.
- Disintegrations are a statistical phenomenon and occur exponentially; 1 disintegration per second = 1 dps.
- The mathematics of radioactive decay is based on the fact that the number of atoms disintegrating per unit of time is proportional to the number of radioactive atoms present. There is constant proportionality known as the decay constant.
- The symbol for the decay constant is λ and may be found by the equation:

$$\lambda = \frac{\ln 2}{T_{1/2}} \text{ or } \frac{0.693}{T_{1/2}}$$

- T

$T_{1/2}$ is the half-life; this is the time required for the number of radioactive atoms to decay to half the initial value.

- T

T_a is the mean or average life; this is the average lifetime for the decay of radioactive atoms.

$$T_a = 1.44(T_{1/2}) \text{ or } \frac{T_{1/2}}{0.693}$$

- In theory, the time it takes for all atoms to decay is infinite.
- Activity refers to the rate of decay or the strength of radioactive material. The traditional unit for activity is the Curie (Ci). The standard international unit is the Becquerel (Bq).
- Important equations to remember related to nuclear transformations are:

$$N = N_0 e^{-\lambda t} \quad N = \text{number of atoms} \quad N_0 = \text{initial number of atoms}$$

$$A = A_0 e^{-\lambda t} \quad A = \text{activity} \quad A_0 = \text{initial activity}$$

$$1 \text{ dps} = 2.7 \times 10^{-11} \text{ Ci} = 1 \text{ Bq}$$

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ dps}$$

- Radioactive nuclides undergo successive transformations in which the original nuclide—known as the parent (X)—gives rise to a radioactive product nuclide known as the daughter (Y).
- Naturally occurring radioactive materials are grouped into three decay series: uranium series, actinium series, and thorium series.
- If the half-life of the parent (X) is much longer than that of the daughter (Y), then after a certain time, a condition of equilibrium occurs where the ratio of the daughter activity to the parent activity becomes constant. This is known as secular equilibrium.
- If the parent activity is not very long compared to the daughter activity, then the type of equilibrium established is called transient equilibrium.
- Nuclear transformations manifest as:
 - a. Alpha decay
 - b. Beta decay (negative and positive)
 - c. Electron capture
 - d. Internal conversion
- Alpha decay occurs with very high atomic number nuclides in which two protons and two neutrons are emitted; an example would be in the decay of radium-226.
- Beta negative decay occurs when there is an excessive number of neutrons or high neutron to proton ratio; the element tends to emit negative electrons; the decay of phosphorus-32 is an example.
- Beta positive decay occurs when there is a deficit of neutrons and results in the emission of a positron. The decay may be accompanied by the emission of gamma rays. The excess energy in

the nucleus must be at least 1.02 MeV; sodium-22 decay is an example.

- Electron capture occurs when the excess energy in the nucleus is less than 1.02 MeV. One of the orbital electrons is captured by the nucleus, transforming a proton into a neutron. The captured electron leaves an empty space in an electron shell, which in turn will be filled by another orbiting electron causing a release of energy known as characteristic x-rays.
- The characteristic x-ray may eject an outer shell electron from the atom as it is expelled; such an electron is referred to as an Auger electron.
- Internal conversion occurs with the emission of gamma rays from the nucleus. In most transformations, the daughter nucleus loses energy immediately in the form of gamma radiation. Orbiting electrons may bombard the nucleus and receive some energy from the nucleus. The energized electron may subsequently be ejected from the atom and travel away with an energy equal to the difference between the energy lost by the nucleus and the binding energy that held the electron.
- Other interactions include fission and fusion; these interactions are a result of producing radioactive materials.
- Fission is a result of bombarding certain high atomic number nuclides with heavy neutrons; the nucleus splits into nuclei of a lower atomic number.
- Fusion can be considered the reverse of fission; low mass nuclei are combined to produce one nucleus.

TABLE 2.2**Radionuclide Families**

Isotopes	Same number of protons but different number of neutrons
Isotones	Same number of neutrons but different number of protons
Isobars	Same number of nucleons but different number of protons
Isomers	Same number of protons and neutrons except in a different nuclear state

Review Exercises

1. 1 mCi is equivalent to:

a. 3.7×10

^{10} disintegrations/min

b. 2.22×10

^{12} disintegrations/min

c. 3.7×10

^{4} disintegrations/sec

d. 3.7×10

$^{-2}$ disintegrations/sec

2. What are the differences between the electron and proton?

3. Types of nuclear decay include all of the following except:

- a. Alpha decay
 - b. Neutron decay
 - c. Beta decay
 - d. Internal conversion
4. During x-ray production, the resulting x-ray beam comes from electrons colliding with the target causing interactions such as:
- a. Characteristic radiation
 - b. Bremsstrahlung radiation
 - c. Auger electrons
 - d. All of the above
5. The positive side of the basic x-ray tube is known as the:
- a. Anode
 - b. Cathode
 - c. Filament
 - d. Vacuum
6. The ratio of x-ray to heat during x-ray production is:
- a. Constant at 99% heat and 1% x-ray
 - b. Constant at 90% heat and 10% x-ray
 - c. Variable depending on the maximum energy of electrons traversing the tube
 - d. Variable depending on the strength of the target
7. The radioactive decay of a radioisotope is characterized by its:
- a. Secular equilibrium
 - b. Decay constant
 - c. Fraction decay rate
 - d. Transient equilibrium
8. An elastic collision is one in which:
- a. The incoming electron gives all of its energy to the electron it encounters
 - b. The incoming electron shares its energy with the electron it encounters

- c. The incoming electron is captured by the nucleus
 - d. The incoming electron takes the place of an ejected electron
9. The energy of an electromagnetic radiation is inversely proportional to its:
- a. Frequency
 - b. Mass
 - c. Speed
 - d. Wavelength
10. If a 50-keV electron collides with an inner shell electron with a binding energy of 25 keV, the resulting photoelectron will have an energy of:
- a. 25 keV
 - b. 75 keV
 - c. 100 keV
 - d. 150 keV
11. The energy of an electromagnetic radiation is directly proportional to its:
- a. Frequency
 - b. Wavelength
 - c. Velocity
 - d. a and b
12. The decay of cobalt-60 to stable lead is an example of _____ decay.
- a. alpha
 - b. beta negative
 - c. beta positive
 - d. fusion
13. Regarding isotopes; isotopes of an element have the same number of _____ but a different number of neutrons.
14. Which has the highest photon energy?
- a. Radio waves

- b. Ultraviolet light
- c. Microwaves
- d. Infrared

15. The majority of the mass of the atom is derived from:

- a. Protons and electrons in the nucleus
- b. Protons and neutrons in the nucleus
- c. Protons, neutrons, and electrons in the nucleus
- d. Alpha, beta, and gamma radiation emitted

16. A neutral atom that loses an electron by ionization is called a:

- a. Negative atom
- b. Positive atom
- c. Negative ion
- d. Positive ion

17. What type of nuclear decay is realized when:

a.

$^{88}_{88}\text{Ra}$

$^{226}_{88}\text{Ra}$ decays to

$^{86}_{86}\text{Rn}$

$^{222}_{86}\text{Rn}$ _____

b.

$^{11}_{11}\text{Na}$

$^{22}_{11}\text{Na}$ decays to

$^{10}_{10}\text{Ne}$

$^{22}_{10}\text{Ne}$ _____

18. An atom is neutral if the number of its electrons is equal to its:
- a. Protons
 - b. Nucleons
 - c. Atomic weight
 - d. None of the above
19. What is the threshold energy for pair production:
- a. 0.511 MeV
 - b. 1.53 MeV
 - c. 9.81 MeV
 - d. 1.02 MeV
20. The SI unit for activity is the:
- a. Becquerel
 - b. Curie
 - c. Hertz
 - d. Roentgen
21. To interact by photoelectric effect, the interacting photon must have energy:
- a. Less than the binding energy of the orbiting electron
 - b. Equal to or greater than the binding energy of the orbiting electron
 - c. Of any level
 - d. Of at least 1 MeV
22. The photons produced during the orbital transitions of electrons from a higher to lower energy are called:
- a. Characteristic radiation
 - b. Corpuscular radiation
 - c. Gamma radiation
 - d. Vacancy radiation
23. An electron with the lowest binding energy is most likely located in the:
- a. K shell

- b. L shell
 - c. M shell
 - d. All binding energies are the same
24. Two or more chemicals with the same chemical formula, but having different nuclear states are known as:
- a. Isomers
 - b. Isotopes
 - c. Isobars
 - d. Isotones
25. Which is not true of the electromagnetic spectrum? They all have the same:
- a. Velocity
 - b. Energy
 - c. Mass
 - d. Charge
26. Carbon-14 and nitrogen-14 are:
- a. Isotones
 - b. Isotopes
 - c. Isobars
 - d. Isomers
27. How many electrons are there in 1 g of tissue?
- a. 3×10^{10}
 - b. 3×10^{23}
 - c. 6.02×10^{23}

- d. None of the above
28. On January 1, we receive 80 mCi of an isotope with a half-life of 8 days. The activity remaining on January 25 would be:
- a. 8 mCi
 - b. 10 mCi
 - c. 20 mCi
 - d. 40 mCi
29. The fraction of cobalt-60 atoms remaining after 10 years is approximately:
- a. $\frac{1}{3}$
 - b. $\frac{1}{8}$
 - c. $\frac{1}{2}$
 - d. $\frac{1}{4}$
30. The wavelengths of x-rays are measured in:
- a. Millimeters
 - b. Centimeters
 - c. Roentgens
 - d. Angstroms
31. The relationship between mass and energy is given by Einstein's equation: $E = mc^2$
32. The c stands for:
- a. Energy
 - b. Mass
 - c. Velocity of light
 - d. 3×10^8 m/sec
33. The photoelectric process is essentially an interaction between a photon and:
- a. A free electron

- b. The nucleus
- c. A bound electron
- d. All of the above

33. As the wavelength of light is decreased, its speed is:

- a. Increased linearly
- b. Decreased linearly
- c. Unchanged
- d. Increased exponentially

34. Bragg peak is:

- a. An ionization maximum near the end of the range of a heavy charged particle
- b. A maximum in the curve of activity and time for a parent and daughter radionuclide in equilibrium
- c. A maximum concentration of Compton interactions
- d. The maximum activity of an isotope

35. Different isotopes of the same element will have equal numbers of:

- a. Electrons
- b. Protons and electrons
- c. Neutrons
- d. Electrons and neutrons
- e. Protons and neutrons

36. The half-life of a radionuclide is:

- a. Influenced by temperature and pressure
- b. Directly proportional to the decay constant
- c. Less than the average life
- d. Usually shorter for beta negative than beta positive emitters

37. In the formula $A = A_0 e^{-\lambda t}$, λ is:

- a. The number of atoms decaying per unit of time
- b. The fraction of atoms decaying per unit of time

- c. The fraction of atoms decaying in time
 - d. The linear attenuation coefficient
38. When a very long-lived radionuclide decays to a short-lived daughter, it is known as _____ equilibrium.
- a. thermal
 - b. secular
 - c. transient
 - d. temporary
39. Which of the following is not a type of ionizing radiation?
- a. 2 MHz ultrasound
 - b. Cobalt gamma rays
 - c. Strontium beta
 - d. 15 MV x-rays
40. An electron, proton, and alpha particle each have 20 MeV kinetic energy. Which of the following is true?
- a. The alpha particle travels at almost light speed
 - b. The alpha particle has the least total energy
 - c. The proton has the highest total energy
 - d. The electron travels at almost light speed
41. The mass of an electron is:
- a. The same as a proton
 - b. Half that of a proton
 - c. The same as a neutron
 - d. Much smaller than that of a neutron
42. Ionization implies:
- a. An excited state of the atom
 - b. The production of x-rays
 - c. The removal of an electron from the atom
 - d. A neutral state of the atom
43. When a radionuclide decays, radiation is emitted from the:
- a. Outer shell electrons

- b. Inner shell electrons
- c. The nucleus
- d. All of the above

44. The probability that a photon interacts with a material is:

- a. Dependent on its density
- b. Proportional to the total attenuation coefficient
- c. Inversely proportional to the number of protons in the atom
- d. All of the above

45. The rate of energy loss by a charged particle is:

- a. Proportional to the particle charge
- b. Proportional to the square of the particle charge
- c. Independent of charge
- d. None of the above

46. Heavy particles lose most of their energy:

- a. Immediately as they enter the medium
- b. In the middle of their range
- c. Near the end of their range
- d. Equally throughout their range

47. Bragg peak is not observed in electrons because of their:

- a. High speed
- b. Negative charge
- c. Small mass
- d. Short half-life

48. Excitation produced by electron beams occurs in the:

- a. Nucleus of the atom
- b. Neutrons of the atom
- c. Orbital electrons of the atom
- d. Protons of the atom

49. In the production of bremsstrahlung, the electron:

- a. Ejects a cloud of electrons

- b. Slows down and loses some of its energy as an x-ray photon
 - c. Produces a heavy particle
 - d. Ejects an electron from the atom
50. The term x-ray refers to a part of the electromagnetic spectrum having an energy of:
- a. More than 1 million electron volts
 - b. Less than 1 electron volt
 - c. Between 1 and 100 electron volts
 - d. Between 100 and 1 million electron volts
51. Which of the following types of radiation has a positive electrical charge?
- a. Alpha
 - b. Beta
 - c. Delta
 - d. Gamma
52. Radiation can be described as energy:
- a. In transit
 - b. Destroyed
 - c. Recovered
 - d. In the form of heat
53. $^{131}_{53}\text{I}$ and $^{131}_{54}\text{Xe}$
- $^{125}_{54}\text{Xe}$ have different:
- a. Chemical properties
 - b. Z values
 - c. Numbers of protons
 - d. Numbers of neutrons
 - e. K shell binding energies
54. If the distance from a radiation source is decreased by half, the intensity is:

- a. Increased by half
- b. Increased by four times
- c. Decreased by half
- d. Decreased by a quarter

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CHAPTER 3

Radiation Biology

Waylon Malmay

Focus questions

- What aspects of tissue response are demonstrated with the dose-response curve?
- What aspects of tissue response are demonstrated with the cell-survival curve?
- What is the difference between direct and indirect ionization?
- What are the principles of target theory?
- What aspects of radiation biology may be applied to radiation safety practices?
- What are the differences between early versus late or acute versus chronic effects?
- What are the differences between somatic and genetic effects?
- In what ways may we manipulate tissue response to radiation?
- What are the tolerance doses of certain tissues to fractionated radiation?
- What are the three acute radiation syndromes?
- What are the three cellular radioresponse factors?

Radiation Biology Overview

- Radiation exposure to living tissue may cause direct or indirect effects.
- Direct effects would be consequences of events directly causing the disabling of cellular function.
- Indirect effects would be consequences of a series of events ultimately leading to the disabling of cellular function.
- The response of living tissue to radiation exposure can be examined on various levels: atomic, molecular, cellular, and systemic.
- Responses may be observed within a short time frame (acute) or after a long time period following exposure (latent).
- Specific tissue responses are influenced by multiple factors such as:
 1. Total dose
 2. Radiation type
 3. Cellular sensitivity to radiation
 4. Volume of tissue irradiated
 5. Protraction (period of time over which total dose is absorbed)
 6. Fractionation (fraction of total dose given per unit of time)

Interaction of Radiation and Matter

- Excitation or ionization in the atoms of living tissue is a response to exposure of tissue to ionizing radiation.
- Excitation or ionization events may lead to subtle responses in tissues such as a small increase in temperature at the site or more overtly, in the breaking of chemical bonds.
- The energy of radiation used for imaging and radiation therapy likely leads to ionizing events.
- Two types of interactions occur when radiation interacts with a cell. These interactions are referred to as direct or indirect ionization.
- When the incident particle interacts with the critical target (deoxyribonucleic acid [DNA]) of the beam, this is known as direct ionization.

- This usually occurs with protons, alpha particles, or electrons. These particles produce damage to the critical target, which is DNA.
- Direct ionization usually occurs with densely ionizing radiation such as protons and alpha particles. These are considered high linear energy transfer (LET) radiations.
- Densely ionizing radiations are considered bulkier in terms of mass than electrons, and their energy is deposited over smaller distances in the cell.
- Indirect ionization occurs primarily with sparsely ionizing radiation such as gamma rays and x-rays. These are considered low LET radiations.
- Sparsely ionizing radiation produces secondary electrons with small particles that deposit their energy over great distances in the cell.
- Indirect ionization damages the DNA molecule primarily from splitting of water (H

$_2\text{O}$).

- Due to the majority of the cell consisting of H

$_2\text{O}$, the probability of damage occurring through indirect ionization is greater than the probability of damage through direct ionization.

- It is difficult to say whether the ionizing events are the consequence of direct or indirect effects; most likely they are a consequence of indirect effects.
- The atoms in living tissue come together to form molecules.
- A major molecule in the body is H

$_2\text{O}$.

- Since the body is about 80% water, it is rational to believe that the encounters between water molecules and radiation are what lead to manifested responses in living tissue to radiation.
- The irradiation of water causes the breaking of the chemical bond between the hydrogen and oxygen atoms, leading to the production

of

free radicals .

- A free radical is an uncharged molecule that contains a single unpaired electron in its outer shell, making it unstable and carrying excess energy.
- The result is the development of an ion pair H^+

and OH^-

and two free radicals H^+

and OH^- (

Figure 3.1).

- Free radicals have a short life span but can interact with neighboring cells.
- $OH^\cdot$, the hydroxyl free radical, and hydrogen peroxide (H_2O_2)

O_2

) cause the majority of all radiation damage.

- The effects of radiation exposure may also be demonstrated in encounters with other molecules such as proteins, lipids, carbohydrates, and nucleic acids.
- The largest organic molecules are nucleic acids: DNA and RNA.
- DNA and RNA are responsible for cellular structure and function; they provide the map for developing cells.
- One guaranteed means for cell death is to interrupt transcription and prevent the synthesis of DNA in the parent cell.
- DNA is the primary target for the greatest damage to the cell; a direct encounter with this molecule would be known as a direct effect.

- DNA is a small molecule located in the small cell nucleus and difficult to target during radiation therapy.
- The effect on DNA following irradiation can lead to a variety of consequences involving the nitrogenous bases or chromosomes (

Figure 3.2).

- Some consequences of DNA damage may be repaired, leaving the cells to recover and resume normal function; this type of damage is known as sublethal damage.
- Other consequences of DNA damage may be permanent and may ultimately lead to cell death.
- Favorable effects of radiation therapy depend mostly on random encounters with other parts of the cell and not the nucleus, where DNA is located.
- Radiation interactions may lead to damage of the cell membrane and/or organelles in the cytoplasm.
- The average energy loss of a charged particle to a medium within a designated distance is termed LET.
- The same biologic response is not produced when evaluating equal doses of different LET radiations. This is termed the relative biologic effectiveness (RBE) of the radiation.
- As LET increases, RBE also increases.

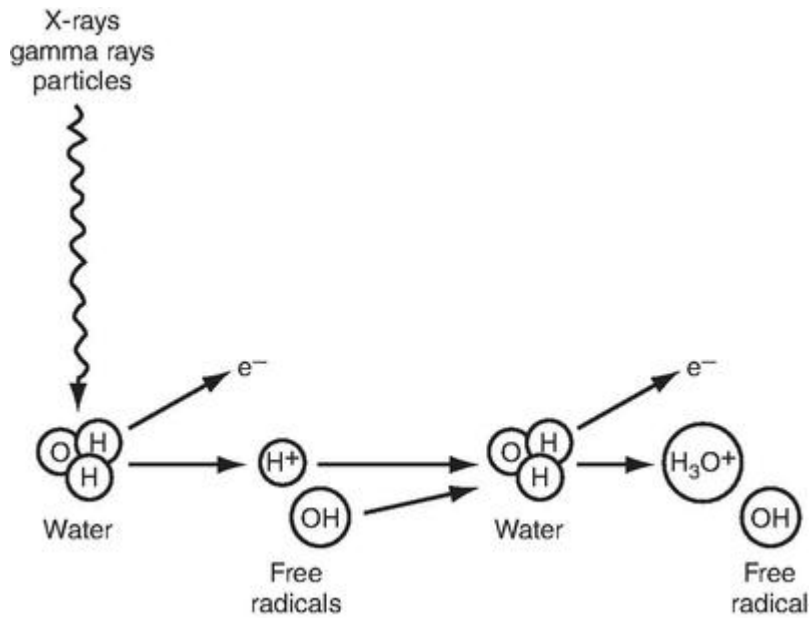


FIG. 3.1 Breaking of water molecules to form free radicals.

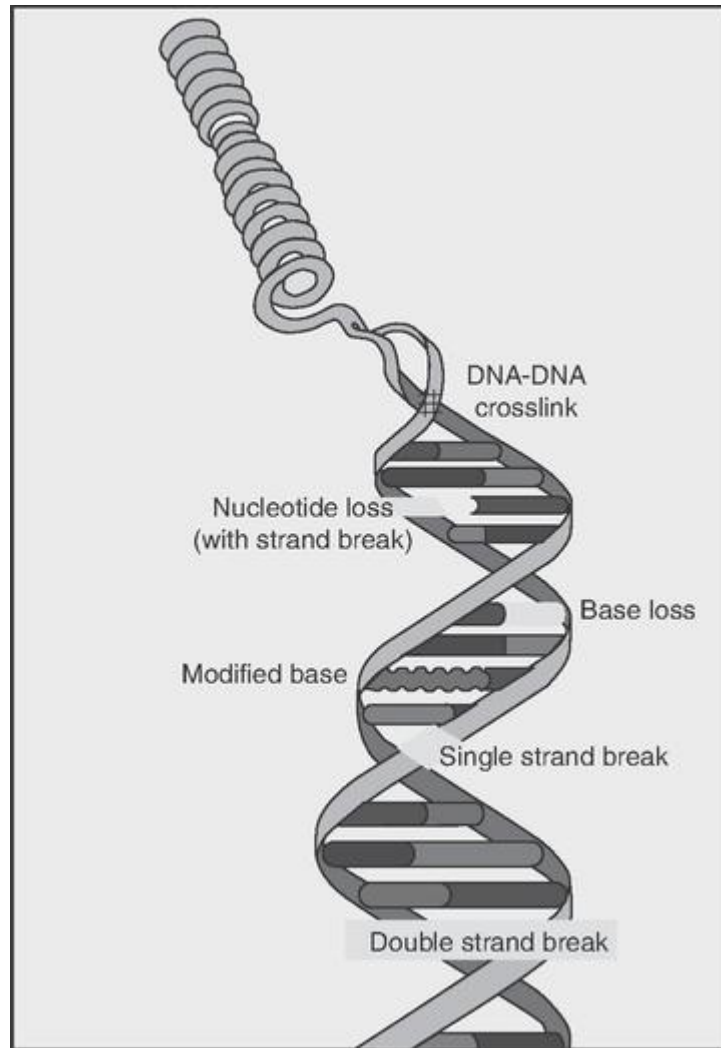


FIG. 3.2 DNA strand showing nitrogenous bases following radiation damage.

Cellular Response

- The functional integrity of tissues depends on the organization and the parenchymal and stromal cells within it.
- Cells differ in their sensitivity to radiation.
- The

law of Bergonie and Tribondeau states that cells that are rapidly dividing, have a long mitotic future, and are undifferentiated are

the most responsive to radiation.

- The living cell periodically progresses through cell division so that new cells may take the place of old worn out or damaged cells.
- Cell division in germ cells is termed

meiosis, whereas cell division in other types of cells is known as *mitosis*.

- There are four phases of division in nongerm cells: mitosis, Gap 1, DNA synthesis, and Gap 2; a fifth phase, known as Gap 0, indicates a period of rest.
- The phase most sensitive to radiation is the M phase; the most resistant is the S phase (

Figure 3.3).

- It is possible to measure the percentage or fraction of cells in certain phases of the dividing cycle at a given time, and the time intervals between cellular mitosis, in research settings.
- The proportion of cells in mitosis is called the mitotic index.
- Being knowledgeable about the patterns of cellular division for certain types of cells is helpful when planning chemotherapy and radiation treatment regimens. This information influences whether chemotherapy is given in one bolus injection or with continuous infusion and whether radiation will be administered using traditional fractionation, hyperfractionation, or hypofractionation schemes.
- Generation time, or interval between mitotic phases, for cell populations typically ranges from 8 to 30 hours.
- All cells do not have the same dividing frequency; some divide until maturation and others continue dividing for the entire life of the host.
- All cells are not in the same phase of division at the same time; therefore some cells in a population are more vulnerable to the

potential damaging effects of radiation exposure than others during a single dose of radiation.

- Radiation may cause interphase death, delay in division, or reproductive failure, eventually causing the mitotic index to decline.
- The rate of decline becomes faster as radiation dose is increased and then reaches a saturation value.
- The decline eventually leads to cessation of increased cell number.
- A delay in reentering the mitotic phase increases as radiation doses accumulate; prolonged division delay will eventually lead to cell death.
- The

cell-survival curve describes the relationship between the radiation dose and the proportion of cells surviving.

- The relationship is logarithmic and therefore curves should be plotted on logarithmic graphs, with the dose along the

x -axis and surviving fraction on the

y -axis.

- The cell survival curve may introduce a third variable and show how the declining mitotic index and surviving fraction differ when:
 1. Radiation type varies
 2. Cell type varies
 3. Cell vasculature and oxygenation varies
 4. Phase of cellular division at time of exposure varies
- Two models have been widely used to plot cell survival and they are: single-hit, single-target theory and single-hit, multiple target theory.
- Primitive cells such as bacteria and viruses could be plotted on a single-target, single-hit model survival curve; there is likely no

shoulder region and one hit would likely hit a critical part of the cell.

- Mammalian cells are plotted on a single-hit, multiple-target curve; these complex cells have many critical portions such as DNA, chromosomes, cytoplasm and its contents, water molecules, proteins, and gate-keeping membranes.
- Although radiation therapy is not usually administered using single doses (single-hit), we can extrapolate the consequence of exposed cells having multiple targets to a single dose forward to standard fractionation.
- When standard fractionated radiation is administered, target hits are random; if hits are uniform, a more rapid cell death could be observed.
- Important values to note when reviewing a cell survival curve (

Figure 3.4) include:

1. D_q = quasithreshold dose; dose required to initiate a steady decline in the mitotic index; dose causing sublethal damage
2. D

D_{37} = the dose required to leave 37% of cells surviving in the straight-line portion of the curve; single-hit, single-target theory

3. D_0 = the dose range for death of 63% of cells in the straight line portion; most reliable value for determining cell sensitivity; multiple-target, single-hit theory
4. N = extrapolation number; relative target number in the cells irradiated and a measure of the shoulder

- Cells with a low D

D_0 are more radiosensitive.

- Cells with a high D

o are more radioresistant.

- The D

o for mammalian cells is normally between 100 and 220 cGy.

- Using radiation with higher LET and exposing cells that are rapidly dividing and well oxygenated during or near the M phase show a rapidly decreasing surviving fraction of cells as the dose accumulates.
- LET describes the average energy deposited per unit of path length to a medium by ionizing radiation as it passes through that medium.
- Particulate radiations have a high LET because of their charge and heavy mass; energy is deposited more densely and the biologic effect on both normal and cancerous tissue is greater.
- Relative biologic effectiveness (RBE) provides a relative comparison of the effectiveness of test radiation to the dose of 250 KV x-ray. It relates the ability of radiation with different LETs delivered under the same conditions to produce the same biologic effect.

$$RBE = \frac{250 \text{ KV dose for a given effect}}{\text{Dose of test radiation for same effect}}$$

- Equal doses of different LET radiations do not produce the same biologic effect.
- The oxygen enhancement ratio (OER) is a comparison of the doses required to reduce survival to a certain level in hypoxic and oxygenated conditions; hypoxic cells are radioresistant.

$$\text{OER} = \frac{\text{hypoxic dose needed to produce a biologic effect}}{\text{Oxygenated dose needed to produce a biologic effect}}$$

- As a tumor grows, a substantial portion of the tumor becomes hypoxic; this makes it critical to detect and begin treatment to tumors as soon as possible following a definitive diagnosis.
- Tumors that have good access to vasculature and are well oxygenated respond to radiation more readily than a poorly oxygenated cell population.
- The response of oxygenated cells to radiation exposure is most pronounced when sparsely ionizing radiation, such as x-ray, gamma, and electrons, are applied.

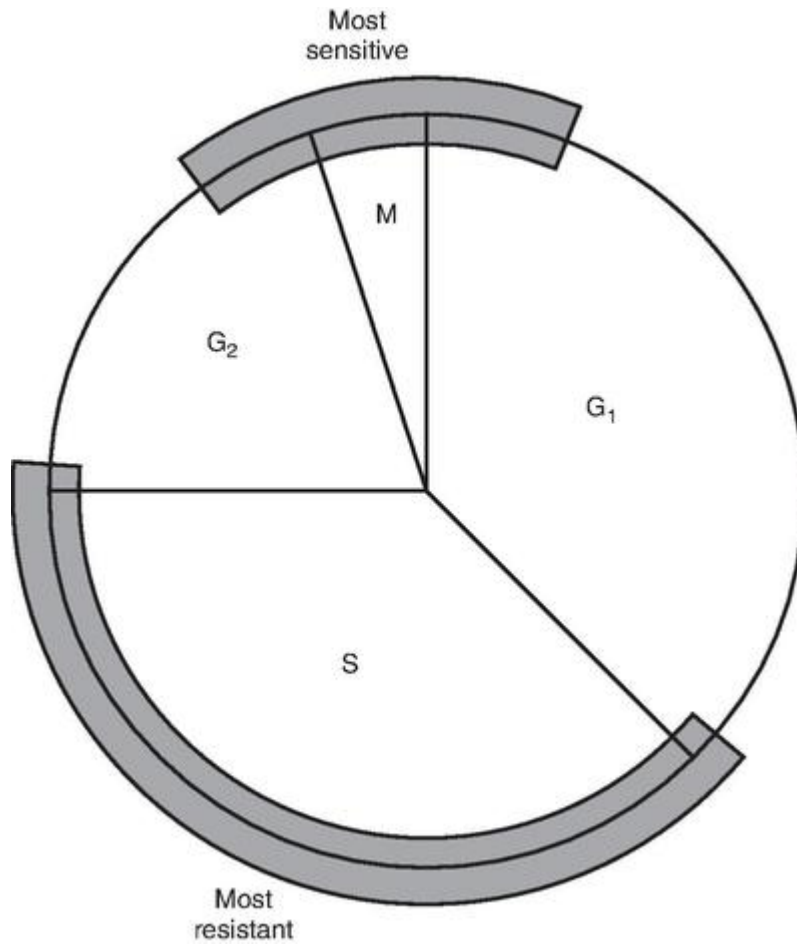


FIG. 3.3 Phases of division showing the most sensitive and resistant phases in shaded areas.

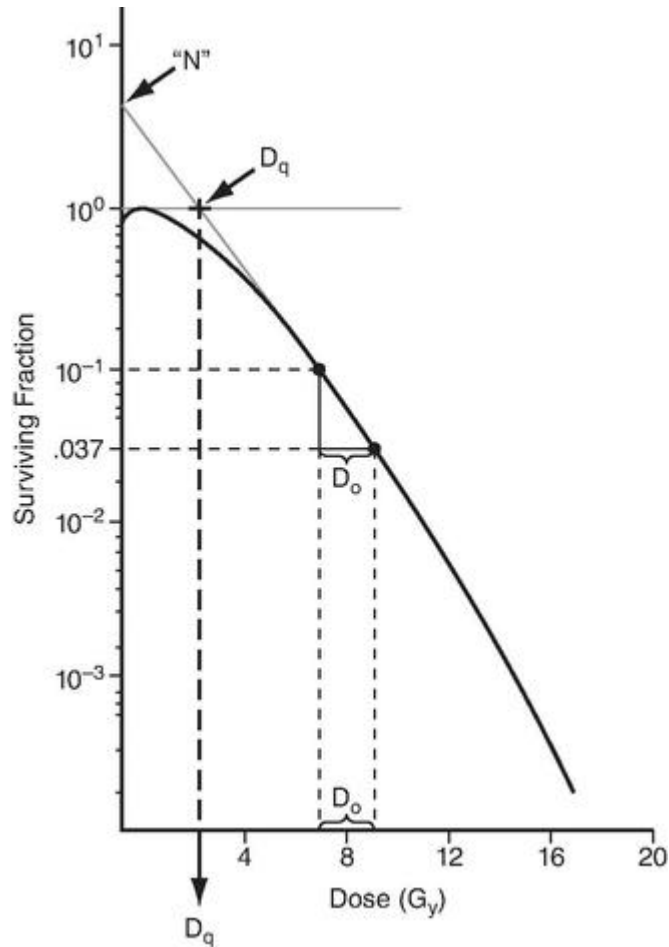


FIG. 3.4 Cell survival curve with important values marked.

Cellular Radioresponse Factors

- These factors include:
 1. Physical: including LET and dose rate.
 - Cellular response to high-LET radiation differs from cellular response to low-LET radiation.
 - After high-LET exposures, cell survival curves tend to be steeper.
 - High dose rates produce more damage than low dose rates.

- The dose rate effect is not noticed with high-LET radiations.
 - The dose rate effect is observed in low-LET radiations such as gamma rays and x-rays.
2. Chemical: including radiosensitizers and radioprotectors
- Radiosensitizers are chemicals that amplify the response to radiation.
 - Molecular oxygen is considered the most potent radiosensitizer.
 - The sensitizing effects of oxygen are most noticeable with low-LET radiations.
 - Radioprotectors do the opposite of radiosensitizers. They reduce the cellular response to radiation.
3. Biologic:
- Cells are most sensitive to radiation during the G2 and M phases and most resistant during the S phase.

Cells

- There are five types of mammalian cell populations. They are the VIM, DIM, vessels/connective tissue, RPM, and FPM cells.
- The VIM cells are the most radiosensitive due to the fact they are undifferentiated and rapidly dividing. The testes and bone marrow contain VIM cells and are considered radiosensitive.
- The FPM cells are the most radioresistant due to the fact they are highly differentiated and do not divide. The muscle, brain, liver, and spinal cord contain FPM cells and are considered radioresistant.

Systemic Response to Radiation

- The response to radiation is often grouped in two phases: responses that occur within 6 months of treatment are considered early or

acute changes and responses that occur 6 months or later are considered late or chronic changes

-
- Late changes are the consequence of irreversible and progressive early changes.
- Late or chronic changes occurring depend on the volume irradiated, dose administered, and the healing ability of the irradiated organ.
- After exposure to radiation, organs can heal by the process of regeneration or repair.
- Replacing the damaged cells by the same cell type refers to the process of regeneration.
- The regeneration process has the possibility to restore a damaged organ to its preirradiated state.
- Replacing damage cells with different cells refers to the process of repair.
- The repair process results in fibrosis or the formation of a scar.
- Healing by the process of repair does not restore damaged organs to their preirradiated state.
- The most common early or acute changes after radiation exposure include edema, inflammation, and possible hemorrhaging.
- Early or acute changes can progress to late or chronic changes such as atrophy, fibrosis, and ulceration.
- Late or chronic changes are not reversible. The most severe late or chronic response to irradiation is necrosis or death.
- Radiation responses that follow high doses of radiation exposure and appear early are termed deterministic.
- Deterministic radiation responses exhibit a dose threshold and have a nonlinear dose-response relationship. As radiation doses increase, the response increases.
- Cancer, genetic effects, and leukemia are stochastic radiation responses. These responses occur years after exposure to low radiation.
- Stochastic responses do not exhibit a dose threshold and have a linear dose-response relationship.

Tissue Response

- There are several tissue types in the body.
- Epithelial, connective, muscle, nerve, and membranes are main tissue categories.
- As cells make up tissues, the sensitivity of certain cell types translates to the sensitivity of tissues the cells comprise.
- Changes in tissues following radiation are similar to changes we see following heat and cold exposure, infections, or traumatic injury.

Cardinal Signs of Injury

Redness
Swelling
Heat
Pain

- Changes may be seen immediately, within days or weeks (acute), or later as in months or years (latent).
- Changes seen within days or weeks may also be called deterministic or

nonstochastic effects.

- Changes seen after months or years of exposure may be called

stochastic effects.

- Immediate effects are rarely seen in therapeutic radiation but may be seen in nuclear accidents where total doses and exposure rates are extremely high.

- The response of tissues following significant doses of radiation may appear as vascular dilation, cellular inflammation, and at high doses, tissue necrosis.
- The four progressive stages of tissue response are easily observed in the skin of the irradiated patient where the absorbed dose to the skin exceeds 50 Gy.

Four Progressive Stages of Skin Response (standard fractionation)

1. Epilation
2. Erythema
3. Dry desquamation
4. Wet desquamation

- Beyond total doses fractionated doses of 50 Gy to the skin, tissue necrosis may occur, necrotic cells may shed, and the area can repair and repopulate.
- Acute effects vary depending on the tissue irradiated and the fractionation and protraction (

[Table 3.1](#)).

- Damage or radiation injury to tissues may be permanent and is greatly influenced by the total dose, fractionation, and protraction.
- During therapeutic radiation, doses high enough to cause tissue necrosis are avoided.
- When prescribing therapeutic doses of radiation necessary to kill malignant tumor cells, radiation injury to normal tissues in the area must be considered.
- Tolerance of normal mammalian tissues is expressed using

TD 5/5 or

TD 50/5 values.

- Tolerance doses (TD) are documented and referenced according to the sensitivity of tissue exposed, the volume of tissue exposed, and widely used fractionation schedules (i.e., 200 cGy per fraction, 5 fractions per week).
- TD 5/5 would be the dose that would likely cause 5% of an exposed population to realize an adverse late effect in 5 years following exposure (

[Table 3.2](#)).

- TD 50/5 would be the dose that would likely cause 50% of an exposed population to realize an adverse late effect in 5 years following exposure.
- Any deviation from the standard fractionation scheme results in a different biologic response in both normal and cancerous tissue.
- Ellis developed an equation, known as the nominal standard dose (NSD) formula, in 1968. The formula was an attempt to design treatment schedules that resulted in optimal tumor response with acceptable normal tissue damage. This equation could also be used as a reference if the treatment schedule was interrupted.

TABLE 3.1**Doses for Onset of Acute Effects (10 Gy/wk at 5 fractions/wk)**

Tissue	Acute Effect	Onset Dose (Gy)
Skin	Erythema	20
	Dry desquamation	30
	Wet desquamation	40
Oral mucosa	Mild, patchy mucositis	30
	Confluent mucositis	40
Esophagus	Esophagitis	25
Salivary glands	Xerostomia	20
Rectum	Proctitis	30
Testis	Decreased sperm	0.25
Bone marrow	Lowered blood counts	4
	Extensive hypoplasia	50
Stomach	Gastritis	20

TABLE 3.2**Radiation Tolerance Doses—TD 5/5 (10 Gy/wk at 5 fractions/wk)**

Tissue	Injury	TD 5/5 (Gy) Whole Organ
Skin	Ulceration/fibrosis	55
Intestine	Stricture	45
Salivary glands	Permanent xerostomia	40
Kidneys	Failure	23
Testis, ovary	Sterility	5-15
Bone	Arrested growth in child	20
Necrosis in adult		60
Bone marrow	Reduced cellularity	20
Spinal cord	Necrosis	45
Lens	Cataract	5
Brain	Necrosis	50

From Emami B, Lyman J, Brown A. Tolerance of normal tissue to therapeutic irradiation.

Int J Radiat Oncol Biol Phys . 1991;21:109–122.

Ellis' formula: $D = NSD \times T$

$0.11 \times N$

0.24

D = total dose, T = elapsed time (protraction)

N = number of fractions, NSD = 1800 rets

- Disadvantages to using Ellis' equation was that connective tissue was the reference tissue, so there was no accounting for more sensitive or more resistant tissues; neither was there a consideration for a variation in volume of tissue irradiated.
- Today, a similar equation may be used when standard fractionation is interrupted or varied. The modern formula is known as the biologic effective dose (BED) formula.

$BED = (nd) \text{ relative effectiveness}$

$nd = \text{total dose}$

$\text{Relative effectiveness} = 1 + d/\alpha$

$\alpha = \text{reference dose for early effects; accepted as 10 Gy}$

****should substitute β for α for late effect; $\beta = \text{reference dose of 3 Gy}$**

- Isoeffect lines show the relationship between total dose and overall treatment time for a specific tissue response, such as early skin reactions and other acute effects, or late tissue responses, such as necrosis or the development of secondary cancers.
-

Dose-response curves give another visual representation of tissue response to radiation exposure.

- Dose-response curves may be linear or nonlinear, have a threshold, or no threshold.
- Dose-response curves showing

deterministic, or early effects typically have a threshold dose-response and are nonlinear; the two variables on this type of curve would be dose and severity of the effect.

- Dose-response curves showing

stochastic, or late effects, typically have a nonthreshold dose-response and may be linear or nonlinear depending on the

endpoint; the two variables on this type of curve would be the dose and the probability of the late effect (

Figure 3.5).

- Stochastic effects may be seen in the individual exposed or in the offspring.
- During radiation therapy, clinicians should monitor the acute or early effects of radiation.
- Monitoring of acute effects is easily performed by using an accepted toxicity scoring system (

Table 3.3).

- QUANTEC (quantitative analysis of normal tissue effects in the clinic) describes the current available three-dimensional dose/-volume/outcome data to update and clarify normal tissue/dose/volume tolerance guidelines.
- One of the goals of QUANTEC is to outline the available 3D dose/volume/outcome data and to assemble practical guidelines. These guidelines allow the radiation oncologist to categorize toxicity based on dose/volume parameters. These values are often posted in the planning laboratory values and used as a reference (

Table 3.4).

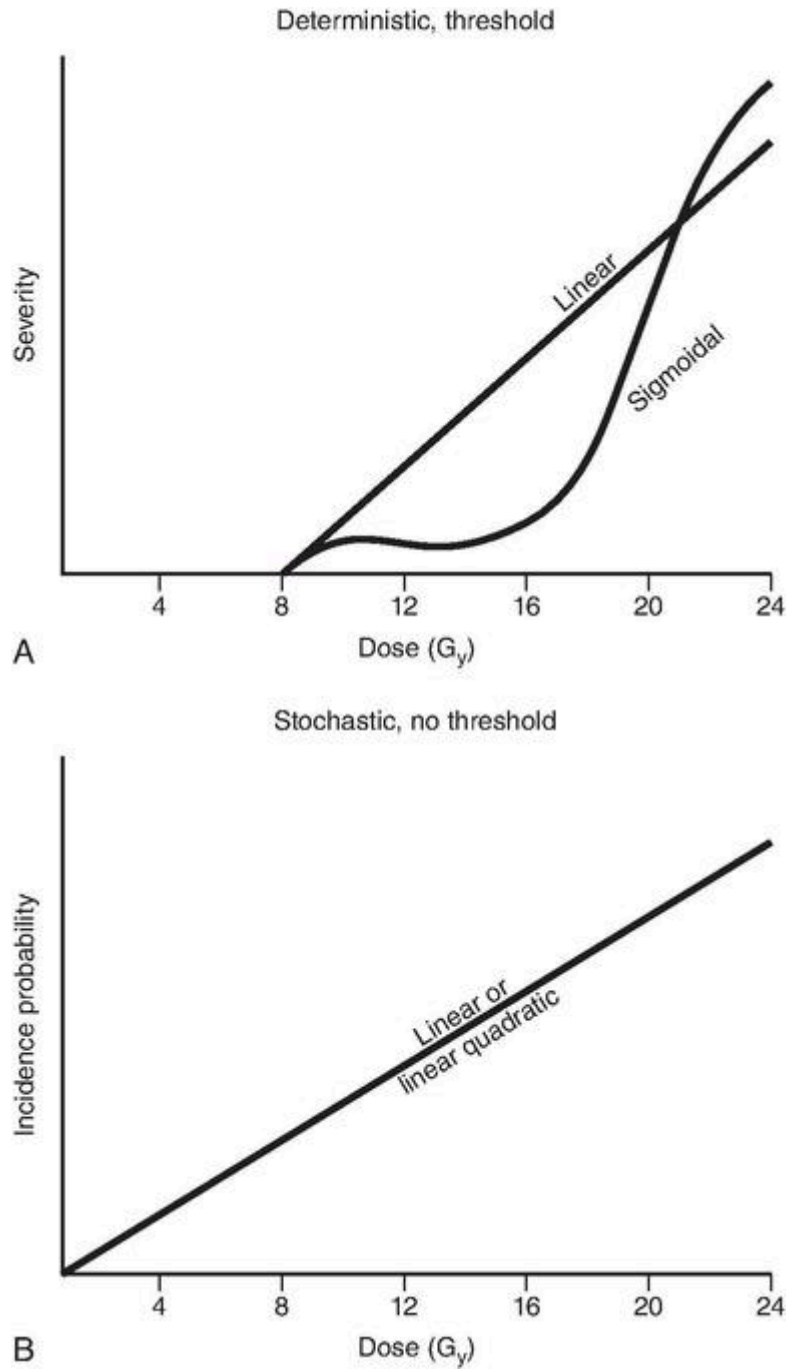


FIG. 3.5 Dose-response curves.

A , Deterministic;

B , stochastic.

TABLE 3.3

Acute Radiation Morbidity Scoring Criteria					
0	1	2	3	4	5
Skin	No change over baseline	Follicular, faint, or dull erythema; epilation; dry desquamation; decreased sweating	Tender or bright erythema, patchy moist desquamation; moderate edema	Confluent, moist desquamation other than skin folds, pitting edema	Ulceration, hemorrhage, necrosis
Mucous membrane	No change over baseline	Injection; may experience mild pain not requiring analgesic	Patchy mucositis that may produce an inflammatory serosanguinitis discharge; may experience moderate pain requiring analgesia	Confluent fibrinous mucositis; may include severe pain requiring narcotic	Ulceration, hemorrhage, or necrosis
Pharynx and esophagus	No change over baseline	Mild dysphagia or odynophagia; may require topical anesthetic or nonnarcotic analgesics; may require soft diet	Moderate dysphagia or odynophagia; may require narcotic analgesics; may require puree or liquid diet	Severe dysphagia or odynophagia with dehydration or weight loss (>15% from pretreatment baseline) requiring N-G feeding tube, IV fluids, or hyperalimentation	Complete obstruction, ulceration, perforation, fistula
Upper GI	No change	Anorexia with ≤ 5% weight loss from pretreatment baseline; nausea not requiring antiemetics; abdominal discomfort not requiring parasympatholytic drugs or analgesics	Anorexia with ≤15% weight loss from pretreatment baseline; nausea and/or vomiting requiring antiemetics; abdominal pain requiring analgesics	Anorexia with >15% weight loss from pretreatment baseline or requiring N-G tube or parenteral support. Nausea and/or vomiting requiring tube or parenteral support; abdominal pain, severe despite medication; hematemesis or melena; abdominal distention (flat plate radiograph demonstrates distended bowel loops)	Ileus, subacute or acute obstruction, perforation, GI bleeding requiring transfusion/abdominal pain requiring tube decompression or bowel diversion
Lower GI including pelvis	No change	Increased frequency or change in quality of bowel habits not requiring medication; rectal discomfort not requiring analgesics	Diarrhea requiring parasympatholytic drugs (e.g., Lomotil); mucous discharge not necessitating sanitary pads; rectal or abdominal pain requiring analgesics	Diarrhea requiring parenteral support; severe mucous or blood discharge necessitating sanitary pads; abdominal distention (flat plate radiograph demonstrates distended bowel loops)	Acute or subacute obstruction, fistula, or perforation; GI bleeding requiring transfusion; abdominal pain or tenesmus requiring tube decompression or bowel diversion
Lung	No change	Mild symptoms of dry cough or dyspnea on exertion	Persistent cough requiring narcotic, antitussive agents; dyspnea with minimal effort but not at rest	Severe cough unresponsive to narcotic antitussive agent or dyspnea at rest; clinical or radiologic evidence of acute pneumonitis/ intermittent oxygen or steroids may be required	Severe respiratory insufficiency; continuous oxygen or assisted ventilation
CNS	No change	Fully functional status (i.e., able to work) with minor neurologic findings, no medication needed	Neurologic findings present sufficient to require home care; nursing assistance may be required; medications including steroids; antiseizure agents may be required	Neurologic findings requiring hospitalization for initial management	Serious neurologic impairment, which includes paralysis, coma, or seizures >3/wk despite medication; hospitalization required

From Radiation Therapy Oncology Group. Accessed December 30, 2009.

<http://www.rtog.org/members/toxicity/acute.html> .

Whole Body System Response

- Whole body effects have only been able to be studied in small populations of people such as victims of nuclear accidents.
- Response to whole body radiation may progress through three phases: prodromal, manifest syndromes, and latent.
- A one-time dose of 350 to 450 cGy could lead to death within 30 to 60 days without medical intervention: LD 50/30 or LD 50/60.
- The likelihood of progressing through and the total time to progress through phases is influenced by total dose and dose rate.
- Prodromal symptoms include nausea, vomiting fatigue, fever, hypotension, and diarrhea.
- Prodromal symptoms exhibited and time frame are influenced by total dose and dose rate.
- Manifest syndromes are hematopoietic, gastrointestinal, and cerebrovascular (

[Table 3.5](#)).

- Late

somatic, or effects to the individual, may include radiation-induced cancers, cataract formation, chronic bone marrow depression, shortened life span, and mutations in germ cells.

- Latent genetic effects may be seen in the offspring of whole body exposure victims.
- Both somatic and genetic, early and late effects of whole body radiation response must be considered when using whole body radiation therapeutically.
- Both somatic and genetic, early and late effects of whole body radiation response are considered when establishing annual dose

limits for occupational radiation workers and the general public.

Table 3.4

QUANTEC Values for Conventional Fractionated 3D-CRT			
Critical Structure	Max Dose	Toxicity Rate	Toxicity Endpoint
Brain	<60 Gy	<3%	Symptomatic Necrosis
Brain	90 Gy	10%	Symptomatic Necrosis
Optic nerve	<55 Gy	<3%	Optic neuropathy
Optic nerve	>60 Gy	>7–20%	Optic neuropathy
Spinal cord	50 Gy	0.2%	Myelopathy
Spinal cord	69 Gy	50 %	Myelopathy

From Emami B, Lyman J, Brown A. Tolerance of normal tissue to therapeutic irradiation.

Int J Radiat Oncol Biol Phys

. 1991;21(1):109–122.

Table 3.5

Whole Body Radiation Syndromes				
Syndrome	Dose Range	Time of Death	Organ Damage	Symptoms
Hematopoietic	100–1000 cGy	3 weeks to 2 months	Bone marrow	Anemia, pancytopenia, infection, and hemorrhage
Gastrointestinal	1000–5000 cGy	3–10 days	Small intestine	Neutropenia, electrolyte imbalance, infection, and watery diarrhea
Cerebrovascular	>5000 cGy	<3 days	Brain	Edema, vasculitis, and meningitis

Acute Radiation Syndromes

1. Hematopoietic Syndrome:

- A total-body dose of 100 to 1000 cGy will induce the hematopoietic syndrome in humans.
- The median lethal dose, LD 50/60 is between approximately 350 and 450 cGy.
- The prodromal phase occurs hours after the initial radiation exposure and is identified by nausea and vomiting.
- The latent phase occurs next and can last a few days to a few weeks.
- The manifest phase occurs 3 to 5 weeks after the initial radiation exposure. All blood cell counts become depleted and the patient becomes anemic, experiences hemorrhaging, and oftentimes a serious infection.
- The primary cause of death due to the hematopoietic syndrome is hemorrhaging and infection.

2. Gastrointestinal Syndrome

- A total-body dose of 1000 to 5000 cGy will induce the gastrointestinal syndrome.
- The average survival time is 3 to 10 days or up to 2 weeks for this syndrome.
- Within hours the prodromal stage occurs after the initial radiation exposure and is identified by vomiting, nausea, diarrhea, and cramps.
- The latent phase occurs 2 to 5 days after the exposure.
- The manifest phase begins 5 to 10 days after the exposure. This phase is identified by vomiting, nausea, diarrhea, and fever.
- Death occurs due to damage of the gastrointestinal tract, bone marrow, dehydration, infection, and electrolyte imbalance.

3. Cerebrovascular Syndrome (Central Nervous Syndrome)

- A total body dose exceeding 5000 cGy will induce the cerebrovascular (central nervous) syndrome.
- The prodromal phase only lasts minutes to a few hours.
- The latent phase only lasts for a few hours or less.
- The manifest phase begins after only 5 to 6 hours of exposure and is identified by convulsions, diarrhea, coma, and death.

- The cause of death from the cerebrovascular (central nervous) system is not completely known. Death occurs in less than 3 days.

Embryo and Fetus

- Early effects to the unborn embryo or fetus may include spontaneous abortion or death in utero; doses as low as 0.05 Gy could be lethal to the embryo in the first trimester.
- As cells mature during the second and third trimesters, lethal radiation doses to the unborn increase.
- Following birth, damage to the central nervous system and/or permanent damage to undeveloped germ cells may also be realized.
- A mother receiving occupational exposure to the fetus should not exceed .5 rem (5 mSv) during the entire gestational period. Monthly exposure should not exceed 0.05 rem (0.5 mSv).
- The embryo and fetus are the most radiosensitive forms of humans and animals.
- The embryo is more radiosensitive than the fetus.

Four Rs of Radiobiology and Time/Dose Considerations

- The rationale for planning radiation therapy regimens is explained by the four Rs of radiobiology.
-

Repair is the first principle and refers to the repair mechanism built into all cells both normal and abnormal. Rest periods in standard fractionation schemes allow the normal cells to repair from sublethal radiation injury. Because tumor cells also have some capacity for repair, prolonged breaks in treatment are discouraged.

-

Reoxygenation is the second principle and refers to the ability of both normal and tumor cell populations to revascularize as cells die in an attempt to continue thriving. This phenomenon is both a help and a hindrance. The presence of oxygen increases cellular sensitivity to radiation through greater potential of free radical formation. Revascularization improves the viability of the abnormal growth; increased vascular supply is good for the recovery of normal tissues in the area.

-

Repopulation is the third principle and refers to the trigger of surviving cells in a tumor to divide faster in an attempt to live. This phenomenon is justification for repeated radiation injury events as provided by fractionated doses. Hyperfractionation and hypofractionation schemes are designed with this phenomenon in mind, with the specific growth and dividing pattern of the cells being irradiated.

-

Redistribution or reassortment, the fourth principle, is the ability for the cell population to return to a more even distribution of younger, dividing cells following decreased surviving fraction. This phenomenon also justifies repeated dosing as in standard fractionation and establishes the importance of avoiding breaks in treatment.

- The use of chemical

radioprotectors is founded on the principles of reoxygenation and repair. These chemicals may scavenge free radicals or facilitate direct chemical repair at sites of DNA damage in normal tissue.

- The use of chemical

radiosensitizers is founded on the principle of reoxygenation as well. Instead of trying to force oxygen into the cell as in the use of hyperbaric chambers, chemicals developed as oxygen substitutes are used to make hypoxic tumor cells respond to radiation as though they were well-oxygenated; some drugs may selectively kill hypoxic cells.

- Radioprotectors and sensitizers have a finite period of effectiveness; it is important to administer radiation doses within an hour or two following these biologic modifiers.

Review Exercises

1. TD 5/5 indicates the dose required to cause a 5% chance of injury to people irradiated within _____ following exposure.
 - a. 5 days
 - b. 5 hours
 - c. 5 years
 - d. 5 minutes
2. LD 50/30 indicates the dose likely to cause death in 50% of the population within _____ following exposure.
 - a. 30 days
 - b. 30 hours
 - c. 30 years
 - d. 30 minutes
3. The TD 5/5 for the whole kidney using standard fractionation is approximately:
 - a. 50 Gy
 - b. 30 Gy
 - c. 23 Gy
 - d. 0.5 Gy
4. The TD 5/5 for the whole brain using standard fractionation is approximately:

- a. 60 Gy
- b. 50 Gy
- c. 45 Gy
- d. 15 Gy

5. The radiosensitivity in tissue may be enhanced by:

- a. Increasing the oxygen in tissue
- b. Increasing the dose given
- c. Decreasing the fractionation size
- d. Decreasing the volume of tissue irradiated

6. The phase of cellular division most resistant to radiation is the _____ phase

- a. M
- b. S
- c. G0
- d. G1

7. The immediate symptoms that appear after an acute radiation exposure are called:

- a. Latent symptoms
- b. Proportional symptoms
- c. Chronic symptoms
- d. Prodromal symptoms

8. The law of Bergonie and Tribondeau states that ionizing radiation is more effective against cells that are:

- a. Actively mitotic
- b. Undifferentiated
- c. Have a long mitotic future
- d. Well differentiated
- e. a, b, and c
- f. a, c, and d.

9. Complete the table to show cellular sensitivity to radiation:

Mitotic Rate	Differentiation	Sensitivity	Examples
High	Undifferentiated		
Moderate	Moderate differentiation		
Low	Moderate differentiation		
Low to none	Well differentiated		

10. Protracted or fractionated dose are better tolerated by tissue than single doses because:

- a. Tissue tolerance increases as dose increases
- b. Tissue repair occurs between exposures
- c. Fewer cells will be struck by radiation
- d. Radiation damage cannot occur in previously killed cells

11. As the dose of radiation increases:

- a. The recovery rate in tissue remains unchanged
- b. Tissue recovery time decreases
- c. Tissue recovery time increases
- d. Tissue recovery time increases until a certain dose threshold

12. In linear or nonlinear threshold dose-response curves, the following is true of the response:

- a. Response will occur at all doses
- b. Response may not occur at low doses
- c. Response will never be realized
- d. Response is proportional to dose

13. Radiation sickness symptoms associated with the reduced number of leukocytes is a major characteristic of:

- a. Prodromal syndrome
- b. Hematopoietic syndrome
- c. Gastrointestinal syndrome
- d. Cerebrovascular syndrome

14. The average energy deposited per unit of path length to a medium by ionizing radiation as it passes through that medium best describes:
- a. Linear energy transfer
 - b. Radiation absorbed dose
 - c. Radiation equivalent
 - d. Tissue absorbed dose
15. The most radiosensitive tissue group among the following is the:
- a. Central nervous system
 - b. Alimentary tract
 - c. Muscle
 - d. Cardiovascular system
16. The four Rs of radiation biology are:
- a. Reoxygenation, repopulation, reimplantation, redistribution
 - b. Reoxygenation, repopulation, redistribution, repair
 - c. Reoxygenation, reimplantation, redistribution, repair
 - d. Reoxygenation, repair, repopulation, reduction
17. The whole-body syndrome most likely to be observed following a single dose of 1 to 10 Gy is the:
- a. Lethal dose syndrome
 - b. CNS syndrome
 - c. Hematopoietic syndrome
 - d. Gastrointestinal syndrome
18. Which of the following would be a stochastic or late radiation response?
- a. Sterility
 - b. Bone marrow suppression
 - c. Skin erythema
 - d. Lung cancer
19. Which of the following is a more accurate representation of cell radiosensitivity?

- a. Do
- b. Dq
- c. LD 50/30
- d. D

37

20. The central nervous system syndrome may be observed in those exposed to single whole body doses of:

- a. 300 cGy
- b. 5000 cGy
- c. 500 Gy
- d. 10 Gy

21. Without medical intervention, a person exposed to a single whole body dose of _____ may die within 10 days.

- a. 10 Gy
- b. 0.25 Gy
- c. 1.0 Gy
- d. 1.0 cGy

22. Normal tissue healing following radiation occurs by:

- a. Regeneration
- b. Repair
- c. Revitalization
- d. a and b

23. Exceeding the TD 50/5 for the spinal cord may lead to:

- a. Perforation
- b. Ulceration
- c. Myelitis necrosis
- d. Obstruction

Circle the Correct Word

24. The TD 5/5 for the colon is (higher, lower) than the TD 50/5 for the colon.
25. The TD 5/5 is (higher, lower) for immature bone than for mature bone.
26. The TD 5/5 is (higher, lower) for bone marrow irradiation in a single dose than in fractionated doses.
27. An anticipated response to radiation dose above 55 Gy to the colon is (erythema, fistula).
28. The TD 5/5 for the ovary is (higher, lower) than the TD 5/5 for the lung.
29. The most radiosensitive tissue group is:
- a. Central nervous
 - b. Alimentary tract
 - c. Lens
 - d. Urinary
30. The occupational dose limit for deterministic effects to the lens of the eye is lower than the limit for the skin because:
- a. The lens has a greater sensitivity to radiation than the skin
 - b. The skin has a greater sensitivity to radiation than the lens
 - c. The lens is easier to protect from radiation than the skin
 - d. The skin cells are more differentiated than the lens cells
31. The main objectives of radiation protection include:
- a. Prevention of radiation-induced deterministic effects
 - b. Prevention of radiation-induced stochastic effects
 - c. Production of radiation-induced stochastic effects
 - d. a and b
32. The onset dose for wet desquamation during standard fractionation is:
- a. 15 Gy
 - b. 20 Gy
 - c. 30 Gy
 - d. 40 Gy

33. Somatic effects are:

- a. The effects limited to the exposed individual
- b. The effects manifested in subsequent generations
- c. The effects seen after large doses only
- d. The effects seen after small doses only

Think About It

34. When irradiating the spleen for metastatic disease, hypofractionation may be employed, whereas certain primary head and neck cancers may employ hyperfractionation. Briefly explain the rationale for this difference.

35. An error has caused you to discover that your patient has received twice the prescribed dose during the first 2 weeks of treatment. Once you discover the error, what adjustments to this patient's treatment course are necessary?

36. Your patient has not yet received his radioprotector. It is time for his scheduled appointment and your two subsequent appointments have already arrived. In the essence of time, you could take him now and send him back to the waiting room to receive his injection later. Is this a feasible plan? Explain your answer.

37. You have a patient on a special hyperfractionation protocol. He is to receive two fractions per day. His first treatment was at 9:00

am and his second is scheduled for 3:00

pm. However, there has been a cancellation and you can squeeze him in at 1:30. Is this a feasible plan? Explain your answer.

38. There is a patient scheduled for 6 weeks of radiation using standard fractionation. After week 2 he informs you that he will be taking a 3-week cruise and plans to complete therapy when he returns. What would your counseling include?

39. The cardinal signs of tissue injury include:

1. Redness
2. Swelling
3. Heat
4. Pain

- a. 1, 3
- b. 2, 3, 4
- c. 1, 3, 4
- d. 1, 2, 3, 4

40. Regarding the tolerance of tissue, as the volume irradiated increases:

- a. The tolerance dose increases
- b. The tolerance dose decreases
- c. The tolerance dose doubles
- d. The tolerance dose decreases inversely by the square of the volume

41. Lethal damage:

- a. May be repaired by the body if circumstances are right
- b. Is irreparable and leads to cell death
- c. Is usually repaired by the body
- d. Is shown in the shoulder of the survival curve

42. The steps of cellular division in proper order are:

- a. M, G1, G2, S
- b. G1, M, G2, S
- c. M, G2, S, G1
- d. G1, S, G2, M

43. A cell survival curve:

- a. Usually has a shoulder and straight portion
- b. Cannot be drawn for human cells
- c. Cannot show the effects of dose rate
- d. Usually shows the fraction of surviving cells on a linear scale

44. High LET radiation usually has:

- a. An RBE of 1
 - b. An RBE of 0
 - c. High RBE
 - d. No relation to RBE
45. Which dose-effect curve implies that if radiation dose is doubled, the biologic effect will be doubled?
- a. Sigmoidal
 - b. Linear quadratic
 - c. Quadratic
 - d. Linear
46. The key target in the human cell is the _____.
- a. Cytoplasm
 - b. Mitochondria
 - c. Organelle
 - d. DNA
47. Cells are about _____ water.
- a. 50 %
 - b. 85%
 - c. 10%
 - d. 100%
48. On the cell survival curve, the “n” number denotes the:
- a. Quasithreshold dose
 - b. Mean lethal dose
 - c. Extrapolation number
 - d. Median lethal dose
49. Radiation would have less effect on a cell if given
- a. Over a short period of time
 - b. Over a long period of time
 - c. All at once
 - d. In the presence of oxygen
50. When radiation exposure is fractionated:

- a. The LET changes
- b. There are more direct effects
- c. The biologic effect is lessened
- d. The time period is shortened

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CHAPTER 4

Radiation Protection and Safety

Waylon Malmay

Focus questions

- Which organizations are responsible for setting the standards for radiation protection?
- What are the various sources of radiation exposure?
- What is the ALARA principle and how does it apply to occupational radiation workers?
- What are the dose limits for occupational workers, students, and the general public?
- What are the advantages and disadvantages of the most common types of radiation monitors?
- What materials are most feasible to use as barriers?
- What factors are necessary for the calculation of primary and secondary barriers?
- How do brachytherapy safety procedures differ from safety procedures applicable to external beam?

General Objectives of Radiation Protection

- Radiation protection involves physical, technical, and procedural factors used to protect patients, personnel, and the public from unnecessary radiation exposure.
- Before we protect ourselves, our patients, and others from the harmful effects of radiation exposure, we must identify potential sources of exposure (

[Table 4.1](#)). These sources may be grouped into the following major categories:

TABLE 4.1

Annual Exposures From Various Sources

Source of Radiation Exposure	Yearly Exposure
Cosmic radiation	30 mrem
Terrestrial radiation	29 mrem
Internal sources	39 mrem
Radon to lungs	200 mrem
Nuclear medicine procedures	14 mrem
Nuclear power plants, consumer products	10 mrem
X-ray imaging	40 mrem

Natural Background Radiation

- a. Cosmic rays from nuclear reactions in space.
- b. Terrestrial radiation from natural, radioactive earth elements.
- c. Internal radiation from radioactive material always present in our bodies such as carbon-14, hydrogen-3, strontium-90, and

- potassium-40. The greatest contribution to internal exposure is potassium-40.
- d. The radioactive gas radon is located in granite formations and in the atmosphere.

Man-Made Radiation

- a. Medical x-ray equipment
 - b. Radioactive sources produced for nuclear medicine and brachytherapy
 - c. Television
 - d. Nuclear reactors and weapons
- Natural background radiation is the source of the majority of annual exposure. It is not possible to be totally protected from natural radiation; some amount of exposure is inevitable.
 - We must make every attempt to limit exposure to man-made sources of radiation.
 - The key to limited exposure is to follow the principle of ALARA.
 - ALARA is an acronym for “as low as reasonably achievable”; refers to what must be done to keep exposure to potentially harmful radiation at a minimum.
 - Remember three key terms for keeping exposures low: time, distance, and shielding.

Time—limit your time in the area of exposure.

Distance—keep the greatest distance possible between you and the source of exposure; inverse square law:

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Shielding—use adequate, protective barriers between you and the origin of exposure.

NCRP Dose Limit Recommendations

Minimizing Patient Exposure

- The x-ray voltage is measured in kilovolt peak (kVp).
- The x-ray current is measured in milliamperes (mA).
- A 15% increase in kVp is equal to doubling the mAs.
- Providing shielding between the exposed person and radiation source greatly reduces the amount of radiation exposure. Lead is the most used material when shielding patients in diagnostic radiology.
- Gonadal shields should be used on all women of childbearing age.
- Collimation restricts the size of the useful x-ray beam to the part of the body being imaged and spares adjacent tissue from unnecessary exposure. This reduces the dose to the patient.

MRI Screening

- Before the MRI exam, the patient must be screened for implanted devices such as a hearing aid, pacemaker, defibrillators, or prosthetic devices.
- These devices can possibly prevent the patient from receiving the MRI exam.

- The patient should completely disrobe and remove all metal.
- A ferrous-free environment must be maintained for the safety of personnel and the patient.
- Oxygen tanks, wheelchairs, and IV poles should not enter the MRI room. These items can forcefully be pulled into the MRI bore due to the strength of the magnet.
- All immobilization and positioning equipment must be MRI compatible.

Radiation Protection and Safety Organizations

- The International Commission on Radiological Protection (ICRP) develops standards of protection for users of x-rays and other ionizing radiation. They are a group of experts interested in the safe use of all types of radiation; they publish recommendations for protection against exposure.
- The National Council on Radiation Protection and Measurements (NCRP) is a national group of experts who make recommendations for protection against exposure.
- The Nuclear Regulatory Commission (NRC) is the national group that collaborates with individual states to establish regulations that are incorporated into federal and state laws.
- The American Association of Physicists in Medicine (AAPM) issues reports on performance improvement and quality assurance.
- Other agencies involved in radiation safety include the Department of Transportation (DOT), the Food and Drug Administration (FDA), the Occupational Safety and Health Administration (OSHA), and the Environmental Protection Agency (EPA).
- Radiation dose limits were called skin erythema doses in the early days of radiation therapy.
- The term

tolerance dose was used to describe exposure limits in the 1930s.

- Currently, dose limits are simply referred to as recommended dose limits (DL).
- Dose limits are based on actual outcomes out of research that continues; this makes the recommendations fluid and apt to change over time.
- Dose limits for occupational workers are greater than those for the general public and are set at a risk level comparable to that for workers in other industries.
- Dose limits are established below the threshold value for deterministic effects and at a level to adequately limit the risk of stochastic effects.

Units Of Exposure and Methods of Detection

- Exposure is measured using units such as the Roentgen or coulomb/kilogram, the rad or Gray, and the rem or Sievert.
- The Roentgen, one of the earlier units and named after Wilhelm Roentgen, measures the amount of ionization produced by photons in the air per unit mass of air; the system international unit is the coulomb/kilogram.
- The traditional rad, system international unit Gray, measures absorbed dose in a medium, such as tissue.
- The rem, system international unit Sievert, measures equivalent dose and is appropriate for personnel exposure reporting. The conversion of this equivalent dose into absorbed dose requires the application of a quality factor assigned to the type of radiation and tissue weighting factor assigned to the specific organ exposed (

[Table 4.2](#)).

- To detect exposure, several different tools may be used.
- Some tools are appropriate for personnel monitoring, while others are appropriate for surveying an area to detect the presence of radiation or for verifying adsorbed dose in the patient.

TABLE 4.2

Radiation Exposure Unit Conversions			
Quantity	Traditional Unit	Conversion Factor to	System International Unit
Exposure	Roentgen	2.58×10^{-4}	Coulomb/kilogram
Absorbed dose	Rad	10^{-2}	Gray
Equivalent dose	Rem	10^{-2}	Sievert

Common personnel exposure monitors (

Table 4.3) include:

1. Film badge
2. Thermoluminescent dosimeters (TLD)
3. Optimal stimulated luminescence (OSL)
4. Pocket ionization chambers

- Personnel should be monitored if it is expected that the worker may receive

$\frac{1}{10}$ of the recommended dose limit.

- Film badge monitor reports should be generated periodically and may specify “deep” or “shallow” dose equivalents. The sum of these doses would be the total effective dose equivalent (TEDE).
- Deep dose is measured at 1 cm depth and refers to external dose.
- Shallow dose is assigned to any internal dose received by ingestion or inhalation during the handling of radioactive materials.
- Exposure levels shown on film badge reports are given using units of equivalent dose: rem or Sievert.
- To calculate the effective equivalent dose as indicated by the equivalent dose value, the type of radiation and tissue exposed must be considered.
- The effective equivalent dose is calculated by the formula:

$$E = W_t(W_r) \times \text{absorbed dose}$$

E = effective equivalent dose

W

_t = tissue weighting factor assigned to tissue type other than whole body

W

_r = radiation weighting factor or quality factor

- Since personnel monitors such as the film badge are intended to measure whole body exposure and the film badge is useful in detecting x-rays, gamma, or electrons, the quality factor is assumed to be 1; therefore 1 rem = 1 rad and 1 Sv = 1 Gy
- If the effective equivalent dose is to be known for a specific organ, tissue weighting factors are given by their relative sensitivity to radiation.
- Tissues with the greatest sensitivity will have weights under the whole body weight of 1.

Example of Tissue Weighting Factors (W

_t)

Gonads = 0.20

Bone marrow = 0.12

Bone surfaces = 0.01

- Special dose limits are expressed for the protection of the embryo/fetus of the radiation worker.

- Once pregnancy is known, the dose limit for the unborn takes precedence over the limit for the worker.
- Students under 18 years would be subject to recommended dose limits to the general public.
- Students over 18 years are subject to occupational limits.

TABLE 4.3

Personnel Exposure Monitors			
Film Badge	TLD Lithium Fluoride	Pocket Dosimeter	OSL Aluminum Oxide
+ Measures kV, MV photons, electrons, gamma; can detect approximate energy + Inexpensive + Provides permanent record of exposure – Excessive heat, humidity, or light exposure can damage – Has to be sent out for reading – Error margin $\pm 20\%$	+ Measures photons, electrons, other particles + Responds more like tissue; has similar atomic number so very accurate + Small enough to fit into ring badge + Humidity will not damage + Can be processed on site if equipment available – Cannot estimate the energy of radiation exposure	+ Reading is immediate + Initial cost is high but once obtained is inexpensive + Small enough to fit in pocket + Very accurate to within $\pm 2\%$ – Humidity and mechanical shock will give erroneous readings	+ Wide range, accurate, and very sensitive + Can be reanalyzed for confirmation of dose + More sensitive than TLD – More expensive – New technology not well understood

+, advantages; –, disadvantages.

Work Areas

- Work areas should be designated as restricted/controlled or unrestricted/uncontrolled.
- Restricted areas are those in which exposure levels of personnel are monitored; barriers and other engineering controls should reduce exposure to less than 100 mrem/wk or 0.1 rem/wk or 1 mSv/wk and 5 mSv/year.
- Unrestricted areas are ones that may be occupied by anyone; the maximum allowed exposure would be less than 1 mSv/yr or 2 mrem/wk or 0.002 rem/wk and 1 mSv/year.
- Federal and state agencies require that signs be posted where there is radioactive material or radiation-producing equipment.
-

Caution-Radioactive Material is the required sign when the quantity of the radionuclide exceeds the activity specified by local law; appropriate locations would be the radioisotope inventory room or on source packaging and transported radioactive sources should also show:

Radioactive I white label—less than 0.5 mR/hr

Radioactive II yellow label—less than 1.0 mR/hr

Radioactive III yellow label—50 to 200 mR/hr and less than 10 mR/hr at 3 feet

-

Caution-Radiation Area is the required sign necessary when an employee could receive more than 5 mrem/hr or 100 mrem in 5 days.

-

Caution-High Radiation Area or

Caution-Airborne Radioactivity is necessary when the dose rate is greater than 100 mrem/hr (not typical in the clinical setting).

- The radiation symbol required on radiation signs (

[Figure 4.1](#)) is a three-bladed symbol in magenta on a yellow background.

- Protective barriers are designed to ensure that dose does not exceed the recommended dose limit to workers or the general public.
- Primary radiation, coming directly from the source, requires a primary barrier.
- Scatter or leakage radiation, coming from source housing or after interacting with the patient requires secondary barriers.
- There are several factors to consider when designing protective barriers.

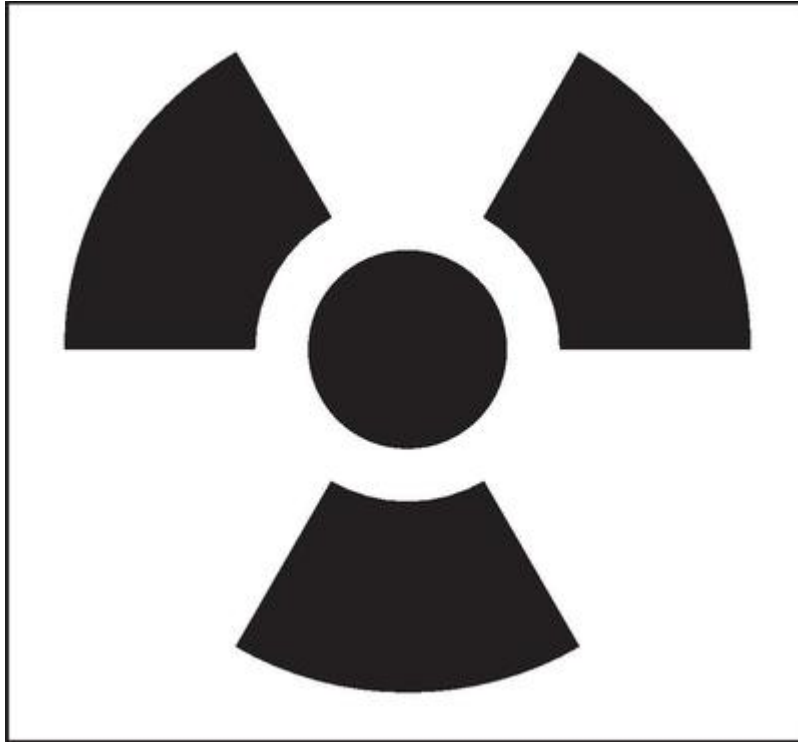


FIG. 4.1 Radiation symbol.

Factors to Consider for Protective Barriers

- a. Workload—W: how much the primary beam is in use; number of patients $\times$ number of fields $\times$ average dose/field $\times$ dose rate $\times$ number of treatment days/week.
 - b. Use factor—U: the fraction of the workload in which a barrier is directly irradiated
 - c. Occupancy factor—T: the fraction of time during which an area is occupied
 - d. Maximum energy of the beam in use
 - e. Distance from the source—d
-
- The barrier material selected and thickness required is influenced by the maximum energy.
 - Calculations for thickness of a barrier would include the linear attenuation coefficient and half-value layer (HVL).

$$I = I_0 e^{-M(X)}$$

I = intensity transmitted

I

I_0 = original intensity on the absorbing material

M = linear attenuation coefficient

X = thickness of material

$$HVL = \frac{0.693}{M}$$

- For minimum exposure, the barrier material and thickness could not allow transmission of more than the recommended dose limit.
- Common materials used for barriers are concrete, iron, and lead; concrete is used widely as compared with lead because of minimal expense.
- Considering all other factors, primary barrier transmission factors could be calculated by applying the following formulas:

$$\text{Primary barrier factor} = \frac{0.1 \text{ rem (d)}^2}{W(U)(T)}$$

$$\text{Secondary barrier factor} = \frac{0.002 \text{ rem (d)}^2}{W(U)(T)}$$

- Work areas need to be monitored for the presence of radiation when equipment is in use and especially in areas of radioactive sources.
- There are a variety of changes that can be caused by ionizing radiation interacting with the air or other materials; the changes are what give indications of the presence of radiation.
- Combinations of change in material are potentially useful as a radiation detector.

Radiation Detection Mechanisms

1. Ionization-release of ion pairs by radiation
 2. Biologic change in living systems
 3. Chemical release of free radicals in solution
 4. Heat/temperature rise from deposited energy
 5. Scintillation-light flash in a special absorber
 6. Thermoluminescence-light release on heating a phosphor
 7. Super-heated drop bubble formation in a gel matrix
- Ionization-based detectors are capable of high sensitivity as single ionizing events can be distinguished.
 - The ion chamber designed to measure the output of a therapy machine is not necessarily suitable for measuring low levels of radioactive contamination.
 - Special surveyors are needed to measure low levels of radiation in leak testing.
 - Biologic and chemical-based detectors (

[Table 4.4](#)) are relatively low in sensitivity; they require a lag time for results.

- It is appropriate to survey an area for radiation after brachytherapy procedures, after sources have been removed from a patient, when there are sources in storage, and after the installation of new equipment.
- Surveying equipment must be calibrated annually and following any repairs.
- Inside of the treatment room neutrons can be detected by using activation detectors.
- Outside of the treatment room neutrons and x-rays can be detected by using an ion chamber with hydrogenous walls.
- Silicon diodes are used for relative dosimetry.
- They are small in size, high sensitivity, instantaneous response and offer advantages over ionization chambers.
- Silicon diodes works well with relative measurements in output constancy checks, electron beams, and in vivo patient dose monitoring.

TABLE 4.4

Radiation Detectors and Applications					
Ion Chamber Cutie Pie	Geiger Counter	Proportional Counters Scintillation Counters Neutron Counters (Rascal)	Silicone Diodes	Chemical-based Fricke Dosimeter	TLD
+ Measures dose rate in mR/hour + Cutie Pie good for measuring leakage from cobalt + Can detect x-rays, electrons on pulsed machines such as the linear accelerator (linac), and gamma + Special ion chambers filled with hydrogenous walls can detect photons and neutrons – Temperature and pressure corrections needed for free air chambers	+ More sensitive than ion chamber + Detects photons and particles + Has audible signal – Exposure rate with thin-window GM counters, otherwise can only detect presence and does not quantify – Not useful on pulsed linacs, has slow recovery time	+ Detects all particles, gamma and x-rays + Measures dose rate in mR/hr or mrem/hr + Good for measuring neutron contamination in and around accelerators + Good for measuring low levels of radiation	+ More sensitive than ion chambers + Measures absorbed dose + Get immediate results + Good for monitoring output constancy or dose monitoring in patients		+ Measures absorbed dose – Need special, expensive equipment for reading

+, advantages; –, disadvantages.

Radioactive Sources

- Sources must be stored in heavily shielded areas in an area secure from theft or loss.
- Proper ventilation is required, especially for encapsulated powdered sources.
- Inventory room should have a sink for cleaning applicators with a filter or trap to prevent loss.
- There should be a barrier behind which sources may be prepared; “L” block.
- Long forceps should be available in the room for handling of sources.
- Sources should be transported around the facility in lead containers or carts called “pigs.”
- Trucks that transport must follow shielding regulations as dictated by the NCRP and DOT.
- Received packages should be visually inspected for damage or leaks.
- The appropriate radioactive content label should be present.
- Any packages containing more than 1 mCi and physical half-life greater than 30 days need to be wipe tested within 3 hours of receipt/18 hours outside of work hours.
- When disposing of radioactive waste NRC recommendations should be followed.

For Disposal of Radioactive Waste

1. Sewer system may include flushing; draining into a hold up tank for decay then flushing; emptying into an effluent pond or retention basin and holding for decay; placing in shielding container for delivery to a special chemical processing plant
2. Incineration requires a special license unless source is approaching background levels
3. Transfer to authorized recipient

4. Burial requires special license

- All waste receptacles should be close to the area they service, shielded, and out of the flow of traffic.
- A hot sink should be present and used only for discharge of radioactive wastes.
- Records of disposals should be maintained and readily available.
- Inventory of all sources must be performed for all sources quarterly, even if no sources have been used in that time frame; inventory records must be maintained for 3 years.
- Inpatient rooms used for brachytherapy need to be private with dedicated restroom.
- Bed placement has to be such that neighboring patients would receive limited exposure.
- Nurses and other caregivers should wear monitoring devices and be instructed on how to care for the patient in a timely manner; bedside shields should be available.
- Other ancillary personnel needing to enter the patient room should be educated on exposure potential.
- Appropriate sign must be displayed on patient's room door.
- Visitors should be limited to adults; visits should be short; rule of thumb is 20 minutes or less.
- In case of an emergency, such as a radioactive spill or source loss:

evacuate, contain/isolate area,

notify, and then appropriate personnel will

decontaminate

- High dose rate (HDR) procedures should be performed in appropriately shielded rooms.
- Room surveys should be conducted following low dose rate (LDR) and HDR procedures to verify all sources have been returned to designated locations.

- Geiger-Müller counters may be used for room survey; keep in mind, Geiger counters can only detect the presence of radiation in the area but cannot quantify the amount of dose in the area.
- After-loading procedures should be thoroughly preplanned to limit exposure of personnel and patients.

Review exercises

1. According to the current recommendations, which of the following will have the highest annual dose limit?
 - a. The lens of the eye
 - b. The hands of a member of the general public
 - c. The embryo/fetus
 - d. The hands of a pregnant therapist
2. According to the current recommendations, the guidance levels for cumulative exposures for a 30-year-old occupational worker with 3 years of experience is:
 - a. 600 mSv
 - b. 300 mSv
 - c. 330 mSv
 - d. 50 mSv
3. All of the following are advantages of the film badge personnel monitor except:
 - a. Provides permanent record
 - b. Exposure to interpretation delay
 - c. Measure dose over large body area
 - d. Radiation type can be determined

4. It is recommended that radiation exposure to the fetus should not exceed _____ for the entire gestation period.
- a. 0.1 rem
 - b. 0.5 rem
 - c. 1.5 rem
 - d. 3.0 rem
5. Which of the following devices is not normally used to monitor occupational dose exposure?
- a. Film badge
 - b. TLD
 - c. Cutie pie
 - d. Pocket dosimeter
6. The roentgen is a unit of measurement that specifies the _____ of air by x-rays or gamma radiation.
- a. excitation
 - b. ionization
 - c. absorption
 - d. attenuation
7. When film badges are used for radiation monitoring, which of the following factors may affect the accurate reading of the badge?
- 1. Exposure to excessive heat
 - 2. Submersion of the badge in fluids
 - 3. Damage to the film wrapper
- a. 1, 2
 - b. 1, 3
 - c. 2, 3
 - d. 1, 2, 3

8. The term quality factor (Q):
- a. Varies with different types of radiation
 - b. Varies with different types of tissue
 - c. Varies as a function of age and gender
 - d. Is measured in rem
9. Any container in which radionuclides are transported, stored, or used must have a label saying:
- a. Caution - Breakable Container
 - b. Caution - High Radiation Area
 - c. Caution - Radioactive Material
 - d. Grave Danger - High Radiation Area
10. The organization in the United States that is principally responsible for recommending radiation dose limits is the _____.
11. The annual dose limit for the occupational worker's lens is _____.
12. The annual dose limit for the occupational worker's skin is _____.
13. The fraction of time that a radiation beam is directed at a specific barrier is termed the _____.
14. The annual radiation dose to the lung from radon gas is estimated to be _____.

Think About It

- 15a. If a survey meter shows an exposure rate of 300 mR/hour at 3 feet from the sources during the loading of a Fletcher intracavitary applicator, and the duration of the procedure is expected to be 6 minutes, what would be the exposure to the person standing 3 feet away from the sources?
- 15b. What would the exposure be to the same person if they stood just 2 feet away from the sources?

16. The dose rate is 0.5 rem/min at 40 feet away from a source. An office will be constructed 20 feet away from the source. An individual will occupy this office 8 hr/day, 5 days/wk, and is allowed to receive 10 mrem/wk or less. How many tenth value layers of material are needed?
- 17a. A linear accelerator accommodates 35 patients/day, 5 days/wk. The average number of fields per patient is 4 and the average dose per field is 45 cGy. Calculate the workload.
- 17b. Calculate the primary barrier transmission factor at the console located at 1 m from the source for the restricted linear accelerator area in the previous question.
18. If the HVL for cobalt-60 is 1.1 cm of lead, what percent of transmission is expected using 4.4 cm of lead as a barrier?
19. Compare how dose is measured using the film badge and TLD.
20. Compare how exposure is measured using an ion chamber and Fricke dosimeter.
21. Dose equivalent is measured in units of:
- a. roentgen
 - b. rad
 - c. sievert
 - d. curie

The Following Are True/False Corrective Statements. Put T on the Line if the Statement Is True. If the Statement Is False, Place an F on the Line, Then Make the Statement Correct Without Changing the Intent of the Statement

22. ____ Maximum exposure rate at a specific distance from a patient following insertion of radioactive sources can be measured with TLDs.
23. ____ Two half-value layers of a material for a given radiation would decrease radiation intensity to 25%.
24. ____ The requirement for barrier protection in walls/ceiling from primary radiation is reduced when there is a beam stopper on the treatment unit.
25. The agency that regulates the use of radiation-producing machines is the:
- a. AAPM
 - b. NRC
 - c. DOT
 - d. FDA
26. An example of a deterministic effect is:
- a. Carcinogenesis
 - b. Genetic effects
 - c. Birth defects
 - d. Cataracts
27. The radiation detection device helpful in finding a lost radioactive source would be a/n:
- a. Ion chamber
 - b. Geiger-Müller counter
 - c. TLD
 - d. Neutron counter
28. The largest dose from natural background radiation comes from:
- a. Terrestrial
 - b. Radon
 - c. Cosmic
 - d. Internal
29. The amount of energy absorbed in a medium is expressed in units of:

- a. Roentgen
- b. Coulomb/kilogram
- c. Sievert
- d. Gray

Write the Letter C for Cosmic, T for Terrestrial, or I for Internal Next to the Statement That Refers to the Appropriate Component of Natural Background Radiation

- 30. _____ Product of interactions with the stars
- 31. _____ Defined as “of the earth”
- 32. _____ Increases with altitude
- 33. _____ One major contributor is potassium-40
- 34. _____ No shielding between the source and the person exposed
- 35. _____ Varies according to composition of the soil
- 36. The two main types of background radiation are:
 - a. Natural and man-made
 - b. Cosmic and terrestrial
 - c. Confluent and regressive
 - d. Internal and external
- 37. Exposure from terrestrial radiation varies according to:
 - a. The thickness of the atmosphere
 - b. The magnetic field distribution of the earth
 - c. The number of diagnostic x-rays received
 - d. The composition of soil or rock in nearby areas
- 38. What quantity is measured directly by the TLD?
 - a. Exposure
 - b. Absorbed dose
 - c. Activity
 - d. Lag time

39. Appropriate disposal of radioactive sources include:
- a. Transfer to an authorized recipient
 - b. Incineration
 - c. Burial
 - d. All of the above
40. The radioactive source inventory room should have a sign that reads:
- a. Caution - Radioactive Material
 - b. Caution - Radiation Area
 - c. Caution - High Radiation Area
 - d. Grave Danger-High Radiation Area
41. The workload describes:
- a. How much the primary beam is in use
 - b. The fraction of the workload in which a barrier is irradiated
 - c. The fraction of time during which an area is occupied
 - d. Energy of the beam in use
42. In the construction of a new radiation therapy center, the choices for primary barriers include concrete, lead, or iron. Measure for measure, I would need more_____ for adequate absorption.
- a. Concrete
 - b. Lead
 - c. Iron
43. High dose rate (HDR) brachytherapy procedures should be performed in:
- a. A private surgical suite
 - b. In a private hospital room
 - c. In a patient examination room
 - d. In a shielded vault
44. Internal radiation exposure comes from radioactive materials always present in our bodies such as:

- a. Xenon-131
 - b. Technetium-99
 - c. Hydrogen-3
 - d. Boron-12
45. Radioactive sources should be transported around the treatment facility in:
- a. Sterile bags
 - b. Biohazard bags
 - c. Shielded containers
 - d. Sterile boxes
46. Nursing and other patient care staff caring for an admitted patient undergoing low-dose radiation (LDR) brachytherapy should:
- a. Wear gown and gloves to prevent radioactive spills
 - b. Wear a face mask to prevent inhalation of radioactive material
 - c. Wear goggles to prevent splashes of radioactive fluids to the eyes
 - d. Use standard precautions and perform duties as quickly as possible
47. A monthly radiation exposure report says an employee received 0.5 Sv. If the source of exposure were determined to be gamma radiation, the translation to absorbed dose would be:
- a. $0.5 \text{ Sv} = 0.5 \text{ Gy}$
 - b. $0.5 \text{ Sv} = 0.5 \text{ cGy}$
 - c. $0.5 \text{ Sv} = 10 \text{ Gy}$
 - d. $0.5 \text{ Sv} = 100 \text{ Gy}$
48. The half-value layer for a 6 MV beam is 32 mm of lead. The linear attenuation coefficient would be:
- a. 46 mm
 - b. 0.002 mm

-1

c. 22 mm

-1

d. 0.0216 mm

-1

49. How many half-value layers reduce transmission to 2%?

a. 2 HVLs

b. 5 HVLs

c. 6.5 HVLs

d. 5.6 HVLs

Think About It

50a. The half-value layer for cobalt is 11 mm of lead. What is its linear attenuation coefficient?

50b. How much lead would reduce this cobalt beam to 3% transmission?

51a. The linear attenuation coefficient for a certain megavoltage beam using concrete as an absorber is 0.089 cm

⁻¹. What is the half-value layer?

51b. How much concrete is required to reduce transmission to 2% of the primary beam?

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CHAPTER 5

Radiation Therapy Equipment and Quality Assurance

Leia Levy

Focus questions

- How has radiation therapy treatment equipment evolved over time?
- What are the major components of the linear accelerator?
- Describe systems for treatment portal verification
- What benefits were there to introduce the computed tomography (CT) simulator to radiation therapy planning procedures?
- What benefits were there to introducing record and verify systems to radiation therapy treatment accelerators?
- Compare and contrast the conventional fan-beam CT and cone-beam CT.
- What are some of the applicator devices used in brachytherapy procedures?
- Compare and contrast the linear accelerator, cyclotron, microtron, and betatron.
- Compare and contrast the characteristics of the x-ray beam to the heavy particle beam.
- List and compare some treatment portal verification systems.

- What quality assurance procedures are appropriate for treatment equipment?

Therapy Equipment Evolution

- Therapy machines operated in very low energy range in the early years of radiation therapy; x-ray tubes ranging from 5 to 800 kV were used.
- Grenz ray x-ray tubes operated in the range of 5 to 15 kV.
- Low-energy Crookes tubes operated in the range of 50 to 100 kV and were also referred to as superficial therapy machines; treatment distance was at 15- to 20-cm source to skin distance (SSD).
- Medium energy tubes, developed by William Coolidge, also known as “hot cathode” tubes, could generate higher energies in the range of 100 to 200 kV. They were also known as orthovoltage/deep therapy machines; treatment distance was at 50-cm SSD.
- Superficial and orthovoltage machines simply required an x-ray tube and mobile collimator system. Filters such as aluminum, tin, or copper would be required to be placed between the source and the patient to harden the beam.
- Coolidge paved the way for supervoltage units, also known as cascading tubes, in the 1930s. They operated in the range of 500 kV or greater; treatment distance was at 80- to 100-cm SSD.
- The first supervoltage machine operating as high as 1 MV was used in London. GE made a supervoltage unit that was installed at Mercy Hospital in Chicago in 1933.
- Other particle accelerators such as the betatron and cyclotron were used clinically in the 1930s.
- Megavoltage units (1 MV and greater), including the cobalt machine, and linear accelerator came on the scene in the United States in the 1940s.
- In the mid-1940s, William Hansen invented the linear accelerator. His research was based on work by Russ and Sigurd Varian,

brothers who founded Varian Associates; 1954 marked the first medical use of the linear accelerator.

- In the meantime, radium (which had been discovered in 1898 by Marie and Pierre Curie) was being used to treat deep tumors.
- In 1949, L.G. Grummet, MD, designed a container for the use of cobalt-60 as a substitute for radium.

The Linear Accelerator (LINAC)

- The accelerator structure resembles a long pipe. The pipe is the path where charged particles (electrons) travel and gain energy from an alternating electromagnetic field.
- The typical accelerator consists of five main components: drive stand, gantry, patient support assembly (PSA), electronic cabinet, and console.
- The drive stand connects to the gantry; the gantry rotates on a horizontal axis on bearings within the drive stand, which is firmly secured to the floor; the stand contains the apparatus that drives the accelerator.
- The gantry is responsible for directing the beam out toward the patient. The major components in the gantry are the waveguides, electron gun, accelerator structure, and collimator head.
- The treatment gantry head (

Figure 5.1) contains many intricate parts, including the bending magnet, target, primary collimators, monitor ion chamber, mirror and bulb assembly, secondary collimators, scattering foils, and flattening filter.

- The source of electrons is the electron gun; electrons start from rest in the gun and gain enough energy to approach the velocity of light after being assisted to intense acceleration by microwaves.
- Electrons enter the accelerator structure with relatively low velocity and experience progressive acceleration due to the introduced microwaves.

- The final electron energy is directly proportional to the length of the waveguide. Due to the limitations in the physical size of clinical linear accelerators (linacs), another technology has been developed that permits a shorter accelerating tube known as a standing wave accelerator guide.
- The design of the standing wave guide makes use of the concept of interference/Coolidge's cascading theory: when two electromagnetic waves are present at the same place, their energy potential increases across the tube.
- The microwave power necessary to provide energy in the waveguide is provided by a magnetron or klystron.
- The magnetron is usually used in low energy linacs and generates high-frequency microwave power.
- The klystron is required for higher energy units and is a generator of high-frequency microwaves and also amplifies the microwaves.
- High-energy machines have long accelerator tubes and need to be positioned horizontally. A bending magnet is therefore needed to direct the horizontal stream of electrons down and out toward the target and collimator opening.
- Two types of bending magnets are used: 90- or 270-degree bending magnets.
- The 90- and 270-degree bending magnets both serve the same purpose; however, the 270-degree magnet minimizes spatial dispersion of the beam.
- The electron beam is narrow in cross-section—3-mm diameter. Its intensity is high in the center and drops quickly to nil as you move away from the center.
- The raw electron beam is referred to as a pencil beam.
- A scattering foil is used to spread the electron beam and achieve uniform electron fluence across the collimated area. This foil consists of thin metallic material, usually lead.
- The electron field size is typically defined by attachable cones; cones help control the free scattering of electrons in the air.
- For the production of x-rays/photons in the linac, the high-energy electron beam is manipulated in a manner similar to electrons in

diagnostic x-ray machines: the electrons are accelerated toward and collide with a heavy metal target, causing deceleration and conversion of energy to produce x-rays.

- The resulting photon beam has intense energy in the center and falls off as you move away from the central axis.
 - The flattening filter is introduced into the path of photons to evenly distribute the energy of the photon beam; it is usually made of lead, tungsten, uranium, steel, aluminum, or a combination of heavy metals.
 - The exiting beam is first collimated by a fixed primary collimator and then is incident on a monitoring ion chamber.
 - Monitoring ion chambers keep track of dose rate and field symmetry.
 - After passing through the ion chamber, the beam is further collimated by a mobile pair of collimators and/or multileaf collimators. The collimator area opening is typically limited to 40 cm × 40 cm.
-
- Field size setting is the actual measured field size at the isocenter of the linac and not at the location of the mobile collimators.
 - The PSA is the apparatus that holds the patient and should have functions to move horizontally, vertically, and laterally and rotate on a stable axis around the isocenter.
 - The operator's console is on the outside of the treatment vault and is where the patient may be monitored and the accelerator can be programmed to deliver a prescribed dose. Record and verify systems retain, recall, and display patient treatment data and record doses delivered.
 - The electronic cabinet may be in the treatment vault or outside on an opposite wall and contains the auxiliary power distribution system and primary power distribution system, cooling system, and circuit breakers.

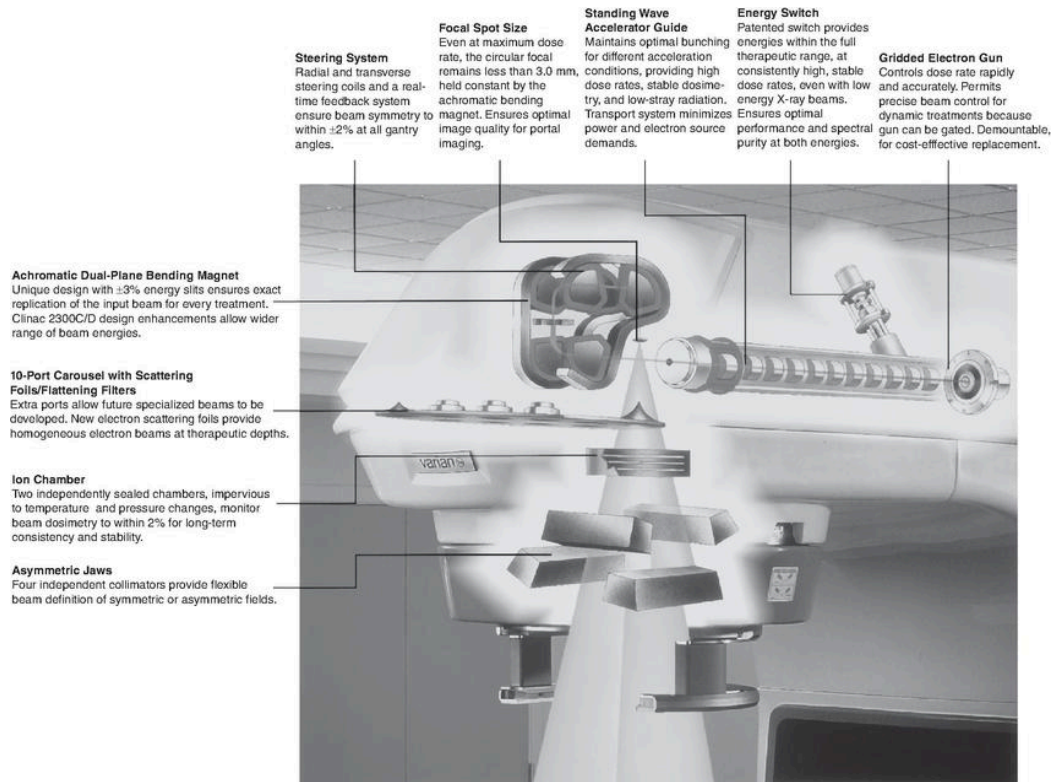


FIG. 5.1 Linac gantry head cross-section.

Quality Assurance for Linear Accelerators

- As the mechanics of the linear accelerator are very intricate and critical to the production of a quality beam and reliable output for dosing, regular quality assurance procedures are necessary.
- Values taken regarding output and performance are initially taken during acceptance testing.
- Acceptance testing requires comparison of output and performance values as measured against what the manufacturer has promised.
- After acceptance testing, commissioning takes place so that output and performance values are documented and used for treatment planning and dose delivery and for consistency in machine performance.
- Quality assurance procedures must include review of machine mechanics and reliability of indicators for beam direction and

quality. What is most important is target accuracy and dose concentration with minimal effects on normal tissues.

- In addition, any built-in interlocks in the record and verify (R and V) system instituted to keep patients, personnel, and the general public from unnecessary radiation exposure must be reliable on a daily basis.
- Quality assurance procedures are grouped by priority: those of critical importance for accurate treatment delivery and patient/personnel safety should be verified daily. Other factors are recommended for review weekly, monthly, and/or yearly.
- Review the recommended quality assurance procedures published by the AAPM (

Tables 5.1 ,

5.2 , and

5.3) .

TABLE 5.1

* Refer to AAPM task group 142 report for monthly and annual QA. September 2009.

TABLE 5.2

Adapted from

Washington and Leaver's Principles and Practice of Radiation Therapy . 5th ed. Elsevier; 2021; refer to the American Association of Physicists in Medicine Task Group 142 (TG 142).

TABLE 5.3

Adapted from

Washington and Leaver's Principles and Practice of Radiation Therapy. 5th ed. Elsevier; 2021; refer to the American Association of Physicists in Medicine Task Group 142 (TG 142) report for further information.

Other Particle Accelerators

The Betatron

- The betatron accelerates electrons and consists of a magnet fed by an alternating current of high-frequency waves.
- Electrons are injected into an evacuated circular chamber and accelerated in a circular orbit in the presence of an electric field. Magnetic flux changes and keeps the electrons in the orbiting pattern, and the electron beam may be deflected out toward the collimator opening.
- A target may be introduced after the deflector to produce an x-ray beam.
- The betatron (

[Figure 5.2](#)) was used in megavoltage radiation therapy in the 1950s, but it has very limited field sizes and low dose rates compared with the linac, making it unpopular for use in therapy today.

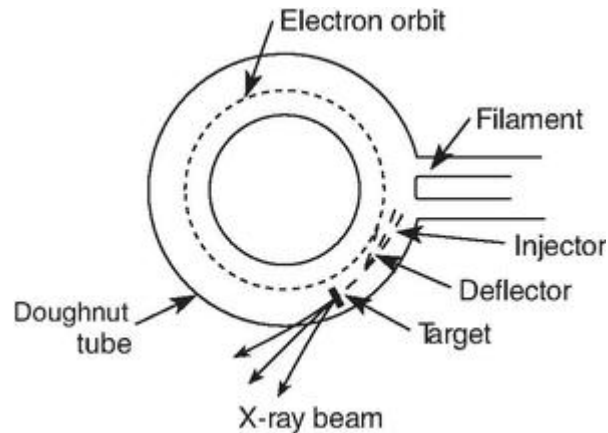


FIG. 5.2 Betatron.

The Cyclotron

- The cyclotron has been and is still used in nuclear power plants to produce radioisotopes. Fluorine-18 used in Positron Emission Tomography (PET) imaging is produced in proton cyclotrons.
- The cyclotron can produce deuteron, neutron, and proton beams and has been modified for more widespread use in therapy.
- Particles are accelerated in a spiral pathway inside two evacuated D-shaped cavities, called dees (

Figure 5.3

), by a uniform magnetic field. The dees have a small space between them and have opposite polarity.

- An oscillating radiofrequency voltage with a constant frequency is introduced between the two dees and the charged particles accelerate while crossing the space between the two; more energy is gained as the particles continue to cross the space and the spiral diameter increases.
- Heavy particles can gain enough mass in the cyclotron that they go out of synch with the oscillating field; a special machine reduces

the frequency of the voltage as the particle energy increases to keep this from happening. This is known as a synchrocyclotron.

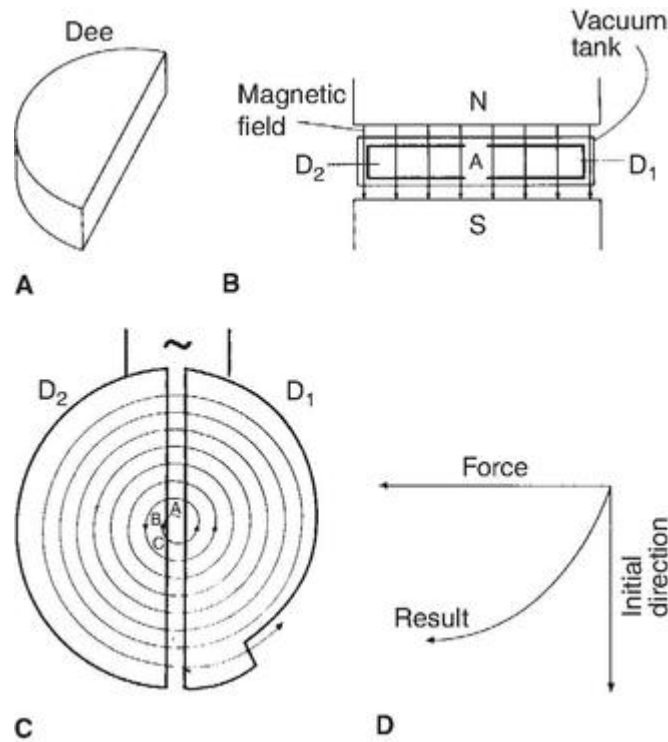


FIG. 5.3

Cyclotron.

The Microtron

- The microtron is an electron accelerator. The first microtron, used in 1972, generated a 10-MeV electron beam.
- A higher-power microtron was later introduced and could produce a 22 MeV electron beam. It also had the ability to generate high-power photons and multiple electron energies.

- In the circular microtron, electrons are accelerated by an oscillating electrical field of one or more microwave cavities. A magnetic field forces the electrons to move in a circular path and return to the “resonant cavity.”
- As the electrons return, they receive higher energy and the orbits of increasing radius occur in the magnetic field similar to the betatron.
- A deflection tube of steel extracts the beam from the accelerating path. An electron or photon beam can be produced.
- The advantages of the microtron over the linac is that it has a simpler design and is physically smaller than the typical linac.

Tomotherapy

- The tomotherapy machine, designed in the 1990s, has a ring gantry design such as the CT scanner and delivers radiation doses of 6 MV energy in a helical fashion.
- There is a binary multileaf collimator for beam shaping and intensity modulation.
- As the gantry rotates simultaneously with the advancing couch, helical fan-beam intensity modulated radiation therapy (IMRT) is delivered from all angles around the patient.
- The width of the fan beam is 40 cm and the maximum length the moving couch can accommodate is 160 cm.
- Delivery of a modulated dose, 360 degrees around the patient, allows for more conformal delivery to small target volumes than what is accomplished with multiple angles and segments as in traditional IMRT regimens on a linear accelerator.
- During the treatment regimen, diagnostic quality sectional and/or three-dimensional images may be acquired using the tomotherapy unit (

Figure 5.4

) to verify accurate focus on the target volume.

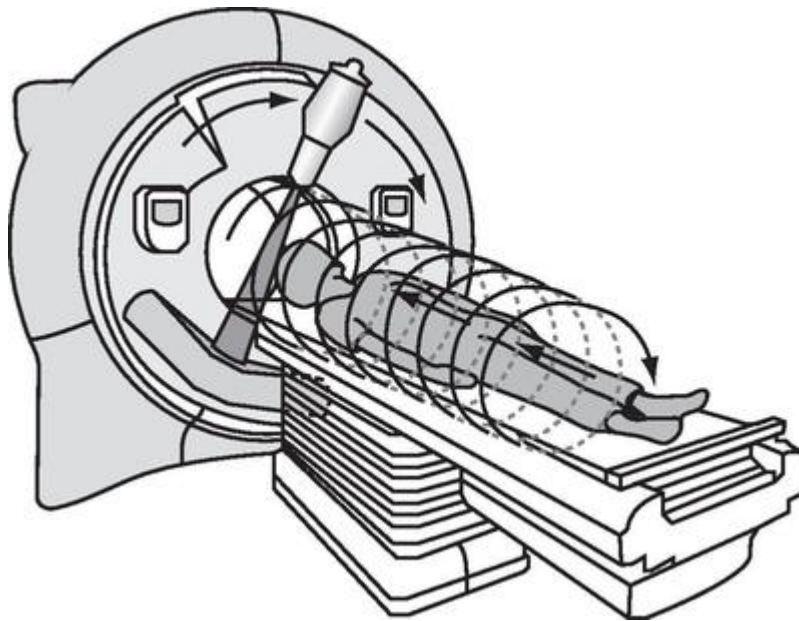


FIG. 5.4 Tomotherapy unit with patient on PSA.

Brachytherapy Equipment

- Radioactive sources used in brachytherapy are available sealed or unsealed.
- Sealed sources come in pellets, seeds, capsules, needles, buttons, or metal rods; pellets can be contained in small catheters with spacer material.
- Unsealed sources can be suspended in liquid for injection or ingestion; radioactive isotopes (

[Table 5.4](#)) may also be electronically infused into dense materials known as plaques for surface applications.

- Traditional manual loading of sources requires the use of special applicators/holders such as the tandem, ovoids, trocars, and in-dwelling catheters.

- Manually placed applicators historically would assure relatively stable placement of sources, after which placement could be verified with imaging.
- Manually placed applicators and containers also facilitate ease of source removal in temporary brachytherapy procedures.
- Today, there are remote, afterloading applicators, such as accelerated breast irradiation devices (MammoSite and electronic HDR units).

TABLE 5.4

Modified from Clifford Chao KS, Perez CA, Brady LW.

Radiation Oncology: Management Decisions . 3rd ed. Lippincott, Williams, and Wilkins; 2011.

Quality Assurance for Brachytherapy

- When radioactive sources are used, dose rates are critical for reference at any point in time.
- Dose rates of radioactive isotopes are given by the use of radiation detectors.
- Radiation detectors need regular calibrating so that readings are reliable.
- Detectors should be calibrated monthly or after each repair.
- Sources themselves should be inspected for physical integrity by visual inspection, leak testing, and activity measurement.
- Physical integrity should be checked before each use.
- Source strength or activity should be checked upon receipt and then verified at an agreed upon interval depending on the half-life; activity should be checked against the stated manufacturer's value.
- Source strength calibrations have to be traceable to a national standards laboratory.

- Source uniformity and symmetry can be checked using radiographic procedures.
- All sources maintained in inventory are required to be wipe tested for leakage radiation semiannually at a minimum.
- Wipe testing should be performed upon receipt and then at 6-month intervals for sources with long half-lives.
- Afterloading devices can be checked using radiographic imaging for source position.
- Remote afterloaders should be checked for functional performance and source activity (

Table 5.5).

- Following implantation, radiation surveys must be performed immediately in and around the patients room.
- If the patient is to remain in the hospital, adjoining rooms must be lower than 0.2 mSv per hour.
- If the patient is to be released with permanent implants, radiation levels need to be less than 0.5 mSv/hr at 1 m.
- If the patient is released following temporary implants, surveys must be performed of the room to assure that all active sources have been removed and returned to a safe location.
- Main objectives for the quality assurance program regarding brachytherapy should include appropriate documentation of written prescription, date, identification of the patient, treatment area and related calculations, and any deviations from standard practices or complications.

TABLE 5.5**Quality Assurance of Remote Afterloading Brachytherapy Units**

Test ^a	Tolerance
Room safety; door interlocks, lights, and alarms	Functional
Console functions; switches, batteries, printer	Functional
Visual inspection of source guides	Free of kinks and firmly attached
Verify accuracy of ribbon preparation	Autoradiograph

Adapted from

Washington and Leaver's Principles and Practice of Radiation Therapy. 5th ed.; Kutcher GJ, Coia L, Gillin M, et al.

Comprehensive QA for Radiation Oncology: Report of AAPM Radiation Therapy Task Group 40. 1994.

www.aapm.org/pubs/reports/RPT_46.PDF . Accessed January 28, 2025.

^a Each test is performed before each treatment day.

CT Simulators

- CT simulators were invented to enhance target localization; conventional simulators only provided anatomic target data in two dimensions showing bone and air or contrast-filled cavities, whereas the CT simulator brought the capacity to view anatomic data in three dimensions with all tissue densities easily visualized.
- CT simulators are modeled after the diagnostic CT scanner for the production of cross-sectional images; the cross-sectional image allows the planning therapist, dosimetrist, and physician to visualize the target volume and all other tissues around it.
- The CT simulator must have a large bore to allow for a variety of patient positions and positioning devices; room lasers and flat table top are also required.
- Acquisition of anatomic data can occur using axial or helical scanning.
- Helical scanning is thought to provide more data for the computer to use for image reconstruction; however, data for reconstruction can be controlled by setting appropriate slice thicknesses and scan intervals in either mode.
- Images from the CT simulator should be easily transferable to the treatment planning system.

Quality Assurance for CT Simulators

- CT simulators give detailed information on tissue density and geometry; therefore, the quality assurance procedures for the CT simulator focus on the interpretation and transfer of data and geometry.
- Patient and personnel safety cannot be ignored in quality assurance for CT simulators.
- As you review quality assurance for the CT simulator, note that safety switches, alignment of a gantry laser with the center of the image, and image performance (to include CT number accuracy for water, image noise, and in plane spatial integrity per

x and

y directions) are daily recommended checks (

Table 5.6).

- Orientation of gantry lasers, spacing of lateral wall lasers with respect to lateral gantry lasers, orientation of wall and ceiling lasers with respect to the imaging plane, mechanical table functions, image reconstruction, and exposure quality are recommended to be checked monthly.

TABLE 5.6

Adapted from Washington CM, Leaver DT, Trad M, eds.

Washington and Leaver's Principles and Practice of Radiation Therapy . Fifth edition. Elsevier; 2021. Mutic S, Palta JR, Butker EK, et al. Quality assurance for computed-tomography simulators and the computed-tomography simulation process: report of the AAPM Radiation Therapy Committee Task Group No. 66.

Med Phys . 2003;30(10):2762–2792.

Digital Imagers for Field Verification

- In the early days of therapy, treatment field verification was achieved during therapy by placing film in special cassettes opposite the beam as it exited the patient (film-screen method).
- Special emulsion film in heavily screened cassettes or in oncology cassettes could be exposed with just a few monitor units to a couple hundred monitor units.
- Dark room or daylight processing of film was required before portal verification would be possible.
- Images using the film-screen method on megavoltage therapy machines had low contrast due to the high beam energy and low

absorption in the patient.

- Today systems such as cone-beam CT (CBCT) have improved treatment portal verification greatly.
- CBCT provides three-dimensional imaging for field verification; its cone-shaped kilovoltage beam captures a broader volume of data at each revolution around the patient (

Figure 5.5) .

- The cone-shaped beam makes it easier for the associated image translator to reconstruct anatomic data, producing a clearer and more accurate image.
- CBCT can be integrated into a linear accelerator system and mounted on the gantry so that three-dimensional or two-dimensional sectional target localization verification may be performed before treatment delivery.
- Onboard imaging (OBI) systems (

Table 5.7) such as CBCT help therapists make adjustments to treatment fields more readily as

reproducibility of setup fluctuates or patient external and internal anatomy changes throughout the treatment course.

- Another OBI device comes in the form of a kV x-ray tube, also available to be integrated into the linear accelerator; it is mounted on the gantry.
- The kV x-ray tube allows for the capturing of two-dimensional diagnostic quality images to verify field placement before treatment.
- Another OBI device consists of a simple image detection unit, digital image processor, and color monitor.
- The detection unit and image processor are mounted to the linac gantry; images are captured, filed, and stored on disk for archiving and retrieval.

- The digital processor substitutes the poor contrast MV images with a high x-ray energy digital fluoroscopy imaging system, resulting in instant images of better quality.
- Small exposures of three monitor units or less are all required; an image is produced in 1 second, limiting motion while filming.
- The image is formed on the fluoroscopic screen and transferred to the camera via a high reflectance mirror positioned at 45 degrees under the fluoroscopic screen.
- The camera must be calibrated every few days and the detector should be calibrated monthly or whenever the detector may have been bumped or moved.
- The detector has a fluoroscopic screen and a high-resolution video camera located near the gantry.
- Respiratory gating systems may also be used as a means toward portal verification but most appropriately as a means toward using the location of the target to focus the radiation from day to day.
- Image-guided radiation therapy (IGRT) is a concept introduced after it became apparent that some targets are mobile.
- To maintain small margins around target margins that are mobile, a method for daily localization is necessary.
- Respiratory gating was developed in Japan for use in heavy ion therapy; now it can be used with the linac and can be applied during treatment of any area where breathing may affect the location of the target.
- A reflective marker is placed on the patient, a video camera follows the marker and will track its position as the patient breathes.
- Marker movement sends a signal that is processed by a computer that initiates a beam hold when the target is out of preset parameters; parameters have to be set during simulation with markers in place.
- Another system uses breath hold for administration of dose; breathing patterns are monitored and measured by a mouthpiece and shown on a monitor.
- When optimal breath hold volume is achieved, a balloon blocks airflow to the patient for a brief period of time and dose can be delivered only during the breath hold periods.

- A mobile ultrasound unit was introduced to use sound wave imaging as a means toward IGRT.
- An ultrasound unit—B-mode acquisition and targeting (BAT) — positioned near the linac treatment table can be used to visualize the location of targets before treatment.
- The location of the target during each imaging session is compared with the location of the target during simulation and table and patient may be adjusted to bring the visualized target in line with the predetermined isocenter.
- Widest application for BAT has been for the localization of the prostate gland as it has been noted that the gland may move from day to day; ultrasound is performed transabdominally.
- Similar to BAT is the BrainLab system; it uses a reflective marker array attached to an ultrasound probe.
- The array is calibrated by an infrared tracking system relative to reflective markers on the patient's body.

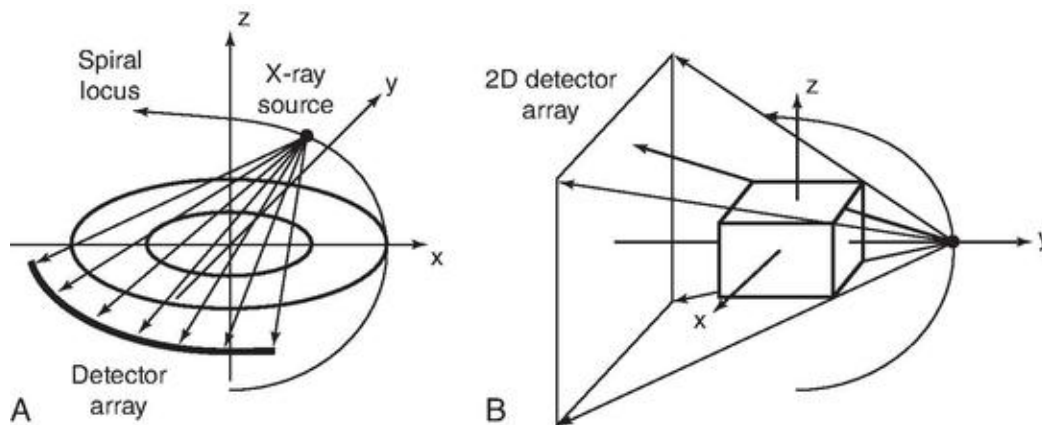


FIG. 5.5 Fan beam versus cone beam CT geometry.

TABLE 5.7

Quality Assurance for Portal Verification Devices

- Portal verification systems must be calibrated regularly to assure that quality images are produced, limiting the need for repeat imaging.
- OBI systems need regular calibration so that digital image processing is at an optimum.
- Systems such as the Theraview system sends a weekly message indicating that the fluoroscopic screen needs to be exposed so that adjustments may be made to the detector.

Stereotactic Radiation Therapy Devices

- Stereotactic radiation therapy (SRT) or stereotactic radiosurgery (SRS) are techniques that use very small and highly conformal, noncoplanar beams to treat small target volumes while sparing neighboring tissues.
- The main characteristics that distinguishes SRT/SRS are circular beams, arc angles, and often multiple isocenters through multiple planes to achieve high dose concentration.
- SRT can be performed in a single fraction or multiple fractions.
- When single fractions are used, the term appropriate is SRS; when multiple fractions are used, the appropriate term is SRT.
- Single-dose SRS procedures are performed on functional disorders, some benign tumors and metastatic lesions, and sometimes for dose boosting where doses range from 12 to 25 Gy.
- Multiple fraction SRT typical dose sizes are 7 Gy/fraction for a total of 42 Gy or 4 Gy/fraction for a total of 40 Gy.
- Techniques may make use of photons, electrons, or gamma radiation beams.
- During SRT/SRS margins are very small, requiring elaborate immobilization and targeting systems along with strict treatment planning.
- Stereotactic head rings/frames are surgically attached to the skull and have to be fitted to an indexed positioning device attached by

brackets to the patient support apparatus (multiple fraction SRT would require this to be in place for a prolonged period).

- A gamma knife unit allows the positioning of up to 201 sources in a hemispherical helmetlike shield; the helmet only accommodates the skull for SRS to brain tumors. Stereotactic frame then fits tightly into the hemispherical helmet where the cobalt sources are collimated with beam channels; channels may be 4 to 18 mm in diameter.
- Linac-based SRT uses strict localization of the target, stereotactic frame, PSA brackets, and focused circular fields (achieved dynamically or with attachable cones); beams may be arced or static.
- Attachable cones are typically made of Cerrobend encased in stainless steel; cones range in diameter from 5 to 30 mm.
- A miniature 6-MV linac on a robotic arm, known as CyberKnife, is another approach to SRS.
- No stereotactic frame is used for CyberKnife; rather, an image-guided target localization system is used so that treatment may be delivered to extracranial targets.
- Monitoring and tracking of a target position is continuous so that the beam is aimed accurately.

Treatment Accessories

- Treatment accessories are used to indicate beam direction and location of the isocenter, modify the absorption and scattering characteristics of the beam, or to aid in positioning and immobilization of the patient.
- Beam directional devices would include: front and back pointers, lasers, cross hairs, graticule, field light and mirror assembly, digital readouts for gantry and collimator angles, and electron cones and collimators.
- Beam modifiers would include: standard wedges, dynamic wedges, custom tissue compensators, bolus materials, Cerrobend blocks, and multileaf collimators.

- Positioning aids help establish the desired patient position and would include: pillows and sponges, headrests, chin-straps, breast boards, and wing boards.
- Immobilization devices are intended to limit patient motion and would include: Aquaplast, vac lock systems, alpha cradle, bite blocks, casts, molds, and tape (simple immobilization).

Quality Assurance for Accessories

- Treatment accessories need to be checked for physical integrity and reliability.
- Latching mechanisms for interlocking accessories such as cones, trays, and standard wedges should be checked monthly.
- Fabricated Cerrobend blocks may be checked for voids using radiographic imaging; when pouring, care must be taken to prevent air bubble formation.
- Bolus materials should be checked regularly for cleanliness and voids, and for appropriate thickness.
- Positioning and immobilization devices should be regularly inspected for tears, leaks, and broken parts.

Treatment Planning and Record and Verify (R and V) Systems

- There are several computerized treatment planning systems.
- Before computerized treatment planning, hand-drawn isodose renderings had to be generated for customized planning.
- Single- and multiple-field atlases were available to superimpose over hand-drawn anatomic drawings to find the optimal plan for the patient.
- Early computerized planning systems only allowed two-dimensional representation of anatomy and isodose distribution.
- Systems needed to be programmed with special algorithms for the calculation of cumulative dose points and could only generate open

field plans.

- Today's systems have programmed algorithms that allow for therapy planning with cumulative dose points throughout the treated volume, tissue density heterogeneity recognition, visualization of dose points in three dimensions, and ability to shape fields and reflect dosimetric influences on referenced output.
- Computers also brought the ability to store individual patient data for daily verification of field details.
- Record and verify systems (R and V) were developed to minimize treatment errors.
- Errors in treatment may be related to mechanical malfunction, patient variations, or technical variations.
- Before computerized R and V, therapists had to rely on hand-written documentation of treatment parameters and manual settings.
- R and V systems in its early stages would only show patient parameters as reference data without any interlocks or warnings if parameters did not agree.
- Today's systems not only show patient parameters but also have safety interlocks that require an override when parameters do not match; moreover, daily doses are recorded on disk, making manual charting unnecessary.
- As R and V systems serve as both a quality control system and documentation tool, quality assurance processes must include a review of accurate translation of inputted data and accurate retention of daily treatment activity.

Quality Assurance for Treatment Planning Systems and R and V Systems

- Treatment planning systems are an integral part of accurate treatment delivery.
- Its fundamental performance must constantly be under scrutiny; this includes the interpretation of data and algorithmic calculations.

- As these computerized systems are relied upon for daily and cumulative dose information, it is imperative that a small tolerance of error is acceptable (2% tolerance for isodose distributions and monitor unit calculations).
- Some departments may employ a secondary calculation program to double-check the primary treatment planning software for dose calculation; the double-check may be computerized or manual.
- Input and output devices should be checked daily, prediction algorithms and transfer of data (i.e., from CT) should be checked monthly for reliability; it is acceptable to verify monitor unit calculation accuracy yearly.
- It should be noted that some treatment centers may also employ external dose-measuring mechanisms to verify the accuracy of planning systems, such as TLD, and diode measuring for surface dose verification.
- IMRT systems should be checked for accurate dose delivery. Independent and individual plan verification is strongly recommended.
- A quality tool such as the “mapcheck” system, which produces portal intensity maps for each field using a phantom, is a good indicator for planned intensity across the treatment field.
- Record and verify systems are only as good as the data inputted.
- Quality assurance for the R and V systems may include a manual, labor-intensive review of data.
- A thorough weekly review of the patient charts (

[Table 5.8](#)) is recommended whether in written form or electronic.

- A relatively easy way to check the R and V system is for the therapist to review the treatment plan before the initiation of treatment.
- Review the computerized treatment plan to verify that field sizes, portal arrangement, beam shaping, and use of modifiers documented in the plan agree with the information shown in the R and V system; this quick review gives adequate opportunity to identify and intercept potential errors.

TABLE 5.8

Review Exercises

1. The target of the linac must have:
 - a. A low melting point
 - b. A high melting point
 - c. The ability to bend
 - d. Low thermal conductivity
2. The source of electrons in a linear accelerator is the:
 - a. Klystron
 - b. Magnetron
 - c. Electron gun
 - d. Waveguide
3. What type of target is used in high-energy linear accelerators?
 - a. Transmission type
 - b. Reflection type
 - c. Refraction type
 - d. None of the above
4. Which of the following machines does not accelerate electrons?
 - a. Microtron
 - b. Betatron
 - c. Cyclotron
 - d. X-ray tube
5. The purpose of the flattening filter in the linac is to:
 - a. Direct the stream of electrons out toward the collimator opening
 - b. Prevent deflection of microwaves
 - c. Evenly distribute and spread out the raw electron beam across a specified area

- d. Evenly distribute the energy of the photon beam across a specified area
- 6. What is the purpose of the ion monitor chamber in the linear accelerator?
- 7. What is the purpose of the magnetron and klystron in the linear accelerator?

Think About It

- 8. Irregular surface contours may be compensated for by using standard wedges, using customized tissue compensators, or by appropriately placing bolus material on/in the irregular surface. What is the advantage of using standard wedges and customized tissue compensators over bolus materials for irregular surface contours?
- 9. Radium has an extremely long half-life and a relatively high average gamma energy, making the source easy to use repeatedly for a long period and suitable for delivering substantial, penetrating dose to tissue. Why is radium no longer used in brachytherapy procedures?
- 10. Which of the following radioisotopes is used for diffuse bone metastasis?
 - a. Cesium-137
 - b. Cobalt-60
 - c. Strontium-90
 - d. Strontium-89
- 11. Which of the following radioisotopes is a pure beta emitter?
 - a. Cesium-137
 - b. Cobalt-60
 - c. Phosphorus-32
 - d. Iodine-131
- 12. The field light on the linear accelerator is intended to represent:

- a. The area of radiation exposure
 - b. The size of the target
 - c. The width, length, and depth of the treatment field
 - d. The distance from the source of radiation to the patient's skin
13. The scattering foil is placed in the path of the stream of electrons in the linear accelerator when programmed to operate in the _____ beam mode.
- a. proton
 - b. electron
 - c. x-ray
 - d. fluoroscopic
14. The klystron or magnetron is the source of _____ in the linear accelerator:
- a. microwaves
 - b. alternating current
 - c. accelerated electrons
 - d. magnetic fields
15. The cyclotron may produce _____ beams.
- a. electron
 - b. x-ray
 - c. proton
 - d. gamma ray
16. The purpose of a positioning device is to:
- a. Make the patient comfortable
 - b. Accommodate the most appropriate position for accurate treatment delivery
 - c. Prevent or limit patient motion during treatment
 - d. Limit the setup time
17. The energy range for the early-generation superficial therapy machines is:
- a. 50 to 150 kV

- b. 150 to 500 kV
 - c. 600 to 1000 MV
 - d. 20 to 25 MeV
18. A long cylinder loaded with radioisotopes and placed in the vaginal space could be used to treat the:
- a. Vaginal vault
 - b. Endometrium
 - c. Pelvic side wall
 - d. Vulva
19. The linear accelerator generates a high-energy photon or electron beam by:
- a. Accelerating charged particles in a circular pattern
 - b. Accelerating charged particles in a linear path
 - c. Producing electromagnetic pulses used to accelerate protons and neutrons
 - d. Keeping photons in synch with a magnetic field

Matching

20. _____

Radium-226 A. 74.2 days

B. 60 days

21. _____

Iodine-125 C. 30 days

D. 2.7 days

22. _____

Cesium-137 E. 30 years

F. 1622 years

23. _____

Gold-198 G. 1622 days

24. Heyman capsules may be used to treat the:

- a. Vaginal vault
- b. Endometrium
- c. Vulva
- d. Prostate

25. The Fletcher's suite application is an example of:

- a. Interstitial low-dose rate brachytherapy
- b. Intracavitary low-dose rate brachytherapy
- c. Permanent implant brachytherapy
- d. Injected, unsealed source brachytherapy

26. The BAT system uses _____ energy to localize the treatment target.

- a. x-ray
- b. microwave
- c. radiofrequency
- d. ultrasound

27. The important QA test(s) associated with the light field are (circle all correct):

- a. Field size accuracy
- b. Beam output
- c. Light and radiation field coincidence
- d. None of the above

28. Functional performance of radiation therapy equipment can (circle all correct):

- a. Not vary with time
 - b. Change due to malfunction of system electronics or component fault
 - c. Change due to wear and tear of the equipment
 - d. Change due to environmental conditions
29. The target to patient skin distance is measured using (circle all correct):
- a. A meter scale
 - b. An SSD rod
 - c. An ODI indicator
 - d. None of the above
30. The tolerance for the localizing laser and the ODI indicator is:
- a. 1 mm
 - b. 2 mm
 - c. 5 mm
 - d. None of the above
31. The constancy of linac output for photon and electron beams must be checked:
- a. Daily
 - b. Weekly
 - c. Monthly
 - d. Only during commissioning
32. The constancy of linac output, when compared with the benchmark values established during commissioning, must be within:
- a. 1%
 - b. 3 %
 - c. 5 %
 - d. None of the above
33. The symmetry and flatness of the clinical photon beam can be checked using (circle all correct):
- a. Film

- b. A beam profiler
 - c. A calorimeter
 - d. None of the above
34. The x-ray beam in the linac must exhibit flatness within about:
- a. 1%
 - b. 2%
 - c. 5%
 - d. None of the above
35. Scan and couch vertical positional accuracy for CT planning must be:
- a. <1 mm
 - b. About 2 mm
 - c. About 5 mm
 - d. About 1 cm
36. Full calibration and overhaul of treatment equipment must be carried out:
- a. Daily
 - b. Weekly
 - c. Monthly
 - d. Annually
37. In the case of brachytherapy sources:
- a. All sources must be leak tested
 - b. Short half-life sources need never be tested for leakage
 - c. Sources not in use need not be tested for leakage
 - d. Long half-life sources only need leak testing annually
38. The exact position of the source in the applicator can be checked by (circle all correct):
- a. Visual inspection
 - b. Measuring the strength of the source
 - c. Taking a radiograph
 - d. None of the above

39. Brachytherapy sources must be calibrated (circle all correct):
- a. By the manufacturer only
 - b. By the accredited dosimetry calibration laboratory only
 - c. Before being used for clinical dosimetry
 - d. By a user using a chamber with calibration traceable to an accredited dosimetry calibration laboratory
40. In a brachytherapy procedure room, the following items must be available all the time (circle all correct):
- a. A radiation survey meter
 - b. A temporary storage container
 - c. A cutter and long-handled tongs
 - d. All of the above
41. The tolerance for the coincidence of light and radiation field, in the case of the medical linac is:
- a. 2 mm or 1% of field length being measured, whichever is greater
 - b. 3 mm
 - c. 5 mm
 - d. None of the above
42. Localizing lasers on simulators must be within _____ of isocenter.
- a. 1 mm
 - b. 2 mm
 - c. 3 mm
 - d. 2 cm

Below Are 13 Components of the Linear Accelerator. In the Statements That Follow, Indicate Which Components Are Used. Some May Be Used More Than Once

A. Electron gun B. Accelerating guide C. Waveguide D. Bending magnet
E. Target F. Scattering foil G. Flattening filter H. Ion chamber
I. Field light J. Collimator jaws K. Klystron L. Modulator
M. Radiofrequency driver

43. Microwave power is produced to accelerate electrons. _____

44. Microwave power is directed toward the accelerator guide.

45. Reference signal is provided for generation of microwave power.

46. Electrons are produced. _____

47. Electrons are accelerated to high energy. _____

48. At the end of acceleration, high-energy electrons are focused
toward the collimator opening. _____

49. X-rays are produced by bremsstrahlung and characteristic radiation
process. _____

50. The electron beam is spread out uniformly over the field area.

51. X-ray beam intensity is made uniform over the field size at the
isocenter. _____

52. Monitors radiation output. _____

53. Monitors radiation beam uniformity by monitoring and controlling
symmetry and flatness. _____

54. Produces high voltage and high power electrical pulses to generate
microwave power. _____

55. These components, through which electrons travel, are under very
high vacuum. _____

56. Microwaves travel through these components and are prevented
from reflecting backward. _____

57. During a split field test for longitudinal displacement of the
collimator for jaw symmetry, the collimator is rotated through an
angle of:

a. 360 degrees

b. 270 degrees

c. 180 degrees

- d. 90 degrees
58. To check the accuracy of gantry digital readouts, one could use:
- a. Closed collimators
 - b. A spirit level at 45-degree angle increments
 - c. A breast bridge at 90-degree angle increments
 - d. A spirit level at 180-degree angle increments
59. A short exposure is taken on a radiographic film aligned with metallic marks on the borders of a collimated light field. This describes testing for:
- a. Light field/radiation coincidence
 - b. Field flatness
 - c. Collimator symmetry
 - d. Field intensity
60. Safety door interlocks should be checked:
- a. Annually
 - b. Monthly
 - c. Weekly
 - d. Daily
61. Which of the following verifies the accuracy of radiation dose delivery?
- a. Back up timer, radiation off switch, door interlock, and emergency off switch
 - b. Back up timer, door interlock, and override switch
 - c. Radiation off switch and override switch
 - d. Door interlock, radiation off switch, and collision ring
62. To ensure the patient's safety during treatment on a megavoltage linear accelerator, the patient must be monitored by:
- a. Directions given before treatment
 - b. Intercommunication systems
 - c. Watching the patient through a window
 - d. Instructing the patient to yell out for help as needed

63. The process for testing a new accelerator against manufacturer's specifications before putting it into service is termed:
- a. Insurance calibration testing
 - b. Acceptance testing
 - c. Error correction testing
 - d. Quality assurance testing
64. A high energy photon unit will require daily quality checks for the determination of:
- a. Light and radiation field coincidence
 - b. Dose rate constancy
 - c. Field symmetry and flatness
 - d. Crosshair centering
65. Gantry and collimator indicators should be accurate to within _____ degree(s).
66. The common acceptable value for field flatness is about _____% over the central 80% of the largest field size at isocenter.
67. All of the following might account for a beam's flatness deviating outside specifications, except:
- a. Flattening filter shift
 - b. Target position shift
 - c. Incorrect mirror angulation
 - d. Fluctuation of current
68. While treating a patient using a rotational arc technique, the gantry rotates beyond the endpoint. This is likely a malfunction of the:
- a. Operator's console
 - b. Limit switch
 - c. Collision ring
 - d. Override switch
69. A mechanical distance indicator is used to verify:
- a. Gantry rotation
 - b. Collimator rotation

- c. Field size congruence
 - d. Accuracy of optical distance indicator
70. If the mirror and bulb assembly has to be replaced, it is critical to perform the following quality check(s) before using the machine:
- a. Dose rate
 - b. Light field and radiation coincidence
 - c. Collimator angle readout
 - d. Gantry angle readout
71. Which of the following has the shortest half-life?
- a. Cesium-137
 - b. Gold-198
 - c. Iridium-192
 - d. Radon-222
72. In early-generation kV therapy machines, the quality of the photon beam could be increased by:
- a. Increasing the mA
 - b. Decreasing the half value layer of material
 - c. Increasing the filtration
 - d. Decreasing the kVp

Write T for True and F for False for the Following:

The effective energy of a photon beam can be increased by:

- 73. Increasing the beam on time. _____
- 74. Increasing the tube current. _____
- 75. Increasing the tube potential. _____
- 76. OBI is an acronym for:
 - a. Onboard imaging
 - b. Off beam indicator
 - c. Optical beam indicator

- d. Off baseline measurement indicator
- 77. The machine that consists of a short metallic cylinder divided into two D-shaped cavities is known as the:
 - a. Cyclotron
 - b. Betatron
 - c. Microtron
 - d. Van De Graaf
- 78. The gantry head of the linear accelerator contains all of the following except:
 - a. Flattening filter
 - b. Ion chamber
 - c. X-ray target
 - d. Klystron

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CHAPTER 6

Treatment Planning

Nishele Dyan Lenards

Focus questions

- What means are there for target localization during radiation therapy planning?
- What are the steps in the planning process using CT simulation equipment?
- How are appropriate patient positioning and immobilization techniques determined?
- What is the importance of acquiring both internal and external anatomy information for planning?
- What considerations are there for selection of treatment parameters, such as geometric field size and shape, modality, energy, and portal arrangement?
- What basic dosimetric calculations are necessary for everyday practice?
- How are diagnostic imaging modalities used in therapy planning?
- How are beam modifiers such as bolus, custom compensators, wedges, and modulation technologies used to customize treatment plans?
- What are key directional terms used in the interpretation of treatment plan data?

- What information is gleaned from the DVH, plan data sheet, and fluence map?
- What are some common beam arrangements?
- What types of clinical situations make certain beam arrangements appropriate?

General Simulation Practices

- During the simulation process, the location of the isocenter is determined.
- The patient should be positioned in a manner that is suitable for the area of treatment and in a manner that can be accurately reproduced on the treatment table.
- Properly placed marks, photographs, and detailed descriptions aid in reproducibility.
- Patient marks can be applied with felt pens, paint pens, carfusion, or tattoos.
- When administering conformal 3D or intensity-modulated radiation therapy (IMRT), margins are tight leaving little room for setup error; patient marks alone are often too unstable to be solely relied upon.
- Verify patient setup radiographically as often as is feasibly possible.
- To assure the patient maintains a level position, place marks using all laser lines.
- Sagittal alignment can be maintained by placing two marks 10 cm to 20 cm apart along the sagittal laser lines.
 - If a treatment machine is used for initial simulation, the crosshairs provided by the graticule can serve the same purpose as the sagittal lasers.
- Portal images are acquired on the treatment machine to verify the beam's path, shape, and central axis with respect to patient anatomy. Portal images can be acquired with film or Electronic Portal Imaging Devices (EPIDs).

- With the advent of image-guided radiation therapy (IGRT), linear accelerators are available with on-board kV imagers capable of cone-beam CT technology. The kV cone-beam CT (CBCT) images are then compared to treatment planning images to determine accuracy of set up or needed shifts on the treatment machine.

XYZ Coordinate System

- During simulation, isocenter localization is accomplished by using a three-dimensional XYZ coordinate system (

Figure 6.1).

- Delineation of the treatment target and the placement of the isocenter relative to the target is referred to as localization.
-

x is the transverse axis that extends right to left in the patient.

-

y is the longitudinal axis extending head to foot.

-

z is axis extending upward from the table top.

- When referencing an isocenter movement during simulation or reproducing the isocenter location for treatment, the XYZ localization method is most effective.
- The XYZ coordinates are fixed relative to the simulator, CT, treatment planning computer, or linear accelerator table top.

1. If the patient is laying supine and head first on the table, the positive

x axis is on the patient's left while the positive

y axis is cephalic and the positive

z axis is anterior.

2. If the patient is laying prone and head first on the table, the positive

x is at the patient's right, the

y axis is unchanged, and the positive

z axis is posterior.

3. If the patient is laying supine and feet first, the positive

x is on the patient's right, the positive

y is caudal, and the

z axis is unchanged.

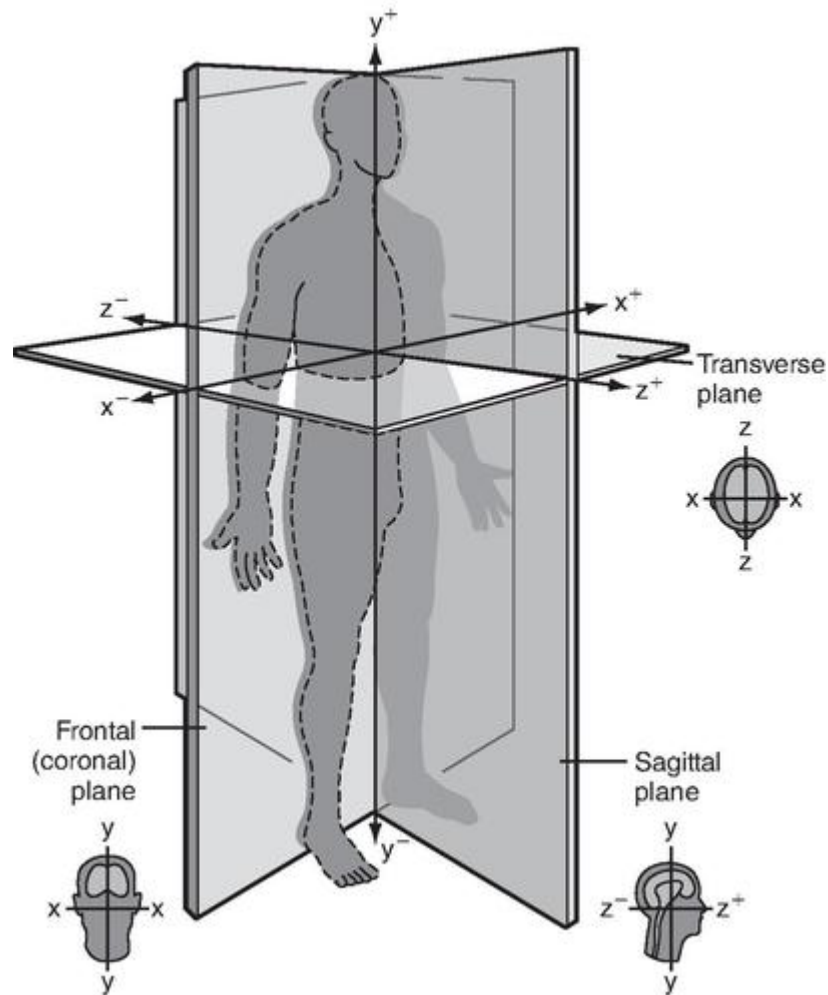


FIG. 6.1 Diagram of XYZ coordinates.

Lasers Used for Localization

- Lasers mounted on the walls and ceilings of simulation rooms and treatment rooms assist in localization.
- Laterally mounted wall lasers in conjunction with sagittal ceiling or wall-mounted toe lasers are designed to converge at the point of SAD or isocenter.
- Lasers broadcast a very narrow beam of light onto the patient.
- Patient marks are placed on the laser light to indicate where the isocenter is located.

- On the treatment machine, isocenter localization is done with table movement.
- For CT simulators, isocenter localization is done either with laser movement or in the treatment planning computer after simulation.

Positioning, Positioning Aids, and Immobilization Devices

- Soft and pliable head holders, pillows, sponges, and table mats should be avoided whenever possible; these devices foster setup inconsistency.
- Firm, commercial positioning aids provide more consistent setup.
- A firm knee support reduces the lordotic curvature of the spine and makes the patient more comfortable on the hard treatment couch.
- Knee supports should be avoided for treatment areas below the level of the diaphragm because leg elevation is seldom consistent. Leg elevation can cause variation in the location of the internal anatomy in the abdomen and pelvis.
- Immobilization devices help maintain patient position.
- Positioning aids should help facilitate a certain position consistently; these aids do not immobilize the patient.
- Whatever position is determined for your patient should be comfortable and easily accommodate the treatment strategy.
- A few examples of positioning aids include commercial head holders, custom head holders, knee sponges, wing boards, prone pillows, Duncan masks, chin straps, and shoulder pulls.
- Immobilization devices help limit movement of the patient during treatment.
- The proper use of immobilization devices can decrease setup and targeting errors significantly.

Head and Neck

- The position for treatment in the head and neck area is usually supine. Supine is comfortable for most patients and portal arrangements typically include the use of lateral beams. The supine position also makes it easy to clinically verify that the sensitive lens is excluded from treatment fields.
- Head and neck positioning and immobilization should include a rigid plastic head holder that cradles the head while supporting the neck at the required chin extension or flexion.
- Thermoplastic molding products such as Aquaplast, which when warmed in water becomes pliable, can be fitted and contoured over the patient's head and secured to the table top.

1. A size that covers only the head works well for treatment areas above the clavicles.
2. A longer style (S-frame) that covers the head and shoulders works well for treatment areas in the head, neck, and supraclavicular regions.
3. Aquaplast dries quickly and becomes rigid.
4. Positioning marks can be applied to the mask avoiding skin marks.
5. While the mask is cooling, use your fingers to mold at the glabella, chin, and entry of the auditory meatus.

- The use of shoulder pulls/adjustable straps tends to be controversial. Their use lends to setup variability.
- More precise shoulder retractor apparatuses come with some head and neck immobilization systems; the position of retractors should be carefully documented and referred to for daily setup.
- When planning for IMRT in the area of the head and neck, two methods may be used to compensate for no shoulder straps. They include:

1. Computer contouring of the shoulders from the distal clavicle to the lateral aspect of the shoulder then set dose constraints on the shoulders.
2. Set gantry angles above or below the shoulders.

- Bite block systems can be both a positioning aid and immobilizer. Bite block systems that are mountable to the table top or to a head holder can lock into place and assure consistent chin extension. Free bite blocks can be used to position and immobilize the tongue and upper and lower jaw.

Breast

- Typical position for treatment of the breast is supine. The prone position using a special prone breast board is useful for patients with large breasts.
- Make sure legs and ankles are not crossed because this causes rotation of the torso.
- Wing boards are suitable for treatment of the breast. They allow the patient to raise both arms above the head with a comfortable resting platforms for the elbows.
- For the breast especially, a wing board can be used along with a breast board at a slight incline to reduce the slope of the chest.
- Use of the wing board for treatment of the breast allows the patient to raise both arms above the head, making the torso more symmetric, thus reducing many of the setup variables associated with a “one arm up” setup technique.
- Breast boards with attachments to help reproduce elbow, wrist, and hand positions are also suitable.
- With 3D treatment planning computers, breast board elevation can be kept at a minimum 5 to 10 degrees. The treatment planning computer can be used to optimize dose distribution and reduce hotspots on a sloped surface.
- The chin should be raised and the head turned away from the treated breast.
- A myriad of devices has been created to secure the breast in a fixed position, but their effectiveness is questionable. Allowing the breast to find its natural position tends to be more reproducible than any breast tissue immobilizer regardless of breast size.

- Skin folds that occur around the breast area are areas prone to erythema and desquamation, but the severity can be reduced by adjusting the position of the arm(s) or chest slope; various computerized treatment planning techniques can help reduce high dose accumulation in areas of buildup.
- A Vac-Loc system used with or without a wing board is a viable alternative to a breast board for breast setups.
- A Vac-Loc bag is filled with Styrofoam beads. When air is removed from the bag, it retains the shape and contour of the patient. These bags are reusable.
- An alternative to the Vac-Loc system is the alpha cradle system that uses two liquids, which when mixed together create a thermal reaction. When placed in a plastic bag and sealed, the chemicals expand and conform to the patient's body and then solidify.

Chest, Abdomen, Pelvis, and Extremities

- The Vac-Loc or alpha cradle systems work well for supine treatments of the chest, abdomen, pelvis, and extremities.
- The wing board is also appropriate for treatment of the chest and abdomen, especially when the use of lateral or posterior oblique fields is anticipated.
- Chin extension is determined based on the upper limits of the treatment fields.
- For treatments in the pelvic region, the Vac-Loc bag should extend from the buttocks to the feet. Supplementing the Vac-Loc bag with a large rubber band around the feet helps to keep the legs from rotating laterally. The exact position of the feet should be easily replicated.
- Although supine position is comfortable, prone position helps decrease the volume of small bowel in the pelvis and decreases gluteal folds where dose easily builds.
- For prone treatments of the pelvic region, belly boards are desirable to move small bowel anteriorly out of the treatment area.

- Planning for lower extremities is typically simple with the patient positioned supine, with reproducible positioning and immobilization of the legs.
- Positioning and immobilization can become more complex and will need to be tailored to individual cases to avoid opposite limbs and neighboring tissues when using high-dose therapies for such cancers as soft tissue sarcoma and primary osteosarcoma.
- Alpha cradle and Vac-Loc systems have appropriately sized units for extremity radiation therapy.
- Planning techniques including bladder/rectal filling or voiding assist in tissue sparing and minimizing side effects; status of these organs should remain consistent throughout simulation and then throughout treatment.

CT Simulation

- Images are acquired with CT during the simulation procedure and contain 3D information about patient anatomy. Used with computer software, these images perform a virtual patient simulation following the CT image acquisition.
- Consideration of likely treatment strategies, target volume, optimal patient position, immobilization, and positioning aids must come before scanning.
- Small radiopaque wires of a density that does not cause any undesirable artifact on the axial images are placed on the patient corresponding to the XYZ coordinates. These may be referred to as surface fiducials.
 1. Wires allow the location of the preliminary isocenter to be viewed on the CT images.
 2. Placement of fiducials allows target localization using the XYZ coordinate system with the marks placed on the patient during simulation as the origin.
- The scan should begin and end at reasonable margins above and below the area of interest and anticipated treatment volume. Slice

- thickness and pitch are selected based on the established protocol.
- The images must be thin and contiguous for best results so the computer can reformat and reconstruct the images to yield 3D representations of the patient.
 - Helical or axial scanning should be selected based on the established protocol. Helical scanning lessens the possibility of skipped anatomic data collection.
 - The CT slice thickness should be 2 to 3 mm to provide enhanced detail and optimal density differentiation for heterogenic dose calculation. For IMRT treatments, 2- to 3-mm slice thickness should be used but for non-IMRT treatments, a 5-mm slice thickness may be used to reduce the amount of contouring during treatment planning.
 - Virtual simulation mimics the mechanical motion of the treatment machine and defines the isocenter. Various computer software tools are used to assist in virtual simulation.

1.

Beam's-eye view (BEV) is a computer-generated radiograph created from CT data, replacing a conventional simulator radiograph, to visualize patient anatomy with respect to the proposed treatment beam (

Figure 6.2).

2.

Digitally reconstructed radiograph (DRR) is a computer-generated radiograph created from CT data to visualize patient anatomy (

Figure 6.3). DRRs can be printed or maintained digitally in an electronic record system.

- Keep in mind that when slice thickness is increased, DRR resolution declines and small structures may not be articulated well on the

reconstructed images.

- Final isocenter markings or set up coordinate markings for required daily treatment shifts are placed on the patient before the end of the CT simulation.
- Patient marks can be applied with felt pens, paint pens, carfusion, or tattoos.
- Taking photos and providing detailed descriptions aid the radiation therapists in setup reproducibility.

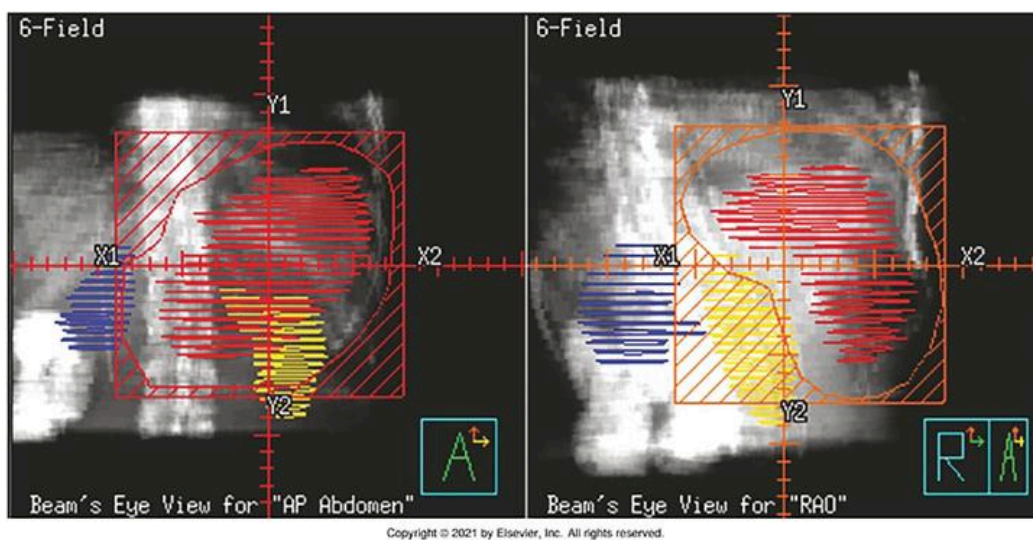


FIG. 6.2 Use of the beam's-eye view (BEV) tool for treatment-field design and placement.

(Washington CM, Leaver D.

Principles and Practice of Radiation Therapy. 5th ed. Mosby; 2020. [Fig 23-14].)

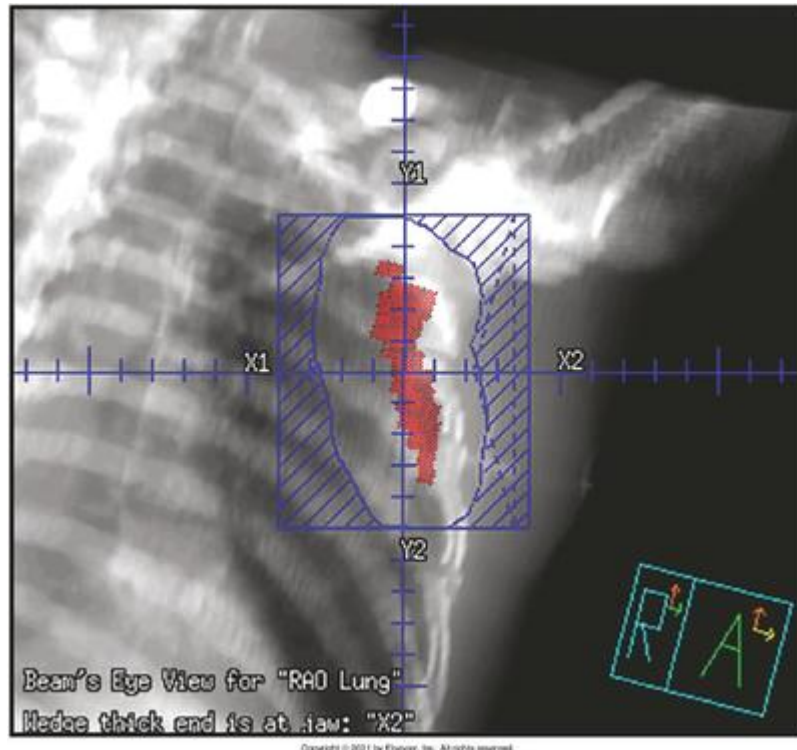


FIG. 6.3 Digitally reconstructed radiograph (DRR) reconstructed from a thoracic data set to produce a view equivalent to that of a radiographic image with a superimposed projection of the contoured CTV and treatment field with a 2-cm margin.

(Washington CM, Leaver D.

Principles and Practice of Radiation Therapy. 5th ed. Mosby; 2020. [Fig 23-17].)

4D CT Simulation

- Term used to describe CT simulation + respiratory motion tracking.
- Two techniques commonly used; both involve a device attached to patient's chest to track motion.
 1. Gated imaging involves the patient holding their breath at maximum inspiration or expiration cycles while the CT couch is moved for imaging acquisition. This technique requires patient cooperation and training.

2. Free breathing imaging involves the patient breathing freely during a helical scan and images are acquired through several respiratory cycles.

MRI Simulation

- Advantages compared to CT simulation are superior soft tissue contrast and ability to obtain metabolic and functional images.
- Disadvantages compared to CT simulation are lack of electron density information for dose algorithms, image distortion, and lack of compatibility of positioning aids with MRI. CT is superior for viewing calcifications/bony anatomy.
- Used routinely for primary and metastatic brain tumors; increasing use with prostate and abdominal tumors.

Computerized Treatment Planning

General Principles

- The physician determines which imaging data sets will be used for anatomical contouring. This may be CT simulation image data sets only or may be in combination with other imaging datasets such as MRI or PET scans.
- After anatomical contouring, the computerized treatment planning process begins.
- Treating a target with a multifield approach is preferable.
 1. Provides a more homogenous dose distribution around the target.
 2. Reduces a potentially high dose in any one area.
 3. Minimizes side effects.

Image Fusion

- Also known as image registration; process of placing two sets of images on the same coordinate system to be superimposed like an overlay and viewed simultaneously.
- One can register two sets of images of different modalities or different sets of the same modality from different dates (

Figure 6.4).

- For treatment planning, common examples include fusion of CT and MRI datasets or CT and PET datasets. For treatment planning, the primary set of images is the CT dataset and dose calculations are completed from this set.
- Reliability of the process depends critically on the quality of the image registration.

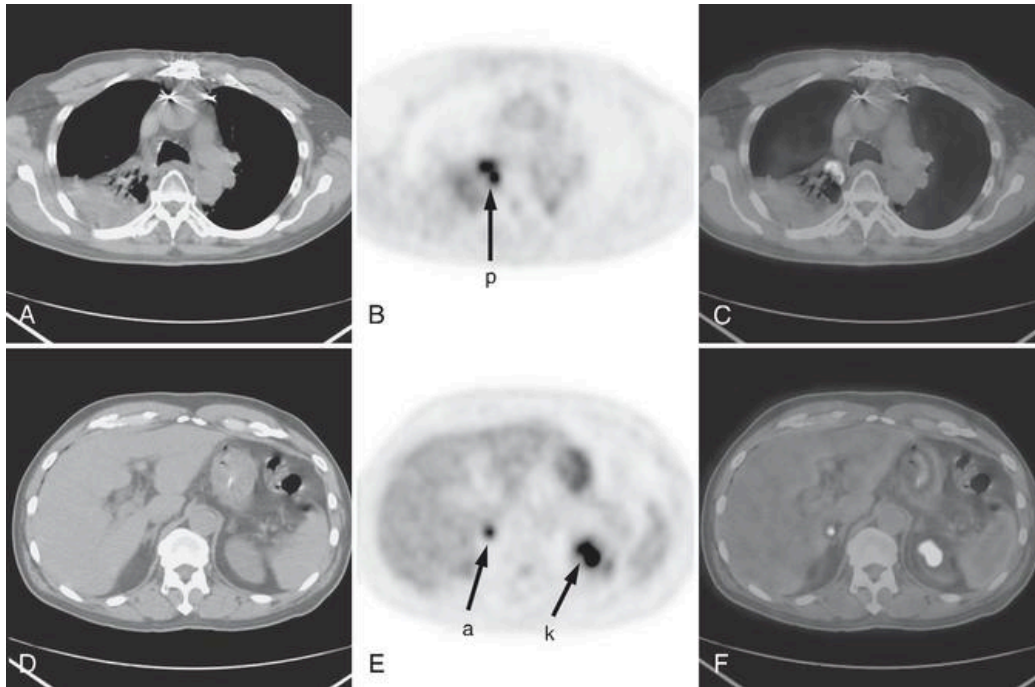


FIG. 6.4 CT/PET scan fusion in patient with lung cancer.

A , Transaxial CT scan.

B , Transaxial PET scan at same level as A.

C , A and B images fused.

D , Transaxial CT scan at a level inferior to set A, B, and C.

E , Transaxial PET scan at same level as D.

F , D and E images fused. a = adrenal gland; p = primary lung tumor;
k = kidney.

Anatomical Contouring

- After image data sets are obtained, anatomical areas of interest must be contoured or delineated (

Figures 6.5a ,

6.5b , and

6.5c). CT data is used to define critical structures, tumor and target volumes by drawing contours on an image-by-image basis.

- Contouring tools used to outline structures =

image segmentation

- Software allows for manual and automated contouring.

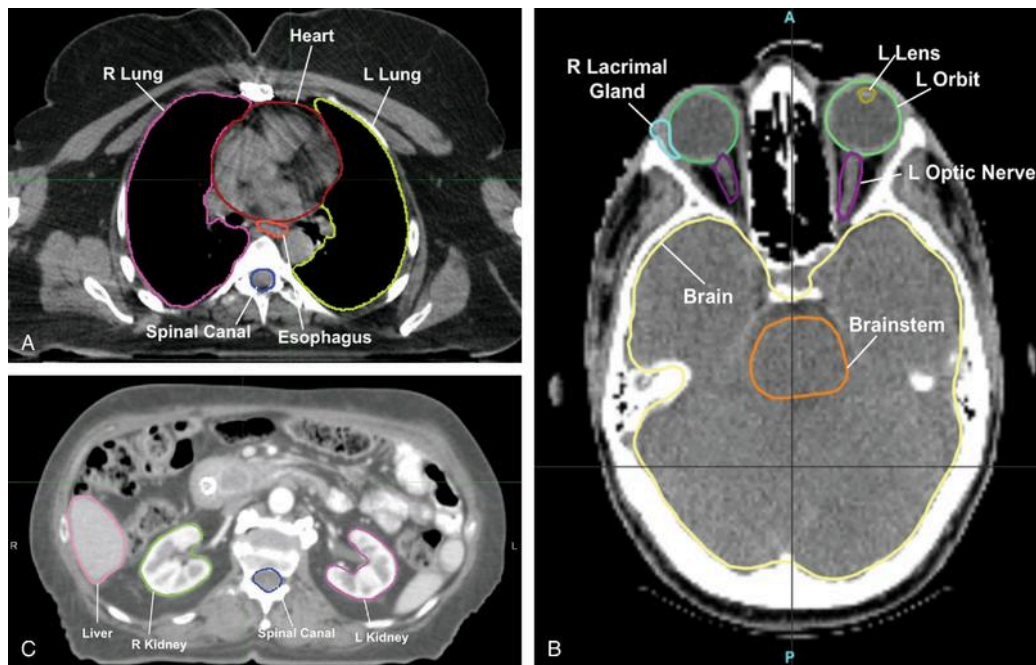


FIG. 6.5A, 6.5B, AND 6.5C CT data sets with anatomical contouring completed during treatment planning.

A. Thorax.

B. Brain.

C. Abdomen.

Target Volume Terminology (Dose Specifications)

With the advent of conformal radiotherapy, the International Commission on Radiation Units and Measurements (ICRU) established terminology for

identifying volumes and reporting dose. These continue to expand with advances in technology. Refer to

Figure 6.6 .

1. Gross tumor volume (GTV) is only the tumor visible by imaging such as CT, MRI, or PET; fusion of images (

Figure 6.4) from PET, MRI, and CT are especially helpful in determining the GTV.

2. Clinical target volume (CTV) is the GTV plus a margin of up to 2.0 cm that encompasses an area where an unseen tumor or disease may be harbored. This margin is variable based on the radiation oncologist's perspective about a specific pathology and protocol requirements.
3. Internal target volume (ITV) compensates for physiologic movements and variations in size and shape or position of the CTV during therapy. Determination of this volume establishes feasibility of image-guided radiation therapy (IGRT) techniques, including surgical fiducial marker localization, BAT (ultrasound localization), and respiratory gating.
4. Planning target volume (PTV) is the CTV with additional margin of 0.5 cm to allow for patient movement and setup error.
5. Treated volume includes additional margins to allow for limitations in the treatment technique.
6. Irradiated volume is any tissue receiving greater than 50% of the specified target dose.
7. Organs at risk (OAR or OR) represent normal tissues whose radiation sensitivity may significantly influence the treatment planning and/or prescribed dose.
8. Planning organ at risk volume (PRV) represents the margins added to compensate for organs at risk movements. Planning organ at risk is outlined to protect the OAR effectively.
9. Internal target volume (ITV) represents an internal margin added to the CTV to compensate for internal physiological movements such

as variations in the site, size, and shapes of organs and tissues contained in or adjacent to the CTV. These may result from respiration, different fillings of the bladder and rectum, swallowing, heartbeat, movements of bowel, etc. Therefore, CTV + ITV + Setup Margin = Planning Target Volume (PTV).

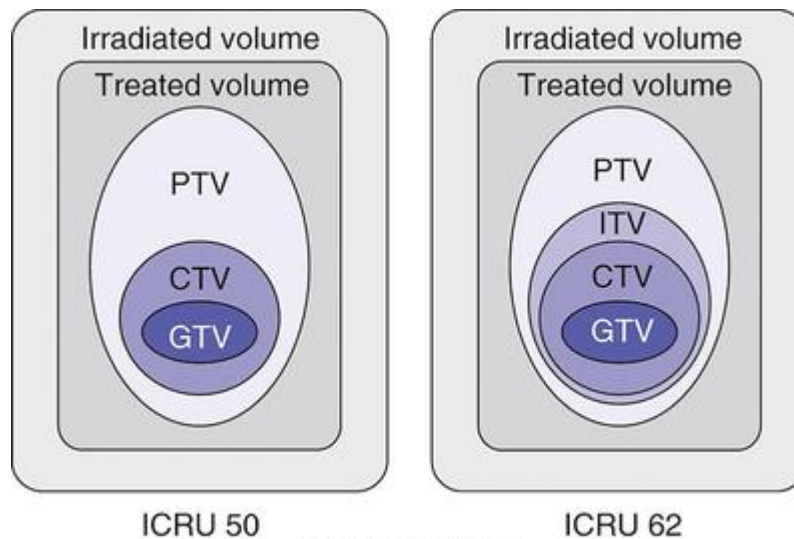


FIG. 6.6 Definition of target volumes used in radiation therapy from ICRU Reports 50 and 62. Description: Definition of target volumes used in radiation therapy from International Commission on Radiation Units and Measurements Reports 50 and 62. CTV, Clinical target volume; GTV, gross tumor volume; ITV, internal target volume; PTV, planning target volume. (Washington CM, Leaver D.

Principles and Practice of Radiation Therapy. 5th ed. Mosby; 2020. [Fig 23-13].)

Choosing the Proper X-ray Energy/Modality

1. A higher energy for deeper targets and a lower energy for more shallow targets.
 - a. Higher energy photons have a deeper Dmax and are more penetrating. They are better suited for pelvic and abdominal treatment areas.

- b. Lower energy photons have a shallower Dmax and dispense their energy more rapidly with depth. Tumors of the head and neck region, breasts, and superficial targets are better served with a lower energy.
- c. Dmax is the depth of electronic equilibrium, or the maximum build up depth.
- d. Skin sparing is a result of Dmax.

Consider this: a 6-MV photon beam has a Dmax of 1.5 cm while an 18-MV photon beam has a Dmax of 3.5 cm.

2. Electron beams are used to treat superficial targets.

- a. Rapid fall off in tissue with some skin sparing; bolus may be used with electrons to reduce skin sparing.
- b. Appropriate electron energy is determined by the depth of the area of interest and which dose line is selected by the physician.
- c. Rules of thumb $E/2$ = the range of the electron beam in cm

$E/2.8$ = the depth of the 80% isodose line

$E/3.2$ = the depth of the 90% isodose line

E = electron energy

Choosing the Proper Gantry Angles

- 1. Avoid dose-limiting organs or at least reduce exposure to them.
- 2. Beams arranged in a symmetrical manner tend to provide a more symmetrical target coverage.
- 3. Avoid using beam angles that are not executable due to lack of clearance with either the table or the patient.

4. Too many beams may have a diminishing return; increased integral dose.
5. When using electron fields, the horizontal axis should be parallel to the treated surface; en face.

Wedges

- Using wedges (

Figure 6.7) and bolus to manipulate dose distribution:

1. The thicker the wedge angle, the more dose distribution is affected.
2. The angle of the wedge is described as the angle of the 50% isodose line at the central axis for low-energy beams or the angle of the dose line located at 10 cm beneath the surface at the central axis for high-energy beams.
3. Rule of thumb when using a pair of wedged fields: Hinge angle = $180 - 2$ (wedge angle)
4. Wedges have a beam hardening effect with poly-energetic beams such as those from a linear accelerator.
5. Avoid placing wedges any closer than 15 cm to the patient to prevent undue electron scatter skin contamination.
6. An alternative to standard, universal wedges is virtual wedging achieved by dynamic collimators. Gradual progression across the treatment field achieves the same dose line tilting as seen when using standard wedges.
7. Bolus can be any tissue density equivalent material.
 - a. Fills in deficits to have a more homogenous dose distribution.
 - b. Shifts dose lines and brings Dmax closer to the skin surface when skin sparing is not desirable.

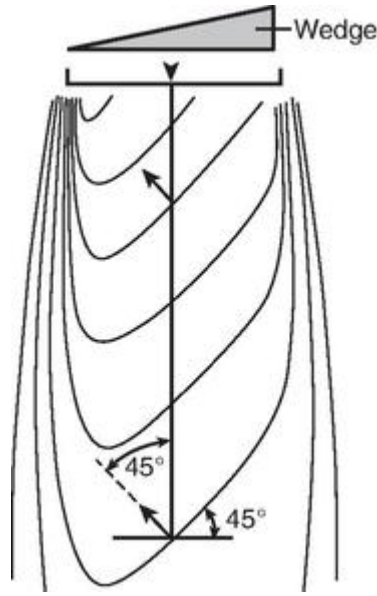


FIG. 6.7 A 45-degree wedge isodose chart.

Determining Field Shape and Size

1. Field shaping is dictated by the tumor size, local extensions, and regional metastasis.
2. When determining field size, do so dosimetrically and avoid guessing target margins.
3. Expand the field size as needed to cover the target with no less than 95% of the prescribed dose.

Interpreting the Treatment Plan

- The treatment plan data sheet should explain the treatment strategy, the number of fields, orientation of fields, field weights, and modifier factors along with monitor unit calculation factors.
- Plan summary sheets (

Figure 6.8) can also provide information regarding regions of interest and their total doses.

- Shifts from the preliminary setup markings placed at simulation time should be indicated on the plan data sheet in XYZ coordinate language, on the summary sheet, and/or on a representative cross-sectional image.
- Composite plans are two or more plans combined to show summative doses for all phases of the treatment regimen.
- Treatment planning using composite plans can optimize the quality of the therapy regimen by accurately depicting dose limitations to vital organs and, if need be, giving early alert for adjustments to assure tolerance doses are not exceeded.
- Composite plans showing dose distributions on cross-sectional data sets can be quick reference for dose points.
- Dose-volume histograms (DVH) are graphs showing the volume of a particular organ and the amount of radiation that organ will be exposed to by percentage of volume (

Figure 6.9).

- Fluence maps (

Figure 6.10) are quick reference tools for concentration of dose when IMRT is used.

04 Ap - IMRT**44 MU**

Machine:	MEVMLC	Isocenter X	-1.0 cm
Model:	Siemens_PRIMUS	Isocenter Y	1.0 cm
Energy:	6X	Isocenter Z	-2.0 cm
Technique:	STATIC	Field SAD:	100.0 cm
Gantry:	0.0 deg	Field SSD:	89.4 cm
Collimator:	0.0 deg	Point SSD:	88.8 cm
Couch Rtn:	0.0 deg	Depth (equiv):	12.1 cm (12.0 cm)
Parent:	X1: +4.2 cm Y1: +3.0 cm	Relative Weight	1.027
Fld Size:	X2: +5.0 cm Y2: +4.8 cm	Dose Contribution:	26.7 cGy
Scale:	Siemens IEC	MLC Type:	Dose Dynamic
MLC:	Siemens 58 MLC		
Action Points:	12		

05 Lao 50 - IMRT**48 MU**

Machine:	MEVMLC	Isocenter X	-1.0 cm
Model:	Siemens_PRIMUS	Isocenter Y	1.0 cm
Energy:	6X	Isocenter Z	-2.0 cm
Technique:	STATIC	Field SAD:	100.0 cm
Gantry:	50.0 deg	Field SSD:	87.6 cm
Collimator:	0.0 deg	Point SSD:	86.9 cm
Couch Rtn:	0.0 deg	Depth (equiv):	14.7 cm (14.3 cm)
Parent:	X1: +3.4 cm Y1: +3.0 cm	Relative Weight	1.018
Fld Size:	X2: +5.4 cm Y2: +4.8 cm	Dose Contribution:	26.7 cGy
Scale:	Siemens IEC	MLC Type:	Dose Dynamic
MLC:	Siemens 58 MLC		
Action Points:	14		

06 Lao 100 - IMRT**43 MU**

Machine:	MEVMLC	Isocenter X	-1.0 cm
Model:	Siemens_PRIMUS	Isocenter Y	1.0 cm
Energy:	6X	Isocenter Z	-2.0 cm
Technique:	STATIC	Field SAD:	100.0 cm
Gantry:	100.0 deg	Field SSD:	84.0 cm
Collimator:	0.0 deg	Point SSD:	84.1 cm
Couch Rtn:	0.0 deg	Depth (equiv):	17.1 cm (17.4 cm)
Parent:	X1: +3.4 cm Y1: +3.0 cm	Relative Weight	0.977
Fld Size:	X2: +4.4 cm Y2: +5.0 cm	Dose Contribution:	20.9 cGy
Scale:	Siemens IEC	MLC Type:	Dose Dynamic
MLC:	Siemens 58 MLC		
Action Points:	12		

07 Lpo 150 - IMRT**43 MU****FIG. 6.8** Plan data sheet.

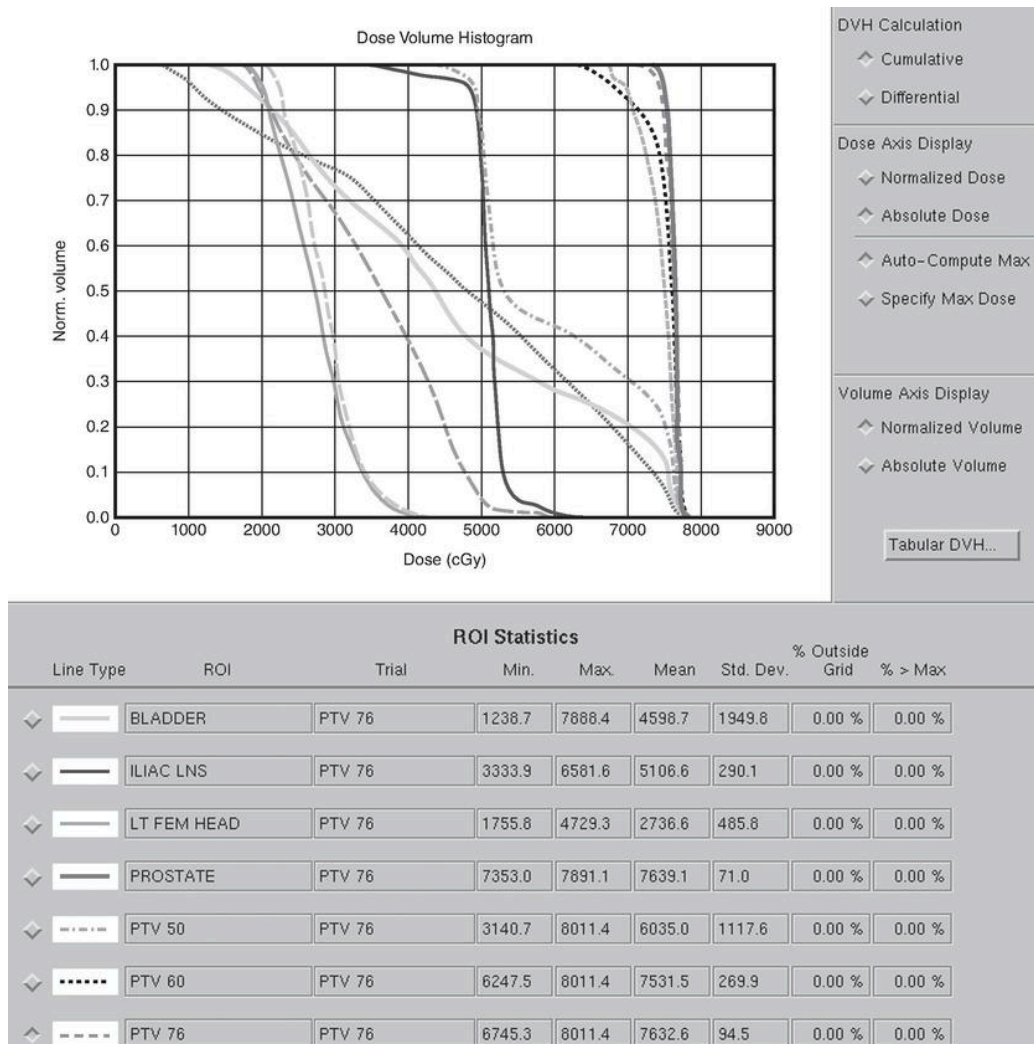


FIG. 6.9 Dose-volume histogram.

Leaf Sequencing

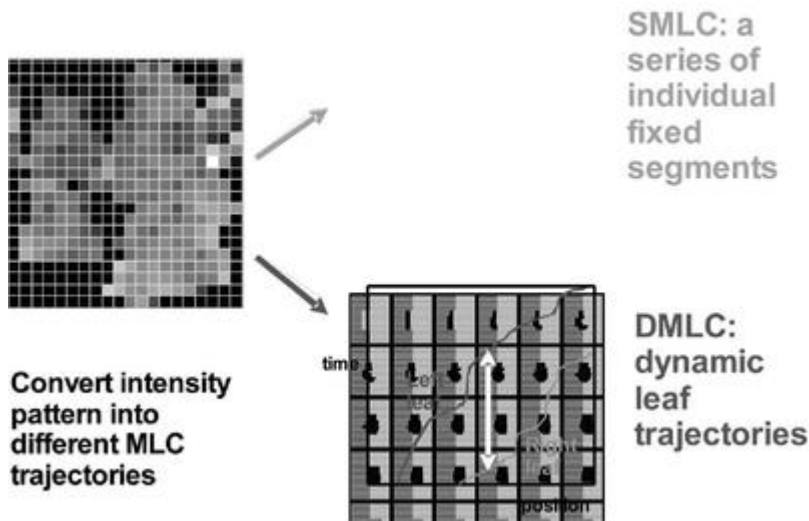


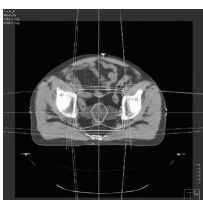
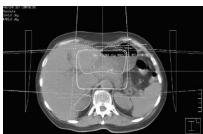
FIG. 6.10 Fluence map.

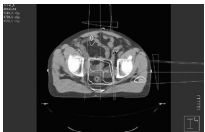
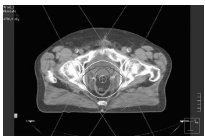
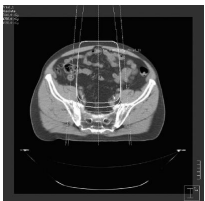
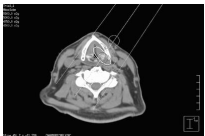
Common Fixed Fields Versus Dynamic Field Arrangements

- Fixed fields are still widely used. Certain fixed field arrangements are appropriate when the optimal dose needs to be delivered to the target and adjacent tissues kept under tolerance (TD 5/5) using simple techniques.
- Dynamic therapy, such as IMRT, rapid arc, and tomotherapy, are most appropriate when a very high dose needs to be delivered to areas in very close proximity to relatively low-tolerance tissues. It attempts to lessen acute side effects and decrease the risk of late effects as compared with conventional, fixed field techniques.
- Tumor localization, localization of adjacent organs, and consideration of tolerance doses aid in determining whether conventional, fixed fields or dynamic fields are appropriate (

Table 6.1).

TABLE 6.1**Common Field Arrangements and Rationale**

Field Arrangement	Features of Dose Distribution	Application
Parallel Opposed Pair 	Assuming homogenous patient contour, even distribution throughout	Centrally located targets with no dose limiting structures in the path such as the whole brain, humerus, femur, breast
4 Field Box 	Concentration of dose near the intersection; sparing of tissues peripherally	Deep-seated targets with dose limiting tissues surrounding such as the prostate, bladder, endometrium
Field With 90-degree Hinge 	Concentration of dose near the intersection; sparing tissues peripherally and especially tissues on either side of the target	Deep targets with dose limiting tissues on one side, such as in treating the pancreas with sensitive kidneys posterior, rectum with sensitive small bowel and bladder anterior

Field Arrangement	Features of Dose Distribution	Application
Field With 90-degree Hinge 	Concentration of dose in or near the hinge; manipulated with modifiers such as wedges	Unilateral targets such as laterally located primary brain tumors, maxillary sinus
Arcs or Multiple Field IMRT 	Concentrated dose toward the center sparing tissues in the periphery	Small, deep targets like the prostate, cervix, pituitary gland with sensitive tissues all around
Single Field Photon 	Dose fall off with increasing depth; sparing tissues beyond the interest point	Targets near the surface such as thoracic spine, upper lumbar spine, superficial supraclavicular lymph nodes
Single Field Electron 	Rapid dose fall off; maximum dose near the surface	Treatment of superficial targets; bolus may be applied to eliminate skin-sparing at the surface

Deviations From the Treatment Plan

- Radiation therapists should be prepared for possible changes in the treatment plan during the course of therapy.
- Deviations without appropriate adjustments can adversely affect the clinical outcome.
- Deviations should be acknowledged and documented, and adjustments made immediately (

[Table 6.2](#)).

TABLE 6.2**Sample Treatment Plan Deviations, Impact, and Adjustments**

Deviation	Possible Impact	Suggested Adjustment(s)
Physician ordered change in field size or MLC position	Target volume, output has changed, absorbed dose is changed	Recalculation of monitor units to comply with prescription
Physician ordered change in dose per fraction or total dose	Absorbed dose is changed	Recalculation of monitor units to comply with prescription
Machine malfunctions and patient treatment incomplete	Absorbed dose is changed	Document actual monitor units given; calculate absorbed dose and adjust for missing dose per physicist
Isocenter is moved, geometric size changed due to new clinical findings	Target volume, absorbed dose is changed	Recalculate monitor units, recontour to include new areas included in field
Patient loses or gains weight or is misaligned	Absorbed dose is changed, position of isocenter is changed	Recontour, remeasure, adjust isocenter placement; monitor unit recalculation may be necessary

Deviation	Possible Impact	Suggested Adjustment(s)
Incorrect field treated	Target volume changed, absorbed dose changed	Replan to document dose to area treated; compensate for missing dose to intended target
Too many fractions treated	Absorbed dose changed; tolerance threshold compromised	Establish and document absorbed dose; find BED, and document
Too few fractions treated	Absorbed dose changed	Establish and document absorbed dose; add fractions if feasible
Missing accessory	Absorbed dose changed; isodose distribution changed	Calculate actual absorbed dose, replan with accessory missing and adjust accessories for the remainder of treatment
Incorrect accessory	Absorbed dose changed; isodose distribution changed	Calculate and replan with incorrect accessory; modify subsequent treatments
Treatment schedule interruption by noncompliance or patient illness	Biologic effect changed	Find BED; adjust fraction size or total dose to complete regimen

Adjacent Fields

- Special care is required when radiation needs to be administered in areas adjacent to each other.
- Computerized treatment planning can produce accurate representations of overlapping, high-dose regions.
- Adjustments to the plan may be made to reduce or eliminate overlapping dose regions.
- Three methods to reduce or eliminate overlapping dose regions are: calculation of surface skin gaps, calculation of beam divergence with implementation of couch kicks or gantry angles, and the use of the half-field technique.

1. Skin gap formula: $\frac{1}{2} A1 \times (d/SSD) + \frac{1}{2} A2 \times (d/SSD)$

A1 and A2 = dimension(s) of the treatment fields along the gap axis
d = depth at which beams will overlap

2. Beam divergence formula: $\tan$

$^{-1} (A/2SSD)$

A = dimension of the treatment field for which divergence is computed

3. The half-field technique uses asymmetric jaws or fabricated Cerrobend blocks to block fields up to the central axis. This allows us the opportunity to take advantage of no divergence at the central axis. When half-field techniques are used, adjacent fields may be directly abutted.
- Special care is required, especially when photon and electron fields are adjacent.

- The electron beam's bell-shaped isodose presents another challenge in attempting to avoid high-dose areas beneath the surface for adjacent fields.
- Computer planning is best to visualize isodose distribution for adjacent electron fields or matched photon and electron fields.
- Physicians may order periodic match line changes/feathering when adjacent fields are treated.

Monitor Unit Calculations

- The physics staff at each oncology center provides calculation tables pertinent to each machine for manual calculations and/or input of data to the treatment planning computer for 3D calculations.

Manual Calculation Parameters

1. Field size factor (FSOF = field size factor $\times$ reference dose rate)
2. Reference dose rate/output/conversion factor (cGy/minute or cGy/MU)
3. Tissue air ratio (TAR)/tissue maximum ration (TMR)
4. Percent depth dose/%DD/depth dose fraction
5. Inverse square factor (ISF)
6. Attenuating factors for block trays (TF), wedges (WF), other compensators
7. Back scatter or peak scatter factor (BSF/PSF)
8. Mayneord F factor
9. Prescribed dose/target dose

For Isocentric (SAD) Setup Techniques

- Target dose $\div$ FSOF $\times$ TMR or TAR $\times$ WF $\times$ TF = Monitor units (MU).

1. Target dose is the amount of dose each field is to receive from the daily total dose.
2. FSOF is the field size output factor derived from the field size at treatment depth.

- a. Use the Sterling formula to calculate equivalent square.

$$2 (\text{field width} \times \text{field length}) \div \text{field width} + \text{field length} = \text{equivalent square.}$$

- b. Using the FSOF tables, find the correct output factor for the given equivalent square.
3. TMR is tissue maximum ratio derived from the effective square cross referenced to treatment depth.
 - a. Effective square is the equivalent square of the unblocked portion of the treatment field.
 - b. Using the TMR tables, find the correct TMR by cross referencing the effective square to treatment depth.
4. TAR is tissue air ratio derived from the effective square cross reference to treatment depth (your center will tell you whether to use TMR or TAR in manual calculations).
5. WF is the wedge factor, also found in the calculation tables.
 - a. WF is dependent on wedge angle, field size, and beam energy.
6. TF is tray factor, which refers to the acrylic tray that supports any blocking that may be required in the field.
 - a. TF is dependent on the type of tray, beam energy, and the number of holes it has.
 - b. If MLC is used, no tray is required. $TF = 1.0$.

For Nonisocentric (SSD) Setup Technique

- SSD treatment techniques were at the genesis of radiation therapy treatment delivery.
 1. Began with source-based teletherapy and bridged into electronic teletherapy.
 2. Unlike isocentric (SAD) treatment techniques, SSD techniques use a setup point on the patient's skin set to that specific unit's designed SSD.
 - a. SSD is usually 100 cm.
 3. The setup point is not isocentric.
 4. For source-based teletherapy units, an output factor is used as a measure of the source activity.
 - a. When using the output factor for dose calculation, the final answer will be in minutes and seconds as opposed to MUs.
 - b. For electronic teletherapy units, the output factor is (1) and the resulting dose calculation is in MUs.
- There are disadvantages to using SSD treatment techniques:
 1. The patient may be moved or repositioned for each gantry angle.
 2. Rotational therapy is not possible.
 3. A slight setup error can result in a potentially more drastic target miss than with SAD techniques.
- There are advantages to using SSD treatment techniques:
 1. More clearance exists between the patient and the gantry head.

2. A larger field size is achievable.
- Instead of using “tissue maximum ratio” in the denominator of the dose calculation, percentage depth dose is used.
- An inverse square factor referencing D_{max}

D_{max} is used in the dose calculation.

- Target dose $\div$ %DD $\times$ FSOF $\times$ BSF $\times$ Inv. Sq. factor $\times$ source output factor $\times$ TF $\times$ WF = Time/MU

1. Percentage depth dose is commonly written as PDD or %DD.

- a. %DD = (dose at depth $\div$ dose at a static reference depth) $\times$ 100
- b. As with TMR, to find %DD, cross-reference treatment depth with effective square.

2. The BSF (backscatter factor) or patient scatter is typically found on the same reference table as %DD.

- a. BSF is referenced by effective square.

3. FSOF (field size output factor) considers scatter from the collimation system.

- a. Equivalent square is used to reference FSOF.

4. An inverse square factor is often incorporated into the formula to compensate for depth of D_{max} . [(SSD

$_1 + D_{max}) \div (SSD$

$_2 + D_{max})]$

2

5. If using a source-based treatment unit, use the appropriate source output factor.

- For an extended distance, a few factors must be considered.

1. The %DD is based on the field size at the new distance.
2. Inverse square
3. Mayneord F factor must be used in the denominator of the calculation.

$$F = \left(\frac{SSD_2 + d_{max}}{SSD_1 + d_{max}} \right)^2 \times \left(\frac{SSD_1 + d}{SSD_2 + d} \right)^2$$

Keep in Mind —Manual calculations may be required for emergency radiation therapy or clinical treatment setups where there is limited time for computer planning.

SAD Photon Calculation

A physician prescribes 300 cGy/fraction for two parallel-opposed beams to the 97% isodose line, 7.5 cm depth, 20 × 20 field size, 100 cm SAD, with 50/50 beam weighting.

Calculate the monitor units for each lateral field.

Tip: SAD photon MU calculation nomenclature may vary depending on textbook or department but the concept of the factors remains the same.

Set up the calculation with the formula below where D

_{ref} = calibration reference dose (cGy/MU), Sc = collimator scatter factor, Sp = phantom scatter factor, TMR = tissue maximum ratio, IDL = isodose line, ISF = inverse square factor, OAR = off-axis ratio, WF = wedge factor, TF = tray factor. For this problem, there is no OAR, WF, or TF.

$$\frac{\text{DOSE (cGy)}}{(\text{Dref})(\text{Sc})(\text{Sp})(\text{TMR})(\text{IDL})(\text{ISF})(\text{OAR})(\text{WF})(\text{TF})} = \text{MU}$$

$$\frac{300 \times 50\%}{(1.0)(1.026)(1.023)(0.871)(0.97)\left(\frac{101.5}{100}\right)^2} = \mathbf{164 \text{ MU/field}}$$

SSD Electron Calculation

A physician prescribes 200 cGy/fraction to Dmax at the 90% isodose line, 6e, 0.5-cm bolus, 6 × 6 cone (0.966), 2.0-cm circle cutout (0.757), 100-cm source-to-bolus distance, 100.5-cm source-to-skin distance.

Calculate the monitor units for each treatment delivery .

Tip: Electron MU calculations are based on six different possible modifiers: cone size, cutout with cone size, normalization or prescribed isodose line, PDD, inverse square factor (based on treatment SSD), and total prescribed dose.

Set up the calculation with the formula below where CF = cone factor, COF = cutout factor, IDL = isodose line, PDD = percent depth dose, and ISF = inverse square factor:

$$\frac{\text{DOSE (cGy)}}{(\text{CF})(\text{COF})(\text{IDL})(\text{PDD})(\text{ISF})} = \text{MU}$$

$$\frac{200}{(0.966)(0.757)(0.9)(1.0)(1.0)} = \mathbf{304}$$

Extended SSD Photon Calculation

A typical SSD calculation formula is seen below where Dref = calibration reference dose (cGy/MU), Sc = collimator scatter factor, Sp = phantom scatter factor, PDD = percent depth dose, IDL = isodose line, ISF = inverse square factor, OAR = off-axis ratio, WF = wedge factor, TF = tray factor.

Tip: SSD photon MU calculation nomenclature may vary depending on textbook or department but the concept of the factors remains the same.

$$\frac{\text{DOSE (cGy)}}{(\text{Dref})(\text{Sc})(\text{Sp})(\text{PDD})(\text{IDL})(\text{ISF})(\text{OAR})(\text{WF})(\text{TF})} = \text{MU}$$

However, at an extended SSD, the

Mayneord F Factor is calculated to accommodate for the PDD change as the SSD changes and is based on strict application of the inverse square law. This is a special application of inverse square

that is rarely used in clinical practice. This factor is multiplied by the old PDD for the new PDD in the MU calculation.

$$F = \left(\frac{SSD_2 + d_{max}}{SSD_1 + d_{max}} \right)^2 \left(\frac{SSD_1 + d}{SSD_2 + d} \right)^2$$

The PDD at a depth of 10 cm for a 10×10 cm

² 6-MV beam at 100-cm SSD is 67.0%. Using the Mayneord F factor and reference depth of 1.5 cm,

what is the PDD for the same field size and depth at 120-cm SSD ?

$$F = \left(\frac{120 + 1.5}{100 + 1.5} \right)^2 \times \left(\frac{100 + 10}{120 + 10} \right)^2 = \mathbf{1.026}$$

$$(1.026) \times (0.67 \text{ old PDD}) = \mathbf{0.6874} \text{ (68.7\%)}$$

When treatments are delivered at a different SSD than the standard reference SSD (e.g., 100 cm for most linear accelerators), a correction needs to be made to adjust for the change in intensity of the radiation. The inverse square factor is calculated to correct for that change.

$$\left(\frac{l_1}{l_2}\right) \times \left[\frac{d_2}{d_1}\right]^2$$

For example, if the dose delivered at 100 cm is 100 cGy, what is the dose at 115 cm (only distance changes)?

$$\left(\frac{100 \text{ cGy}}{l_2}\right) \times \left[\frac{115 \text{ cm}}{100 \text{ cm}}\right]^2 = \mathbf{76 \text{ cGy}}$$

Brachytherapy treatment planning

- Brachytherapy is a radiation therapy delivery system in which radioactive sources are placed on or near the intended target.
- A higher dose can be delivered to the target area while significantly reducing exposure to the surrounding tissues.
- Radioactive sources used in brachytherapy may be applied for seconds, hours, days, or permanently—depending on the type of cancer, its location, and the half-life of the radioactive isotope.
- Areas of common usage are the mouth, tongue, prostate, brain, uterus, bronchus, and vagina.
- There are three general categories of brachytherapy: HDR, LDR, and MDR.
 - HDR (high dose rate) uses an isotope that delivers a dose rate equal to 20 cGy/min.
 - LDR (low dose rate) uses an isotope that delivers a dose rate 0.5 to 2.0 cGy/min.
 - MDR (medium dose rate) is anywhere between 2.0 cGy/minute and 20 cGy/min.

- Therapeutic isotopes can be naturally occurring or artificially made.
- Artificial isotopes tend to have higher gamma energies and shorter half-lives.
- The common types of radioactive decay are:

-

Alpha decay —occurs in elements that have atomic numbers greater than 82 in which a pair of protons and a pair of neutrons are emitted. Consists of two neutrons: a helium nucleus.

-

Beta decay —where a positive or a negative electron from the nucleus is given off. Can be called a positron or a negatron.

-

Electron capture —where an orbital electron is taken in by the nucleus and changes a proton into a neutron and, in turn, the nucleus emits a beta particle.

-

Internal conversion —where the energy within the nucleus is great enough to be passed on to one of the orbital electrons and is then ejected from the atom.

- Common radioactive isotopes used are cobalt, cesium, palladium, gold, iridium, iodine, phosphorus, ytterbium, and strontium.
- With few exceptions, most radioactive isotopes for therapeutic use are sealed in a double layer of steel or similar metal and referred to as sources.
- The double layering of metal on a radioactive source is to ensure containment of the isotope and to filter out low energy alpha and

beta particles.

- The source sizes vary depending on the treatment location and the type of applicator that is available.
- Gynecologic brachytherapy procedures can use many types of source applicators, but the most commonly used are tandems and ovoids; they are referred to as a Fletcher suite when used together.
- A tandem is a long tube placed into the uterus, containing a source such as cesium-137 for LDR therapy or a 10-Ci iridium source for HDR therapy.
- Ovoids are devices used in pairs and placed side by side in the distal vagina for treatment of the vagina and/or cervix. They typically require one cesium-137 source each for LDR or a 10-Ci iridium source for HDR.
- Afterloading is the practice of installing an applicator into the patient first and then loading the sources at a later time.
- Afterloading allows time to verify appliance placement and/or create a treatment plan. Excess dose to personnel is also avoided.
- Remote afterloaders further reduce exposure to personnel.
- Sources can be placed into tumors with long needles referred to as trocars.
- Sources can be imbedded into plastic ribbon to maintain a specific spacing and placed into tumors using trocars.
- Noninvasive prostate gland tumors are commonly treated with small sources placed by trocars via a template.
- Single plane implants are used for narrow target volumes.
- Double plane implants are used for larger target volumes.
- Volume implants are implants that require more than two planes.
- To determine the type of isotope to use, one must consider the following:
 - a. Activity
 - b. Energy
 - c. Half-life
 - d. Shielding
 - e. Capsular attenuation
 - f. Exposure rate

- To find exposure rate from a single source, divide activity in mCi by the distance of the point of interest squared. Then multiply by the exposure rate constant for the particular isotope used.

$$\frac{\text{Activity (mCi)}}{D^2 \times \text{Exposure Rate Constant}}$$

- Most brachytherapy treatments are planned on treatment planning computers with 3D capabilities.
- Before treatment planning computers, several systems used to calculate dose and dose distribution to the irradiated volume were devised, such as:

1. Patterson-Parker or Manchester system

- a. Uses a nonuniform source distribution to give a uniform dose distribution. Gynecologic implants using tandems and ovoids (

[Figure 6.11](#)) commonly use this system to calculate the dose to a point “A.”

2. Quimby system. Uses a uniform source distribution that yields a nonuniform dose distribution, with the highest dose usually in the center of the implant.

3. Memorial system

- a. A version of the Quimby system.
- b. Is described in Khan as a complete dose distribution around a lattice of point sources of uniform strength spaced 1.0 cm apart.

4. Paris system

- a. Used for line sources, such as plastic ribbon with imbedded Ir

^{192}Ir or I

^{125}I

- Types of implants include:
 1. Intracavitary such as a uterus implant
 2. Interstitial such as a prostate implant
 3. Intraluminal such as a bronchial implant or accelerated partial breast brachytherapy using the MammoSite system, for example
- Before planning an implant, the patient usually has an orthogonal set of films taken that are used as a planning database.
- Prostate implants are preplanned using an ultrasound database.

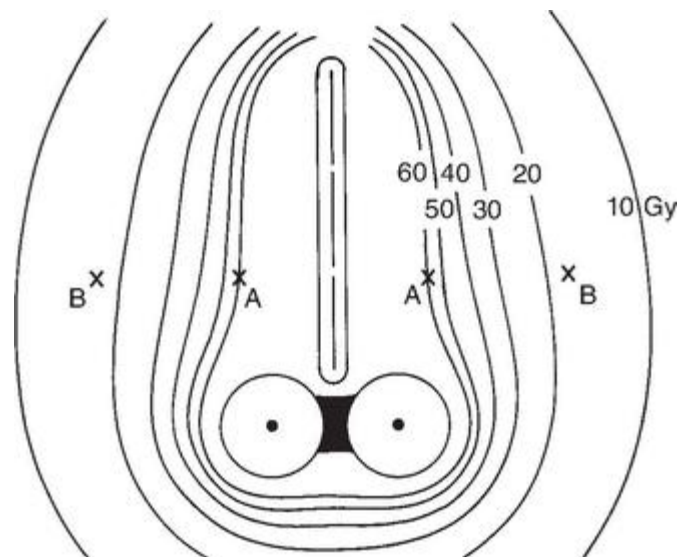


FIG. 6.11 Points A and B for gynecologic brachytherapy.

Review Exercises

1. The removable grids used in linear accelerators to broadcast crosshairs onto a portal image are referred to as all of the following except:
 - a. BB tray
 - b. grating
 - c. fiducial tray
 - d. graticule
2. Source axis distance (SAD) is measured from the _____ to a(n) _____ around which the gantry rotates 360 degrees. Choose the correct answers from the following list:

Image intensifier	Thetatron	Point
Table top	Electron gun	Isodose line
Modulator	Focal spot	Gantry

3. The most commonly used axial image database for a 3D treatment planning computer is:
 - a. MRI
 - b. PET
 - c. CT
 - d. US
4. Which of the aforementioned modalities can be used as a fusion study?
 - a. None
 - b. b, c, d
 - c. a, b, c
 - d. All of them
5. The XYZ coordinate system works well when localizing a target volume.

True False

If false, correct the statement to make it true.
6. Thinner CT slices

↑ or

↓ resolution of digitally reconstructed radiographs.

Circle the correct answer.

7. List three things that help set up reproducibility.
8. The contour of a CT simulator tabletop should look like this.

Choose the correct answer.

- a. —
b. |
c. ∩

9. Patient marks can be effectively applied by all of the following except:
- a. Tattoo
 - b. Ballpoint pen
 - c. Felt pen
 - d. Paint pen
 - e. Carfusion
10. IMRT is a sophisticated method of radiation delivery to a target area and does not require port film verification.

TrueFalse

If false, correct the statement to make it true.

11.

Fill in the blank . For treatments in the chest, head, and neck regions, _____ straightens the lordotic curvature of the spine, making the patient more comfortable during the treatment.

12. A good method for breast immobilization that often affords the best daily reproducibility is:

- a. A plastic cup with straps
- b. Nylon bra
- c. Aquaplast cast
- d. Nothing

13. For nonisocentric treatment techniques, _____ is the factor of choice to demonstrate central axis dose at a given depth.

- a. TMR
- b. TPR
- c. TAR
- d. %DD

14. When looking up the %DD or TMR for a given depth and field size, _____ should be used when there are blocks or MLC.

- a. Equivalent square
- b. Effective square

15. Mayneord F factor is the formula used to find the equivalent square for a given field size.

True False

If false, correct the statement to make it true.

16. List the pros and cons of SSD setup techniques.

17. List the advantages SAD setup techniques have over SSD setup techniques.

18. What invention allowed IMRT to become a reality?

- a. Cerrobend

- b. %DD
- c. Tomotherapy
- d. MLC
- e. CT

19. The Sterling formula is a method to determine:

- a. Extended distance
- b. Equivalent square
- c. Skin gap
- d. Inverse square
- e. Dmax
- f. Penumbra

20. When an extended distance is required for a nonisocentric treatment technique, what changes and additions are needed in the calculation?

More than one answer is correct.

- a. Include Mayneord F factor in the denominator.
- b. Change inverse square to reflect new SSD.
- c. Find new %DD for field size at a new distance.
- d. Change FSOF for different Sc.

21. Explain how the treatment planner can see the patient marks when viewing the axial images on the treatment planning computer.

22. Which of the following is not an advantage of using a multifield approach?

- a. Minimizes side effects
- b. Increases integral dose
- c. Reduces a potentially high dose in any single area
- d. Provides more homogeneous dose distribution around the target

23. Choosing the proper x-ray energy is critical for optimizing a treatment. Associate the following treatment areas with the most probable beam energy used. Write 6 MV or 18 MV behind each area.

Lung tumor _____
Nasopharynx _____
Prostate _____
Cervix _____
Pancreas _____
Breast _____
Upper arm sarcoma _____

24.

Circle the correct answer . Field size determinations should be done (dosimetrically/geometrically).

25. When choosing gantry angles, which of the following is not a valid consideration?

- a. Avoidance of dose limiting organs
- b. Angles that expedite treatment time
- c. Unexecutable gantry positions
- d. Too many beams
- e. Symmetrical arrangements

26. Dmax is defined as:

(More than one answer is correct.)

- a. Skin to isocenter distance
- b. Depth in which 20% of dose is absorbed
- c. Point of peak dose in an irradiated medium
- d. Depth where electronic equilibrium occurs
- e. Area of maximum penumbra

27. Label the following descriptions as either GTV, CTV, or PTV.

- A volume with typically a 0.5-cm margin to allow for patient movement and/or setup error. _____
- Tumor volume encompassing visible tumor as seen on a diagnostic study or simulation images. _____

- A volume with a variable margin of 1.5 to 2.5 cm that includes any suspected or unseen disease. _____

28. Standard wedges can have a beam hardening effect when the radiation is monoenergetic.

True False

If false, what is the correct answer?

29. Name the two primary reasons for a bolus to be used.

30. TD 5/5 means:

- a. 5% chance of complications at 50 cGy.
- b. 5% chance of complications at 5 Gy.
- c. 5 of every 5 patients will experience complications.
- d. 5% chance of complications in 5 years.

Using [Figure 6.12](#) , answer questions 31 and 32.

31. GTV is located at 10-cm depth. A dose of 100 cGy is delivered to the GTV using 4-MV single anterior photon beam. The bladder is at 7 cm deep. Assuming SSD technique, which of the following is true?

Circle all that are correct .

- a. Rectum will get more than 100 cGy
 - b. Bladder will get more than 100 cGy
 - c. Rectum will get less than 100 cGy
 - d. Bladder will get less than 100 cGy
 - e. All of the above are correct
32. If 10-MV photons were used to treat the above tumor to 100 cGy, then compared to 4-MV beam treatment plan, which of the following would be true if all other factors remain the same?

Circle all that are correct.

- a. Rectum will get higher dose
 - b. Bladder will get higher dose
 - c. Rectum will get lower dose
 - d. Bladder will get lower dose
 - e. There would be no difference in rectum or bladder dose
33. A high energy x-ray beam is incident on the surface of water in a water tank. Indicate which one of the following statements is correct.
- a. Maximum dose is at the water surface
 - b. Maximum dose is at a depth dependent on the x-ray energy
 - c. Maximum dose is always at a fixed depth, independent of x-ray energy
 - d. Dose increases with depth beyond the depth of maximum dose
34. Concerning 6-MV and 18-MV x-ray beams:
- The depth of maximum dose for _____ MV is 1.5 cm; and depth of maximum dose for _____ MV is 3.5 cm. At 10-cm depth, the _____ MV beam will have a greater percent depth dose.
35. A deep-seated tumor is treated posteriorly with a high-energy photon beam. The tumor is at 13 cm depth and the percent depth dose is 65%. The spinal cord is in the field and is at 5 cm depth. Percent depth dose at the spinal cord is 85%. If 200 cGy is delivered to the tumor, the calculated dose to the spinal cord would be:
36. A patient is delivered a dose of 150 cGy at a depth of 13 cm with 10 MV photons at 100 cm SSD. The percent depth dose is 60%. Calculate the dose delivered to the depth of maximum dose.
37. The energy loss of megavoltage electron beams in water is approximately _____ MeV per centimeter.
38. Electron arc therapy has what effect on the D

max position, as compared with a stationary electron field of the same energy?

a. Moves D

max toward the surface

b. Does not move D

max position

c. Moves D

max away from the surface

39. What two purposes do the metallic sheaths surrounding radioactive isotopes serve?

Label the following implant types as interstitial, intracavitary, or intraluminal

40. A prostate seed implant _____

41. An accelerated partial breast treatment such as MammoSite

42. Au 198 seeds imbedded into the tongue _____

43. When more than two planes of sources are used, it would be called a:

a. Stereo implant

b. Single-plane implant

c. Orthogonal

d. Volume implant

44. Demonstrate the generic formula for calculating an exposure at a specific distance for a particular isotope.

45. Match the following brachytherapy system with its distinguishing feature.

___Patterson-Parker/Manchester

___Quimby

___Memorial

___Paris

- a. Sources of uniform strength spaced 1.0 cm apart
 - b. Uniform source distribution with nonuniform dose distribution
 - c. Often used for calculating line sources
 - d. nonuniform source distribution with uniform dose distribution
46. When planning a GYN implant, which point is dose calculated to?
- a. W
 - b. A
 - c. J
 - d. F

Fill in the blanks in questions 47 to 49.

47. Alpha particles are similar to the _____ (element) nucleus?
It has a _____ charge.
48. When an element has an excessive number of neutrons, in order to achieve stability, it is likely to experience _____ emission.
49. The radioactive decay process that results in the ejection of a positive or negative electron would be referred to as _____ decay.
50. Considering the weight/size and charge of alpha, beta, and gamma particles, what simple device could be used to separate them?
51. List five of the most commonly used brachytherapy isotopes.

52. Prostate implants are preplanned on a treatment planning computer using a/an_____ database.
- a. MRI
 - b. CT
 - c. Ultrasound
 - d. PET
53. HDR isotopes deliver at a dose rate = _____ cGy/minute.
54. LDR isotopes deliver at a dose rate between _____ and _____ cGy/minute.
55. If the physician changes the field size after the treatment plan has been approved, the therapist should:
- a. Record the new field size and follow the plan as approved
 - b. Record the new field size and submit the change to physics for new calculation
 - c. Reduce the monitor units by 1 if the field size has increased by 1 cm
 - d. Increase the monitor units by 1 if the field size has increased by 1 cm
56. Once it has been discovered that too many fractions have been delivered to the preliminary treatment fields, the therapist should:
- a. Document the error and submit it to physics for necessary adjustments
 - b. Document the error and give less fractions to the boost fields
 - c. Document the error and continue the plan as approved to total dose
 - d. Document the error and skip the boost fields
57. Late Friday afternoon, the physician orders treatment to the whole brain for a recent consult. After field size, collimator and gantry angles have been determined. The next step would be to:
- a. Split the prescribed fraction dose in half and administer equivalent monitor units

- b. Split the prescribed total dose in half and administer equivalent monitor units
 - c. Acquire patient separation data, refer to written prescription, and calculate monitor units
 - d. Acquire the patient separation data and administer monitor units from another whole brain patient chart
58. Your patient has been hospitalized for blood transfusion and infection and has missed three consecutive weeks of treatment. Upon the patient's return, the therapist should:
- a. Relocalize the treatment area, remark the patient, and resume treatment
 - b. Remeasure, relocalize, remark, and resume treatment
 - c. Remeasure, relocalize, remark, and ask for BED adjustments in fraction size or total dose
 - d. Remeasure, relocalize, remark, and ask for OER for adjustments in fraction size or total dose
59. The wedge angle is determined by the tilt of the isodose lines at (select two):
- a. The 50% isodose line in low-energy beams
 - b. A depth of 10 cm for high-energy beams
 - c. The depth of the 20% isodose line in high-energy beams
 - d. The depth of 5 cm for low-energy beams
60. A spinal cord compression at the level of T5-T6 is being treated emergently. The most likely field arrangement would be:
- a. Two parallel opposed lateral fields
 - b. Two parallel opposed AP/PA fields
 - c. A single posterior electron field
 - d. A single posterior low-energy photon field
61. The entire right breast will be treated in your patient diagnosed with T1 N1 M0 infiltrating ductal carcinoma. The most likely field arrangement would be:
- a. Tangential fields with subsequent tumor bed boost

- b. Tangential fields with internal mammary and supraclavicular fields
 - c. Parallel opposed AP/PA fields with spinal cord blocked
 - d. Single field electron field to the entire breast with bolus
62. A primary brain tumor located in the right temporal lobe will likely be treated with:
- a. Two parallel opposed equally weighted photon beams
 - b. A wedged pair consisting of anterior and RPO fields
 - c. A wedged pair consisting of vertex and right lateral fields
 - d. Four field box technique with wedges on the lateral fields
63. Beam modifiers such as wedges would most likely be used in a treatment plan for:
- a. Metastatic bone lesion in the femur
 - b. Primary cancerous lesion in the rectum
 - c. Metastatic bone lesion in the cervical spine
 - d. Primary cancerous lesion in the prostate

64. Use the DVH for analysis (

[Figure 6.13](#)). Does the DVH meet the requirements of the treatment planning directive

20% of the left lung is permitted to receive <40 Gy ?

- a. Yes
 - b. No
65. Shoulder retractors are feasible for positioning and immobilization when treating the:
- a. Lung
 - b. Whole brain
 - c. Thoracic spine
 - d. Neck

66. The optimal hinge angle for a 45-degree wedged pair is:

- a. 30 degrees
 - b. 45 degrees
 - c. 60 degrees
 - d. 90 degrees
67. The angle between two beams is known as the:
- a. Arc angle
 - b. Hinge angle
 - c. Wedge angle
 - d. Divergent angle
68. A suitable wedge angle for two fields separated by 90 degrees is:
- a. 30 degrees
 - b. 45 degrees
 - c. 60 degrees
 - d. 90 degrees
69. What is the equivalent square for a 15×6 field?
- a. 9.5×9.5
 - b. 8.6×8.6
 - c. 10×10
 - d. 2.1×2.1
70. An entire spine is treated by matching two fields both treated at 100 cm SSD. Field number 1 measures 8×20 and field number 2 measures 8×25 . To match these fields at a depth of 5 cm, a _____ cm skin gap would be required.
- a. 1.1
 - b. 2.0
 - c. 5.0
 - d. 3.2

Refer to the plan data sheet ([Figure 6.8](#)) to answer questions 71 to 74.

71. The reference field size for the AP field is:

- a. 7.2×9.8 cm
- b. 9.2×7.8 cm
- c. 8.0×9.0 cm
- d. 9.0×8.0 cm

72. The gantry angle for the LPO treatment field should be:

- a. 100 degrees
- b. 84 degrees
- c. 50 degrees
- d. 87.6 degrees

73. Assuming the patient is positioned supine with the head into the gantry, referencing an axial image view, the shift from the original planning isocenter should be:

- a. 1.0 cm to the patient's right
- b. 1.0 cm to the patient's left
- c. 2.0 cm to the patient's right
- d. 2.0 cm to the patient's left

74. Assuming the patient is positioned supine with the head into the gantry, referencing a sagittal image view, the shift from the original planning isocenter should be:

- a. 2.0 cm cephalad
- b. 2.0 cm caudal
- c. 2.0 cm anterior
- d. 2.0 cm posterior

75. Prescription for boost dose to a soft tissue sarcoma tumor bed at a depth of 5 cm reads: 200 cGy/fraction to the 90% dose line. The appropriate electron energy for this case would be:

- a. 10 MeV
- b. 15 MeV
- c. 20 MeV
- d. 25 MeV

76. A patient is treated with an isocentric AP/PA setup on a linear accelerator. The anterior SSD is 86 cm and the posterior SSD is 92

cm. The patient's AP/PA separation is _____.

- a. 14 cm
- b. 16 cm
- c. 22 cm
- d. 28 cm

77. The field size is set to 16×16 cm

² on the 100-cm SAD linear accelerator. What is the field size measured on the patient surface at 130-cm SSD?

- a. 12.3×12.3 cm

²

- b. 16.1×16.1 cm

²

- c. 20.8×20.8 cm

²

- d. 23.2×23.2 cm

²

- e. 29.6×29.6 cm

²

78. A linear accelerator is calibrated to 1.00 cG/MU to Dmax for a 10×10 cm

² field at 100 cm SSD. How many MUs are needed to deliver 200 cGy to depth if the PDD is 50% for a 10×10 cm

^{2} field at 100 cm SSD?

- a. 100 MU
- b. 200 MU
- c. 400 MU
- d. 600 MU
- e. 800 MU

79. A patient is being treated to a dose of 10 Gy to 10 cm depth with a 6 MV posterior SAD photon beam. The spinal cord is located superior to the target area at 4 cm depth. The TMRs are 0.770 and 0.946 for 10 cm and 4 cm, respectively. What is the dose to the spinal cord?

- a. 8.0 Gy
- b. 10.8 Gy
- c. 12.2 Gy
- d. 13.9 Gy

80. A DVH will be inaccurate if the underlying structure's contours _____.

- a. Are missing slices
- b. Contain stray pixels
- c. Only segment the portion of the structure in the treated area
- d. All of the above
- e. None of the above

81. Calculate the MU per beam required to deliver 250 cGy to isocenter, located at midplane depth of 10 cm from equally weighted parallel-opposed 6 MV beams. The jaw setting is 14×14 cm

^{2} blocked to an 8×8 cm

^{2} equivalent field size with MLC. Reference output 1.0 cGy/MU, D

$_{\max}$, 100 cm SAD, 10×10 cm

² open field. Use

Table 6.3 .

- a. 136
- b. 154
- c. 163
- d. 308
- e. 326

82. The Mayneord F factor accounts for a change in PDD with a changing SSD based on an application of _____.

- a. Electron contamination
- b. Inverse square law
- c. Scattering
- d. Attenuation
- e. All of the above

83. Using a single electron beam, a prescription is written for 3 Gy/fraction to the 75% isodose level, relative to D

max _____ is the dose per fraction to D

max •

- a. 3.00 Gy
- b. 3.25 Gy
- c. 3.47 Gy
- d. 3.75 Gy
- e. 4.00 Gy

84. Compared to CT imaging, which of the following is NOT an advantage of MRI?

- a. MRI produces no ionizing radiation
- b. MRI produces better imaging of soft tissue tumors
- c. MRI produces image acquisition in axial, sagittal, coronal, and oblique planes

- d. MRI-based IGRT can provide real-time monitoring of radiotherapy
 - e. MRI has the ability to image calcifications
85. The advantage of gated radiotherapy for lung treatment is _____.
- a. Reduced treatment time
 - b. Reduced tumor motion
 - c. Improved target dose coverage
 - d. Reduced treatment margin
 - e. None of the above
86. Anatomically, the pancreas is positioned in the c-loop of the duodenum and _____ to the liver.
- a. Superior
 - b. Anterior
 - c. Inferior
 - d. None of the above
87. A head-first supine patient is to be treated with a small field centered on T3. During setup, imaging reveals that the isocenter is presently in the middle of T4. The radiation therapist must move the couch _____.
- a. Toward the ceiling
 - b. Toward the floor
 - c. Toward the gantry
 - d. Away from the gantry
88. A PTV D95 of 60 Gy means that _____% of the PTV receives _____ Gy.
- a. 60; at most 95
 - b. 60; at least 95
 - c. 95, at most 60
 - d. 95; exactly 60
 - e. 95; at least 60
89. The _____ would cease to function properly if a small volume received dose in excess of its tolerance.

- a. Parotid
- b. Kidney
- c. Lung
- d. Optic nerve
- e. Liver

90. Match the following definitions with the appropriate term:

- a. Gross demonstrable extent and location of tumor
- b. CTV + ITV + setup margin
- c. Internal margin added to CTV to compensate for internal physiological movements
- d. Represents true extent and location of tumor
- e. Added margin to target volume to allow for limitations of treatment technique

___TV (treated volume)

___ITV (internal target volume)

___PTV (planning target volume)

___GTV (gross tumor volume)

___CTV (clinical target volume)

91. Using the DVH (

[Figure 6.14](#)) for analysis, which of the following statements is

not correct?

- a. 20% of the esophagus received <2000 cGy

- b. 40% of the heart received <1000 cGy
- c. 25% of the A_LAD received >4500 cGy
- d. 65% of the trachea received 1000 cGy

92. Anatomically, the prostate is positioned _____ to the bladder and _____ to the rectum.

- a. Inferior; Anterior
- b. Inferior; Posterior
- c. Superior; Anterior
- d. Superior; Posterior

93. Match the anatomical contours (

Figure 6.15).

- a. _____
- b. _____
- c. _____
- d. _____
- e. _____

Choices:

- Kidney
- Spinal canal
- Bowel
- Aorta
- Liver

94. Match the anatomical contours (

Figure 6.16).

- a. _____
- b. _____
- c. _____
- d. _____
- e. _____

Choices:

- Rectum
- Femoral head
- Seminal vesicles
- Bladder
- Prostate

95. A patient is treated with an 8×15 cm field at 80 cm SSD to a depth of 5 cm using a 6-MV linear accelerator. The PDD at 5 cm for a 10.5 equivalent square field size is 61%. If the distance is extended to 100 cm SSD, what is the new PDD?
- a. 60%
 - b. 44%
 - c. 62%
 - d. 56%
 - e. 68%
96. The best electron energy to treat a target that is between 1.5 cm and 2.5 cm below the surface while sparing other tissue is ____.
- a. 6 MeV
 - b. 9 MeV
 - c. 12 MeV
 - d. 15 MeV
 - e. 20 MeV
97. A 4D CT simulation is most useful for treatment planning of tumors location near the ____.
- a. Brain
 - b. Neck
 - c. Diaphragm
 - d. Pelvis
 - e. Extremities
98. When the image fusion of a diagnostic PET/CT and a simulation CT is performed, which scans should be registered to each other?

- a. Sim CT to CT from the diagnostic PET/CT
 - b. Sim CT to PET from the diagnostic PET/CT
 - c. CT from the diagnostic PET/CT to PET from the diagnostic PET/CT
 - d. All of the above
 - e. This type of registration is not possible
99. The objective function in IMRT optimization determines the ____.
- a. Beam energy
 - b. VMAT arc length
 - c. PTV
 - d. Beam fluence
 - e. All of the above
100. The benefit of an IMRT plan over a conventional 3D plan is ____.
- a. Less patient-specific QA is needed
 - b. Less linac QA is needed
 - c. There is less linac head leakage
 - d. It is faster to deliver
 - e. It has improved conformity

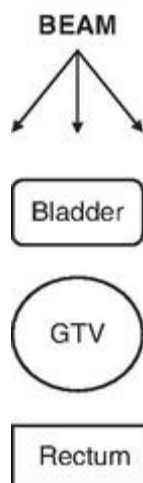


FIG. 6.12 Primary beam incident on a GTV.

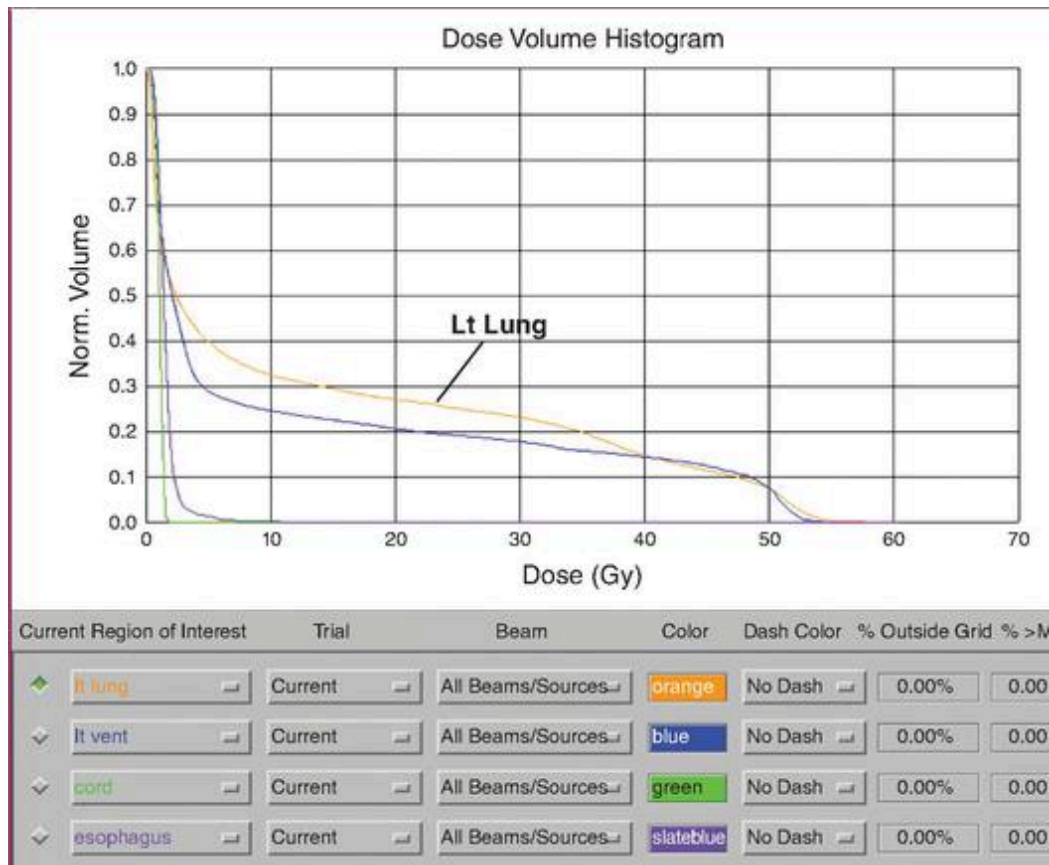


FIG. 6.13 DVH analysis.

TABLE 6.3

Scatter Factors and TMR values

	8 × 8 cm	14 × 14 cm
	2	2
S _c :	0.991	1.014
S _p :	0.993	1.012
TMR (d=5)	0.916	0.928
TMR (d=10)	0.761	0.792
TMR (d=20)	0.502	0.542

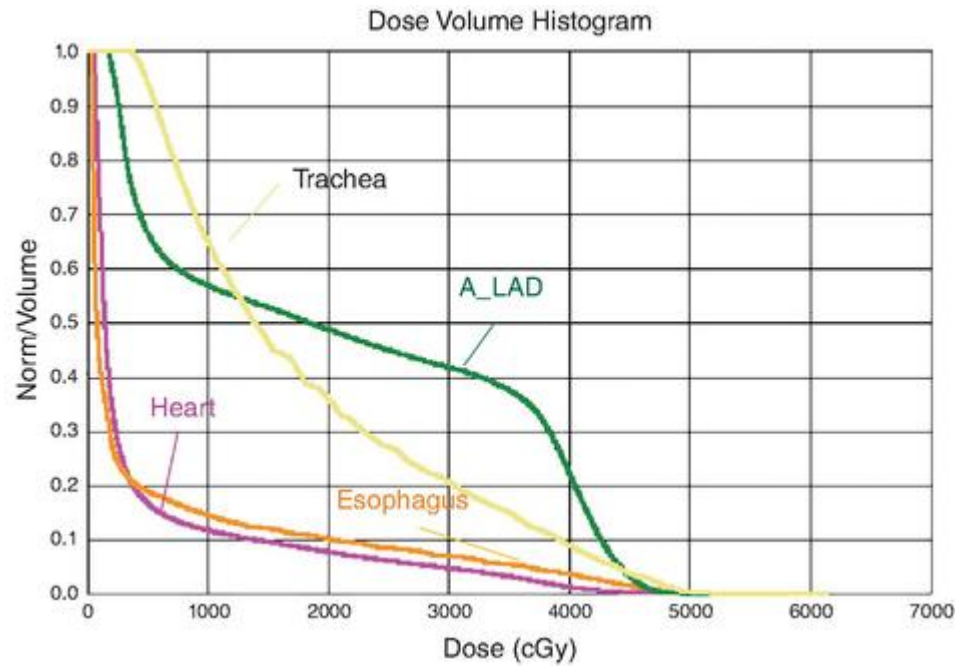


FIG. 6.14 DVH analysis.

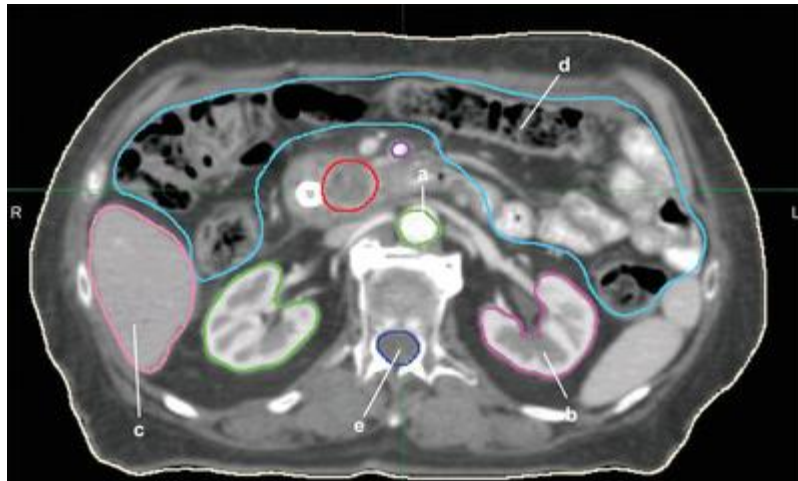


FIG. 6.15 Abdomen CT image.

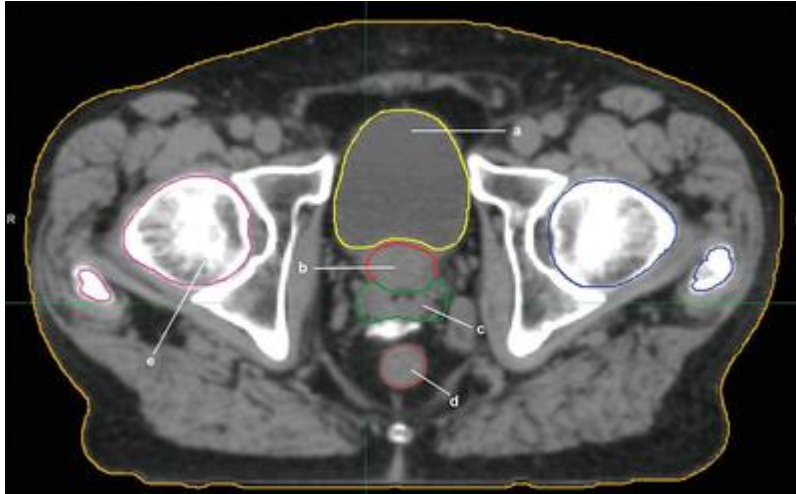


FIG. 6.16 Pelvis CT image.

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CHAPTER 7

Oncology Patient Care

Delores J Whiteing

Focus Questions

- What are the principles of body mechanics, patient transportation, and assistance methods needed to provide for the comfort and safety of the patient?
- What are the principles of patient rights and informed consent?
- How are the principles of medical ethics supported by the law?
- Define the principles of asepsis—surgical and medical.
- What procedures and methods constitute standard precautions?
- List the drugs commonly used in radiation oncology.
- Differentiate between disinfection and sterilization.
- List the rates of temperature, pulse, respiration, and blood pressure that are considered to be within normal limits for an adult.
- What are some potential hazards when administering oxygen?
- List the symptoms of anaphylactic shock.
- Define the five rights of drug administration.
- Explain effective patient education regarding radiation and chemotherapy-related side effects.
- List the factors needed to communicate infectious disease.
- Define the category-specific methods of isolation.
- Demonstrate the correct method of entering and leaving an isolation unit using strict isolation technique.
- What are the appropriate procedures for handling common medical emergencies such as cardiac arrest, respiratory distress and arrest,

stroke, seizure, anaphylactic shock, and syncope?

Ethical and Legal Aspects

- Law and ethics are inseparable.
- Ethics include character, customs, or manners; ethics are what society defines as mannerable and depends on its mores or values.
- Mores are unwritten and accepted laws and values are those things regarded as good and desirable and can be learned from parents and others; both help us decide what's right or wrong.
- What we perceive as ethical is influenced by our personal mores and values.
- Medical ethics and health law have been born out of society's accepted customs, character, and things it presently regards as good.
- There are seven ethical principles that shape how we behave and problem-solve in the medical community. The principles are:
 - Beneficence—always act for the good of another/patient.
 - Nonmaleficence—avoid harm to another
 - Autonomy—ability to make independent decisions
 - Justice—what's considered fair
 - Veracity—tell the truth
 - Role fidelity—operate in your scope; be true to your role
 - Confidentiality—protection of privacy
- Each of the seven medical principles of ethics is supported by federal and state laws that have been passed and certain standards, rules, and procedures established by professional societies and other medical governing bodies.
- The American Registry for Radiologic Technologists (ARRT) is one professional, administrative organization that has established ethical policy as contained in the professional code of ethics.
- The code of ethics for radiation therapists contains language that supports beneficence and other ethical principles.
- Laws supporting beneficence may be found under tort law.

- A tort is any wrongful act against another; wrongs can be intentional or unintentional.
- Unintentional torts—negligence and malpractice
- Negligence—an injury that was caused by an avoidable but unintentional mistake.
- Malpractice—an injury that was caused by an intentionally negligent action.
- Intentional torts—battery, assault, false imprisonment, infliction of emotional distress.
- Battery occurs when one actually inflicts physical harm or offensive touching on a person.
 - Harmful means it results in some type of injury.
 - Offensive means that it insults someone's dignity.
- Assault is the intentional act of making someone fear that you will cause them harm.
 - Examples include verbal threats or physical attacks by patient, family member, or health care provider.
- Quasiintentional torts—defamation of character, invasion of privacy in some cases (wrongful act based on speech committed by a person for another person that results in economic harm and damage to a person's reputation).
- The Elder Abuse and Neglect Act is an example of a federal law that supports beneficence (the promotion of doing good and ensuring the patient's best interest).
- Nonmaleficence is also supported by tort law; this principle is most evident in the establishment of intentional and quasi-intentional tort liability.
- Our national and state rules about credentialing are a good example of administrative laws that support the principle of nonmaleficence.
- Competence as shown through certification, registration, licensure, and continuing education are included in credentialing.
- Autonomy is supported by the Patient's Bill of Rights Act of 1998.
- Autonomy is also supported by documents such as the DNR, living will, power of attorney, other advanced directives, and informed consent.

Autonomy Documentation

DNR

- Do not resuscitate is a request not to have cardiopulmonary resuscitation if your heart stops or if you stop breathing.

Living Wills

- Written legal documents stating the medical treatments or life-sustaining treatments the patient wants if they were seriously or terminally ill

Durable Power of Attorney

- States whom you have chosen to make health care decisions for you
- Becomes active any time you are unconscious or unable to make medical decisions
- Also called *health care proxy*

Advance Directives

- Tells your doctor what kind of care you would like to have if you become unable to make medical decisions

Informed Consent

- Informed consent is a process, not a form
- A consent form codifies and documents the process but does not substitute for clear and appropriate provision of information to the patient with adequate time for questions, answers, and free discussion and exchange.
- Physician provides the patient with information so that the patient can make an informed decision regarding whether to consent to treatment/procedure including:
 1. Nature of procedure, treatment, or disease

2. Expected outcomes and likelihood of success
 3. Reasonable alternatives
 4. Known risks
- There are limits to the principle of autonomy such as:
 1. If an autonomous decision might cause harm to others such as the unborn
 2. In instances of “physician’s privilege” where the physician does what he/she feels is best when the patient’s personal choice has not been expressed
 3. If the autonomous decision may cause harm to society (legal moralism)
 4. If the patient is incompetent and does not have the capacity to make an independent decision
 - The constitution and its amendments support the principle of justice
 - Antidiscrimination laws, civil rights laws, labor laws, and due process also support the principle of justice.
 - The Hippocratic Oath and codes of ethics contain language supporting justice.
 - A special relationship develops at the first encounter between the patient and clinician. Once responsibility for the care of another is accepted, then the relationship becomes fiduciary. Each one commits to being truthful, faithful, and to hold information confidential.
 - The law of informed consent and HIPAA laws support the fiduciary relationship.

Interpersonal Communication

- Communication is critical to building helping relationships with patients and coworkers.
- Patients undergoing treatment for cancer likely have both psychological and social needs.
- Helping relationships in cancer care should address the physiologic, psychological, and social needs of the patient and their caregiver(s) (see [Table 7.1](#)).

TABLE 7.1

Challenges in Communication

Languages

- Translators should be provided by hospital before patient's appointment

Hearing and Speech Impairments

- Interpreters should be provided by hospital before patient's appointment

Impaired Cognition

- Adjust communication strategies to match comprehension level of patient

Literacy

- Read information to patient
- Provide video with information

Modes of Communication

- Verbal
- Written
- Nonverbal
- Nodding
- Eyebrow movement
- Hands making a fist while laying down
- Eyes closed
- Tears

- Smiles
- Laughing

Tools Used for Effective Communication

- Handouts
- Videos
- Books
- Personal testimony
- Other patients
- Support groups
- Solid and honest communication
- Solidify trust between patient and radiation therapist
- Foster a good rapport between the patient and the radiation therapy team
- Allow patient to ask questions
- Compassionate and straightforward
- Assess patient's comprehension level
- Repetition of information

Assessment of Acute Side Effects

- Onset doses for side effects caused by radiation may vary depending on fractionation schemes and volume of tissue irradiated
- Chemotherapy side effects also vary depending on the type of chemotherapy and/or dose
- Side effects may be acute or latent; the objective is to minimize acute effects, manage them when they occur, and prevent latent effects whenever possible

Acute Radiation-Related Side Effects

Skin Reaction

Skin reactions may persist 6 months to 5 years following completion of treatment. Certain areas are more sensitive than others such as:

- Sites where two skin surfaces are in contact
- Sites where epidermis is thin and smooth
- Areas where the integrity of the skin has been disrupted due to surgical incision/trauma
- Areas of inflammation

Progressive Stages of Skin Reactions

- Epilation/alopecia—20 Gy (damage to hair follicles and subsequent hair loss)
- Erythema—20 Gy (damage to cells of the skin in minimal and treatment continues)
- Dry desquamation—30 Gy (skin becomes dry and scaly due to destruction of sebaceous gland in the treatment area)
- Moist desquamation—40 Gy (inflammation, edema, and blister formation and peeling of the epithelial layers of the skin)
- Necrosis—greater than 50 Gy (cell death)

Mucositis/Stomatitis

- Dose 2000 to 3000 cGy

Mucositis is an alteration in the mucous membranes of the oral cavity, which manifests as inflammation, desquamation, and ulceration.

Early signs and symptoms of mucositis

- Dryness of mucous membranes
- Red, inflamed areas of the mucous membranes
- Presence of white or yellow membrane
- Mild burning sensation

Late signs and symptoms of mucositis

- Ulceration
- Necrotic tissue
- Pain
- Bleeding

Esophagitis

Dose—2000 to 3000 cGy

- Produces difficulty in swallowing and pain on swallowing
- Pain may mimic the type of pain associated with a myocardial infarction

Early signs and symptoms of esophagitis

- Difficulty in swallowing
- Pain during swallowing
- Vomiting food or blood
- Chest pain
- Inflammation of esophageal lining

Nausea

- Dose—1000 cGy to 2000 cGy

Occurs when the epithelial cells lining the esophagus, stomach, and/or intestines are destroyed in response to radiation

- Never deny or overestimate the expectation that nausea may occur
- Maintain a positive approach

Signs and symptoms of nausea

- Usually begins 1 to 6 hours after radiation treatment
- Queasy stomach
- Belching
- Watery mouth

- Sour belch

Diarrhea

- Dose—2000 to 5000 cGy
- Epithelial cells in the large colon are destroyed in response to exposure

Signs and symptoms of diarrhea

- Watery stools
- Frequent bowel movements

Fatigue

- Fatigue is a feeling of discomfort, which results in a decrease in motor and mental skills
- Usually begins after the first week of treatment and reaches its peak in 2 weeks, then gradually disappears 2 to 4 weeks after the treatment ends
- Results from destruction of cancer cells and normal cells with the release of waste products into the bloodstream

Myelosuppression

- Occurs when a high volume of bone marrow reserves are irradiated to doses above 20 Gy
- Of greatest concern when irradiating the chest, pelvis, and extremities

Signs and symptoms of myelosuppression

- Fatigue
- Easy bruising, nosebleeds
- Repeated infection
- Lowered blood counts

Xerostomia (Dry Mouth)

- Occurs when doses above 20 Gy are delivered to salivary glands
- Permanent damage to salivary glands may be seen above doses of 40 Gy

Signs and symptoms of xerostomia

- Patient complains of cotton mouth
- Difficulty swallowing food
- Sensation of dehydration/feeling thirsty
- Increased viscosity of saliva

Acute Chemotherapy-Related Side Effects

- Considering chemotherapy drugs differ in their mechanism of action, they impose a number of different side effects.
- Combination chemotherapies commonly increase the risk of patients experiencing overlapping side effects such as myelosuppression (low blood counts).
- A toxicity profile is reviewed and taken into consideration by the oncologist when the chemotherapy treatment approach is decided. Toxicity is graded using a scale of 1 to 4; the higher the grade, the higher the risk for anticipated side effects.
- Experienced side effects are particularly related to a person's pathophysiology. Coincidental factors include body surface area measurement (height and weight proportion), comorbidities of other medical disorders or diseases, gender (women are more prone to nausea and vomiting than men—likely related to hormone ratios).
- For acute side effects, the management goal is prevention. Pre-medications are given to prevent the occurrence.
- Subsequently, when the toxic effect occurs, the management goal becomes supportive.

Dermatologic Effects

- Some chemotherapy agents are classified as vesicants; that is, are toxic to soft tissue and may lead to long-term, local tissue damage (obvious at the injection site).

Manifestations of local tissue damage:

1. Blisters
2. Desquamation
3. Necrosis

Examples of vesicant chemotherapy drugs:

1. Vincristine
 2. Doxorubicin
 3. Etoposide
 4. Mitomycin hand-foot syndrome is a painful skin irritation that would include pain, fissures, redness, and ultimately hyperpigmentation to the palms and soles of the feet; 5-FU and capecitabine may be culprits.
- Monoclonal therapy, also known as immunotherapy, may cause acne-appearing rashes to the face, shoulders, back, and chest.
 - Late effects to the skin—referred to as “radiation recall”—may be seen in patients who are receiving alkylating agents after a radiation regimen or in the case of disease recurrence for which chemotherapy is given, followed by a second course of radiation.

Mucositis, Stomatitis, Esophagitis

- During or after chemotherapy, a patient may have some sort of mouth problem, ranging from dryness to ulcerations.
- Usually 3 to 10 days following chemotherapy, patients experience mucosal burning sensation, followed by ulcers. When ulceration

develops, treatment is mostly supportive until the cells regenerate themselves. This takes approximately 7 to 14 days.

- Basic hygiene is of primary importance and should be initiated before chemotherapy or radiation therapy start.
- Patients should brush their teeth three to four times a day; a suggested schedule is after meals and at bedtime. A soft toothbrush or sponge is recommended. Patients at higher risk for this occurrence should rinse their mouth frequently with salt water or baking soda.
- Chemotherapies that put patients at a higher risk for experiencing mouth sores are fluorouracil (5-FU) and methotrexate.

Nausea and Vomiting

- Nausea and vomiting result from stimulation of the chemoreceptor trigger zone of the medulla (brain). Some chemotherapy drugs are worse offenders than others.
- In most cases, patients are given anti-nausea and vomiting medication (antiemetics) to prevent and control this response.
- It is important to understand that some antiemetics may also have some side effects of their own that patients may experience. Common medications given to prevent and treat nausea and vomiting are listed below.
- Patients who have been prescribed antiemetics for an extended period, beyond the period of chemotherapy, may continue to take this medication due to the continued sensation or as a preventative measure against the anticipated episodes of nausea and/or vomiting.

Antiemetic drug names

- Compazine (prochlorperazine)—Side effects of this medication consist of sleepiness, dystonia reactions (sluggish muscles), lockjaw

- Benadryl (diphenhydramine)—Side effects are drowsiness and dry mouth
- Lorazepam (Ativan)—Side effects consist of sleepiness and confusion
- Ondansetron (Zofran)—Side effects consist of headache and constipation
- Granisetron (Kytril)—Side effects consist of headache and constipation
- Dolasetron (Anzemet)—Side effects consist of headache and constipation
- Dronabinol (Marinol)—Side effects consist of sleepiness, appetite stimulation, and confusion
- Dexamethasone—Side effects consist of insomnia, stomach upset
- Metoclopramide (Reglan)—Side effects consist of diarrhea, anxiety, sleepiness
- Delayed nausea and vomiting can occur after cisplatin, carboplatin, and cyclophosphamide chemotherapy
- The most effective antinausea for delayed nausea and vomiting are Reglan and dexamethasone

Diarrhea

- Diarrhea occurs in 75% of cancer patients receiving chemotherapy due to the destruction of replicating epithelial cells of the gastrointestinal (GI) tract. This alteration causes inadequate digestion and absorption of nutrients.
- The degree and duration of diarrhea depend on the chemotherapy. Some chemotherapy drugs associated with diarrhea are fluorouracil (5-FU), methotrexate, cytarabine (Ara-C), capecitabine (Xeloda), and irinotecan (Camptosar).

Constipation

- Patients may experience constipation due to a number of cancer management medications such as narcotic analgesics for pain, calcium-containing antacids such as Tums, and *vinca* chemotherapies.
- To maintain normal bowel functioning, a bowel regimen should be implemented for patients receiving any of the listed medications:
 - Morphine (MS Contin)
 - Oxycodone (OxyContin)
 - Fentanyl (Duragesic)
 - Hydrocodone (Vicodin)
 - Hydromorphone (Dilaudid)
- Vinca alkaloid chemotherapies have the potential to cause neurotoxicity of the smooth muscles of the GI tract, leading to decreased peristalsis or paralytic ileus.
- The onset of constipation is usually within 7 days
- Vinca alkaloid chemotherapies include:
 - Vincristine (Oncovin)
 - Vinblastine (Velban)
 - Vinorelbine (Navelbine)
- Elderly patients are particularly susceptible to constipation from both narcotic analgesic use and *vinca* chemotherapy.

Myelosuppression

- Myelosuppression is considered to be the most frequent and most serious chemo-related toxicity.
- Patients should be counseled that it is not uncommon to experience some degree of myelosuppression during their course of treatment.
- The majority of chemotherapy agents produce some degree of myelosuppression; however, the severity depends on the drug, the dose, administration frequency, and the route.
- Patients at greater risk for developing myelosuppression would be:
 - (1) the elderly (less resilient bone marrow);
 - (2) those who have been previously irradiated to the bone marrow target areas

- (sternum, pelvis, extremities, ribs); and (3) patients who received high doses of radiation and/or chemotherapy at an earlier date
- Cell-cycle nonspecific drugs, such as antimetabolites, cause a more acute myelosuppression.
 - Cell-cycle specific drugs, such as nitrosoureas, cause a delayed myelosuppressive effect.
 - More severe degrees of myelosuppression are seen in patients receiving alkylating agents.
 - Most myelosuppression occurs 7 to 14 days following chemotherapy administration.
 - Myelosuppression includes neutropenia, anemia, and thrombocytopenia.
 - Neutropenia is a decrease in the number of white blood cells (WBC); low WBC increases the potential for infection since they are the primary defenders for infection prevention.

Important: Patients with decreased WBC should maintain adequate nutrition and fluid intake, avoid crowds and persons with known infections, and report any signs of infections such as fever, cough, sore throat, and stiff neck.

- Anemia is the decrease in the number of red blood cells (RBC), hemoglobin (HGB), and hematocrit (HCT). Fatigue is the most common symptom of anemia due to lack of circulating oxygen in the blood cell. Other signs of anemia include shortness of breath, headache, dizziness, irritability, pale nail beds and palms, and pale oral cavity.

Important: Patients with anemia should maintain adequate hydration.

- Thrombocytopenia is a decrease in the number of platelets (PLT). Bleeding tendencies are the most common sign of low platelet count since platelets are supportive of normal clotting mechanisms. Nosebleeds, bleeding of the gums, petechiae (small red,

generalized spots), bruising, and urinary or intestinal bleeding are manifestations of low platelets.

Important: Patients with thrombocytopenia should limit falling risks, use soft bristle toothbrushes or sponge for teeth cleaning; avoid aggressive nose blowing; avoid aspirin, ibuprofen, and rectal suppositories.

Dry Mouth (Xerostomia)

- Dry mouth can occur as a result of chemotherapy.
- Often dry mouth precludes oral mucosa ulcers.

Management of Acute Side Effects

Interventions for Radiation-Related Skin Reactions

- Gently cleanse skin in the treatment area
- Expose the area to the air as often as possible
- Avoid tight-fitting clothing over the skin
- Avoid wearing harsh fabrics such as wool or corduroy
- Use gentle detergent to wash clothes
- Avoid exposure to cold temperatures
- Avoid swimming in salt water/chlorinated pools
- Avoid powders, creams, deodorant, medicated patches, and Band-aids
- Avoid shaving hair in treatment area
- Avoid exposure to the sun

Interventions for Dermatologic Reactions Caused by Chemotherapy

- Area should be kept clean and dry
- Area should be protected from direct sunlight exposure; suggest light-cotton clothing
- Important to apply topical moisturizers

Interventions for Radiation-Related Esophagitis

- Use antacids
- Use milk products (sour cream, yogurt, cottage cheese)
- Use a straw for liquids
- Use liquid Tylenol
- Eat foods high in calories and proteins
- Small frequent meals
- Avoid hot/spicy foods

Interventions for Chemotherapy-Related Mucositis, Stomatitis, Esophagitis

- Analgesics and anesthetics can be used. Xylocaine is a local anesthetic available as a gel or spray that can be used specifically on the site to decrease pain.
- Protective agents can also be used to provide a protective coating over ulcers and decrease their irritation. Examples of these agents are Maalox and Mylanta.
- A basic solution referred to as Miracle or Magic Mouthwash consists of a combination of agents (analgesic/lidocaine, antacid/Maalox or Mylanta, and an antihistamine/Benadryl) and is commonly used to prevent and/or relieve discomfort of mucosa caused by ulcers.
- Sucralfate (Carafate) is available by prescription to coat the mucosa and relieve discomfort.
- Another agent, an antifungal, can be added or used in the presence of oral fungal infections (*Candida*). It can be either clotrimazole

- (Mycelex lozenges) or nystatin suspension (swish and swallow).
- Xylocaine or lidocaine solution should not be used before meals because of the threat of choking.
 - Avoid the use of hydrogen peroxide because it may worsen or irritate ulcers.
 - Topical steroids should not be used because they can facilitate infections.
 - Patients should be advised not to eat spicy, hot, acidic, or coarse foods or beverages. Food selections should be steered toward moist, soft foods, such as mashed potatoes and soft scrambled eggs.

Interventions for Radiation-Related Mucositis

- Force fluids
- Use a systematic, consistent mouth care regime
- Avoid the use of tobacco
- Avoid alcoholic beverages
- Avoid foods that are thermally very hot or cold
- Avoid citrus fruits
- Avoid foods that are hard or coarse
- Avoid use of dental floss and WaterPiks

Interventions for Radiation or Chemo-Related Nausea/Vomiting

- Encourage an intervention that helped relieve nausea or vomiting in the past, such as with a pregnancy, an illness, or times of stress.
- Eat cold foods or those served at room temperature, such as a deli sandwich.
- These foods are usually better tolerated than warm or hot foods. The odor of hot foods often aggravates the feeling of nausea.
- Snack on dry foods like toast, cereal, or saltine crackers.

- Clear liquid diets assist to reduce nausea. Liquids such as fruit ades, Gatorade, ginger ale, 7-Up, gelatin, and tea are usually well tolerated. These liquids should be served cold and sipped slowly.
- Drink enough fluid to help bowels move regularly, as dehydration and constipation can contribute to nausea.
- Bland foods such as mashed potatoes, applesauce, toast, and cottage cheese are also well tolerated.
- Sour foods, such as sour pickles, hard sour candy, lemon sherbet, lemons, lemon drops, mints, ginger-containing items, and turmeric can also aid to reduce nausea.
- Avoid sweet, fatty, highly salted, spicy, or greasy foods as well as those with strong odors.
- Minimize stimuli such as sights, sounds, and smells that can initiate nausea such as unpleasant odors, perfume/cologne/body sprays, and other people who are nauseated and vomiting.
- Avoid eating or drinking for 1 to 2 hours before and after chemotherapy or radiation therapy.
- Eat frequent, small meals throughout the day.
- Avoid lying down flat at least 30 minutes after eating.
- Get fresh air by sitting near an open window or go outdoors.
- Rest in a comfortable position in a quiet environment.
- Provide distractions such as listening to soft, relaxing music, reading, or watching television.
- Use relaxation techniques with or without visual imagery. Seek services of a professional provider if unable to achieve relaxation alone.
- Use antiemetic.

Interventions for Radiation or Chemo-Related Diarrhea

- Avoid spicy, greasy, fatty, and high-fiber foods.
- East small, frequent meals.
- Hydrate well and replace electrolytes using electrolyte replacement drink, such as sports drinks.

- Antidiarrheal therapy is the primary treatment. The following medications have been shown to be effective in the treatment of diarrhea:
- Loperamide (Imodium) two dosages (capsule or liquid) initially followed by one dose after each loose stool, up to eight doses a day. Side effects from this medication are sedation and drowsiness.
- Lomotil 1 or 2 tablets three to four times a day. Side effects include nervousness and drowsiness.
- The primary goal with episodes of diarrhea is prevention of dehydration. Therefore, adequate fluid intake is critical. At least 3000 mL (12.5 cups) of fluid each day is recommended.
- Recommended fluids would include water, broth, soup, noncaffeinated beverages, and Gatorade.
- When diarrhea is occurring in severe amounts, intravenous fluid support may be required on a short-term basis.

Additional options would include:

- Low-residue diet, high in protein and calories (see [Box 7.1](#)).
- Eliminate foods and beverages that may be irritating or stimulating to the gastrointestinal (GI) tract (see [Box 7.2](#)).
- Adding nutmeg to foods may decrease the motility of the GI tract.
- Foods high in potassium are recommended if the patient exhibits signs of fatigue or weakness or if the potassium level is low.
- High-potassium foods include baked potato, halibut, and asparagus tips.
- Encourage eating small, frequent meals.
- Avoid extremely hot or cold foods. Extremes in temperature may aggravate the diarrhea.
- Before a radiation treatment, it may be helpful to eat foods that are easy to digest. Avoid fried, fatty, and highly seasoned spicy foods, which tend to upset the stomach (see [Table 7.2](#)).
- The banana, rice, applesauce, and toast (BRAT) diet may help treat diarrhea; however, it is essential to remember that proteins should also be included as part of the BRAT diet regime to avoid the risk of nutrient and calorie deficiencies.

Box 7.1

Low-Residue Diet

Cottage cheese, mild processed cheese, eggs, low-fat milk, yogurt, rice, pudding, custard, tapioca, buttermilk

Broth, bouillon, gelatin, apple juice, grape juice

Fish, poultry, ground beef, broiled roast

Cooked cereals (i.e., cream of wheat), crackers, white bread, macaroni, noodles

Bananas, applesauce, peeled apples (apples contain pectin an antidiarrhea agent), avocados

Baked, boiled, or mashed potatoes

Smooth peanut butter

Cooked, mild vegetables (i.e., asparagus tips, beets, green or waxed beans, peas, carrots, spinach, squash, cream vegetable soups)

Box 7.2

Foods Irritating or Stimulating to the GI Tract

Whole-grain bread and cereal, nuts, seeds, coconut, fried, greasy foods (i.e., pork)

Fresh and dried fruits

Raw vegetables, rich pastries, popcorn, potato chips, pretzels

Strong spices and herbs (i.e., chili powder, licorice, pepper, curry, garlic, horseradish, olives, pickles, relishes)

Flatus forming food, such as broccoli, onions, cabbage

Food and beverages containing caffeine such as chocolate, coffee, tea, and soft drinks

Alcohol beverages including strong liquor, beer, wine, tobacco products

Table 7.2

Foods and Beverage Considerations for Managing Nausea and Vomiting

Categories	Recommended Foods and Beverages	Foods and Beverages to Avoid
Foods containing proteins	Juice-type commercial protein supplements (for example, Ensure Clear) blended with ice and eaten with a spoon Cottage cheese Cold sandwiches Boiled or baked meat and fish Poultry, cold meat, or fish salad Well-cooked eggs Cream soups made with low-fat milk Nonfat yogurt	Fried meats and fatty foods, sausage, bacon, spicy foods, Fried eggs Milkshakes (unless made with low-fat milk and ice cream), sardines, salmon, pork, and veal

Categories	Recommended Foods and Beverages	Foods and Beverages to Avoid
Drinks, desserts, and other foods	Clear liquids, Ginger ale, cold fruit drinks, caffeine-free soft drinks and sport drinks, caffeine-free iced tea Pedialyte, coconut water, bone broth, and apple juice Clear liquids, such as bouillon, clear carbonated beverages, apple/cranberry/grape juice, plain gelatin, water Salt, cinnamon, spices as tolerated Sherbet, fruit-flavored gelatin Angel food cake, sponge cake; vanilla wafers Pudding made with low-fat milk Popsicles, juice bars, fruit ices	Extreme cold or hot beverages Alcohol Caffeinated beverages Coffee Pie, ice cream, rich cakes Spicy salad dressings Olives Cream Pepper, chili powder, onion, hot sauce, seasoning mixtures
Rice, pasta, breads, and cereals	Bland foods, low-fiber starches, instant oatmeal, bread, cream of wheat, white rice, noodles Saltine crackers, soda crackers, toast, English muffins, pretzels, bagels	Foods high in sugar, muffins, pancakes, pastries, and doughnuts
Fruits and veggies	Steamed or boiled vegetables —potatoes, squash, green beans, and carrots Canned or fresh fruits, vegetables as tolerated (do not eat if	Raw vegetables— Brussel sprouts, cauliflower beets, sauerkraut, cabbage,

Categories	Recommended Foods and Beverages	Foods and Beverages to Avoid
	poor appetite or severe nausea) Potatoes (baked, boiled, or mashed), applesauce, soft fruits—melons, bananas, avocado, applesauce, pumpkin, and canned fruit (packed in water)	parsnips, broccoli, onions, and corn on the cob, breaded, fried, or creamed vegetables; vegetables with strong odor, potato chips, fried potatoes such as French fries or hash browns Citrus fruits including pineapples, oranges, and grapefruits; tomatoes, cherries, grapes, figs, currants, raisins, rhubarb, seeded berries
Rice, pasta, breads, and cereals	Bland foods, low-fiber starches, instant oatmeal, bread, cream of wheat, white rice, noodles, Saltine crackers, soda crackers, toast, English muffins, pretzels, bagels	Foods high in sugar, muffins, pancakes, pastries, and doughnut
Fruits and vegetables	Steamed or boiled vegetables —potatoes, squash, green beans, and carrots Canned	Raw vegetables, Brussel sprouts, cauliflower beets,

Categories	Recommended Foods and Beverages	Foods and Beverages to Avoid
	or fresh fruits, vegetables as tolerated (do not eat if appetite is poor or nausea is severe) Potatoes (baked, boiled, or mashed), applesauce, soft fruits—melons, bananas, avocado, applesauce, pumpkin, and canned fruit (packed in water)	sauerkraut, cabbage, parsnips, broccoli, onions, corn on the cob Breaded, fried, or creamed vegetables, vegetables with strong odor Potato chips, fried potatoes such as French fries or hash browns Seeded berries, grapes, raisins, tomatoes, cherries, and figs Citrus fruits—oranges, grapefruits, lemons, limes, tomatoes, and pineapples
Protein foods	Boiled or baked meat, fish Poultry, cold meat, or fish salad Well cooked eggs Cream soups made with low-fat milk Nonfat yogurt Juice-type commercial protein supplements (for example,	Fatty and fried meats, sausage, bacon, spicy foods, fried eggs Milkshakes (unless made with low-fat milk and ice cream) Sardines, salmon, pork, and veal

Categories	Recommended Foods and Beverages	Foods and Beverages to Avoid
	Ensure Clear) blended with ice and eaten with a spoon Cottage cheese Cold sandwiches Unseasoned skinless turkey or baked chicken, yogurt and kefir, and scrambled eggs	
Drinks, desserts, and other foods	Clear liquids, Ginger ale, cold fruit drinks, caffeine-free noncarbonated soft drinks as fruit punch and sports drinks Caffeine-free iced tea Weak tea, Pedialyte, coconut water, bone broth, bouillon, and apple juice Cranberry/grape juice, Popsicles, ice chips, carbonated drinks Water, ginger, and peppermint teas Salt, cinnamon, spices as tolerated Sherbet, plain or fruit-flavored gelatin Angel food cake, sponge cake; vanilla wafers Pudding made with low-fat milk Popsicles, juice bars, fruit ices Pretzels	Sodas with caffeine, added sugars, juices, and candy Alcohol Caffeinated beverages Coffee Tea Pie, ice cream, rich cakes Spicy salad dressings Olives Cream Pepper, chili powder, onion, hot sauce, seasoning mixtures

Interventions for Chemo-Related and Analgesic-Related Constipation

- Drink plenty of fluids and eat high-fiber foods.
- Dried prunes or warm prune juice may also help.
- Speak with a registered dietician about soluble fiber supplements.
- Increase dietary fiber amount in food choices ([Box 7.3](#)).
- Drink warm or hot beverages, especially upon arising.
- Drink 3000 mL (12.5 cups) of fluid daily (unless contraindicated).
- Increase physical activity level.
- Use prophylactic stool softener daily, such as Colace 200 mg twice a day.
- If a patient does not experience a bowel movement in 3 days or longer, use of a laxative is necessary.
- Common laxatives include the following:
- Senokot: 2 tablets daily until regular bowel function, then 1 tablet daily.
- Dulcolax: 1 to 2 tablets daily until regular bowel function, then 1 tablet daily.
- If over-the-counter laxatives are ineffective, a prescription can be obtained.
- Lactulose solution is a common prescriptive laxative. With excessive use/doses, diarrhea and flatulence can be the result.

Box 7.3

High-Fiber Foods

Fresh raw fruit with skin and seeds, prunes, dates, raisins
Fresh raw vegetables
Nuts, coconut, corn, popcorn, whole grain products, bran

Fresh fruit and vegetable juices

Interventions for Radiation-Related or Chemo-Related Fatigue

- Conserve energy
- Rest when fatigue is experienced
- Force fluids
- Maintain nutrition
- Seek help with childcare and household duties
- Explore alternative means of transportation

Interventions for Radiation or Chemo-Related Xerostomia

- Encourage the patient to drink (sip) fluid frequently throughout the day
- Suck ice chips
- Suck hard candy
- Chew gum
- A gentle soothing, alcohol-free oral mouthwash referred to as Biotene is a common solution used by patients and is available over-the-counter (OTC).
- Biotene Oral Balance Moisturizing Gel
- Patients should stay away from solutions containing alcohol or glycerin bases because they can irritate or aggravate dryness.

Interventions for Radiation or Chemo-Related Loss of Appetite

- Eat small frequent meals, focusing on calorie and protein-dense meals, even if it is just a few bites
- Keeps snacks on hand

Interventions for Radiation or Chemo-Related Sore Mouth/Throat

- Avoid spicy, acidic, tart, and rough-textured foods, alcohol, and carbonated beverages.
- Eat soft, moist foods with a mild gravy or sauce.
- Use a baking soda rinse after each meal made with ¼ teaspoon of baking soda and 4 ounces of water.

Interventions for Radiation or Chemo-Related Taste Changes

- Practice good mouth care by brushing tongue and teeth and each meal.
- Use baking soda rinse to cleanse palette, or sugar-free gum, peppermints, lemon drops, sorbets, or frozen fresh fruits.

Interventions for Radiation or Chemo-Related Myelosuppression

- [Table 7.3](#) lists interventions for radiation or chemotherapy-related myelosuppression; [Figure 7.1](#) depicts the calculation of absolute neutrophil count (ANC).

TABLE 7.3

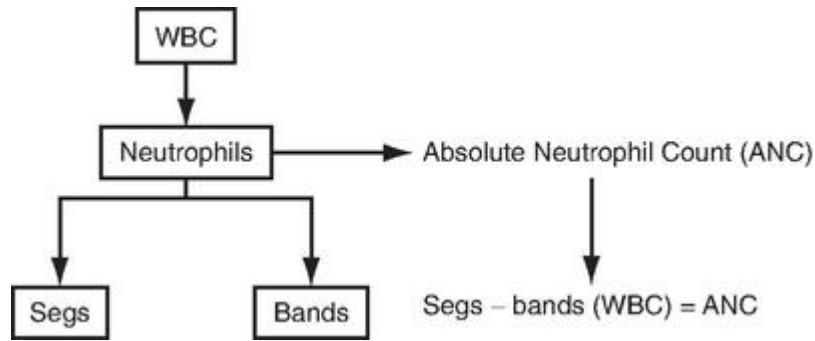


FIG. 7.1 Calculation of ANC diagram.

Latent Effects From Radiation and Chemotherapy

- [Table 7.4](#) includes radiation- and chemotherapy-related late effects.

TABLE 7.4**Examples of Radiation and Chemotherapy-Related Late Effects**

Radiation-Related Late Effects	Chemotherapy-Related Late Effects
Increased risk of secondary cancers	Increased risk of secondary cancers
Genetic mutations	Renal failure
Organ failure	Kidney failure
Tissue necrosis	Cardiomyopathy
Chronic bowel irritability	Delayed, impaired memory (chemo brain)
Pneumonitis	Tissue necrosis
Decreased tissue elasticity	Dental problems
Early menopause	Early menopause
Osteoporosis	Osteoporosis
Hyperpigmentation	Loss of taste
Tooth decay and cavities	Dental problems
Lymphedema	Problems with digestion
Increased risk of stroke	Arrested development of bone and mental capacity
Heart and vascular problems	Heart problems
Hypothyroidism	Nerve damage
Infertility	Infertility
Intestinal problems	Reduced lung capacity

Radiation-Related Late Effects	Chemotherapy-Related Late Effects
Lung disease	Lung disease
Memory issues	Memory issues

Routine Assessments

Normal Patient Vital Signs

- [Table 7.5](#) lists normal vital signs by age groups.
- [Box 7.4](#) features average temperature readings

TABLE 7.5

Vital Signs at a Glance					
Age	Oral Temp	Rectal Temp	Respiration Rates breaths/min	Pulse Rates beats/min	**Systolic Blood Pressure (mm Hg)
Premature newborn	Not applicable	99.6°F (37.5°C)	< 60	140	50–60
Newborn	Not applicable	99.6°F (37.5°C)	< 60	125	70
6 months	Not applicable	99.6°F (37.5°C)	24–36	120	90
1 year	Not applicable	99.6°F (37.5°C)	22–30	120	96
3 years	Not applicable	99.6°F (37.5°C)	20–26	110	100
5 years	98.6°F (37°C)	99.6°F (37.5°C)	20–24	100	100
6 years	98.6°F (37°C)	99.6°F (37.5°C)	20–24	100	100
8 years	98.6°F (37°C)	99.6°F (37.5°C)	18–22	90	105
12 years	98.6°F (37°C)	99.6°F (37.5°C)	16–22	85–90	115
16 years	98.6°F (37°C)	99.6°F (37.5°C)	14–20	75–80	<120
Adult	98.6°F (37°C)	99.6°F (37.5°C)	12–20	60–100	<120

From Adler A, Carlton R. *Introduction to Radiologic Sciences and Patient Care* . 7th ed. Elsevier; 2019; Washington C, Leaver D, Trad M. *Principles and Practice of Radiation* . 5th ed. Mosby; 2016.

** Diastolic blood pressure <80 mm Hg.

Box 7.4

Average Temperature Readings Temperature Readings

Ranges 97.6°F–100°F (36.5°C–37.8°C)

Average Oral Temp 98.6°F

Average Tympanic Temp 97.6°F

Average Rectal Temp 99.6°F

Average Temporal Artery Temp 100°F

Average Axillary Temp 97.6°F

Normal Blood Count

- RBC: Ref. range 3.90 to 5.40 million/mm³
- WBC: Ref. range 5000 to 10,000/mm³
- HGB: Ref. range 12 to 16.0 g/dL
- HCT: Ref. range 37% to 47%
- Platelets: Ref. range 150,000 to 425,000/mm³

Performance Scales

- Karnofsky performance scale uses 0 to 100; describes patient's ability to care for themselves and complete normal activities.
- Performance is related to patient's ability to endure aggressive therapies, such as radiation and chemotherapy.
- Eastern Cooperative Oncology Group performance scale assesses how a patient's disease is progressing and evaluates how the disease affects daily living on a scale from 0 to 5.
 - 0—Fully active, able to carry on all pre-disease performance without restriction
 - 5—Dead
- Glasgow Coma scale ranges from 3 to 15; assesses patient neurologic and cognitive function; good assessment tool when patient consciousness level changes.

Pain Assessment and Management

- Pain levels should be evaluated at regular intervals for all patients.
- Pain scales may take on many forms; when evaluating gather information about the frequency, nature, location, sensation, and duration.
- Simple pain scales may use numerical values 0 to 10; 0 indicating no pain and 10 indicating the worst pain.
- Pain assessment tools should allow the patient to independently express their level, frequency, nature, location, sensation, and duration of pain.
- Management of pain can include:
 - a. Medication
 - b. Meditation, visualization
 - c. Conditioning

Nutritional Assessment and Education

- Patient's nutritional status is critical in fighting disease, cell building, and tolerance of therapy

Anorexia

- The causes of anorexia in a patient can occur due to:
 - Fatigue
 - Dry mouth, esophagitis, nausea, vomiting,
 - Presence of pain
 - Presence of an infection
 - Presence of stress, anxiety, depression
 - Change in usual lifestyle patterns

Ways to prevent/minimize anorexia

- Serve all food attractively and in a pleasant environment
- Avoid eating three large meals; instead eat several small meals at frequent intervals throughout the day
- Consider protein-calorie intake

- Avoid drinking fluids with meals
- Remove all unpleasant smells
- Use nutritional supplements

Nausea, vomiting, and diarrhea lead to loss of electrolytes, vitamins, and nutrients. Therapists can recommend the following:

- Increase your fluid intake by drinking plenty of water each day.
- Eliminate milk and milk products until diarrhea is under control.
- Eat smaller, more frequent meals (example: five smaller meals as compared to three large ones).
- Avoid raw vegetables and fruits. Avoid foods with high roughage content (salads, corn, etc.).
- All vegetables should be cooked.
- Add nutmeg to foods. This spice may decrease stomach irritability.
- Reduce alcohol consumption.
- Avoid tobacco products.
- Avoid extremely hot or cold foods. Foods served warm or at room temperature are more easily tolerated.
- Avoid items that can produce gas or cause cramps, such as carbonated drinks, chewing gum, beans, cabbage, highly spiced foods, skipping meals, and swallowing air while talking and eating.
- Include foods high in potassium—bananas, potatoes, red meat, apricot nectar, and vegetable juices.
- Eliminate caffeine from your diet (coffee, tea, cocoa, soda).

Nutritional Supplements

- Boost
- Ensure
- Sustacal Plus
- Carnation Instant Breakfast Bars
- Vitamins
- Feeding tube

Ergonomics and Monitoring

Body Mechanics

- Principles of body mechanics are utilizing the correct muscles to complete a task safely and efficiently, without undue strain on any muscles or joints.
- The foundation on which the body rests is known as the base of support.

Techniques of body mechanics

- Maintain a stable center of gravity
- Center of gravity is an imaginary location where all weight is evenly distributed
- Stand with feet apart to increase base of support
- Keep your back straight when lifting patients
- Bend at the knees and hips
- Use leg muscles for lifting
- Lifting should be done by bending and straightening the knees
- Avoid twisting or stretching
- Avoid bending at the waist

Assisting Patients With Medical Equipment

Patients with IVs

- Keep IV above injection site
- Keep IV free from tangles
- Keep pump plugged in
- If leakage is spotted, do not clean until verification of liquid is identified
- Handle with gloves

Chest tubes

- Keep lower than injection site
- Keep hemostat available to shut off
- Keep upright, never lay down
- Always handle with two hands

Urinary catheter

- Keep catheter line below site of origin
- Check for leakage
- Never pull out
- Keep untangled

Oxygen administration

- *Do not* use around flames or sparks
- *Do not* stand oxygen cylinder upright unless it is secured
- *Do not* carry cylinder by regulator or valve

Managing Medical Emergencies

Anaphylactic Shock

- Life-threatening condition due to a severe allergic reaction causing bronchial airway to constrict
- May include symptoms such as nausea, vomiting, diarrhea, urticaria, shortness of breath, airway obstruction, and vascular shock

Symptoms of Anaphylactic Shock

- Difficulty breathing (dyspnea)
- Swollen or tingling lips
- Drop in blood pressure (hypotension)

- Vomiting
- Metallic taste in the mouth
- Itching skin
- Hives (urticaria)
- Dizziness
- Temporary loss of consciousness
- Diarrhea

Treatment of Anaphylactic Shock

- Epinephrine injection of adrenaline in outer mid-thigh

Cardiac Arrest

- Sudden abrupt loss of heart function
- Cardiopulmonary resuscitation (CPR) is a critical skill that can help in saving life of an individual.
- CPR combines rescue breathing and chest compressions to temporarily pump blood to the brain until specialized treatment is available.

Steps of CPR

- Check for scene safety
- Check for responsiveness by tapping and shouting
- If no response, call for help
- Check for a carotid pulse and breathing for no less than 5 and no more than 10 seconds
- Shout for help to call 911/activate the emergency response system and send for AED/defibrillator
- Initiate CPR

Circulation:

- Perform high-quality chest compressions (initiates compressions immediately after recognition of cardiac arrest)
- Correct hand placement
 - Put the heel of one hand on the lower half of the breastbone
 - Put the other hand on top of the first hand
- Compression rate of 100 to 120 compressions per minute
- Deliver 30 compressions in 15 to 18 seconds
- Compression depth and recoil at least 2 inches (5 cm) for an adult
- Complete chest recoil after each compression (recoil allows the chest to come back up to its normal position).
- Minimize interruptions in compressions

Appropriate ratio for age and number of rescuers Adult

- 1 rescuer: 30 compressions to 2 breaths
- 2 rescuers: 30 compressions to 2 breaths

Child (person between 1 year of age and puberty)

- 1 rescuer: 30 compressions to 2 breaths
- 2 rescuers: 15 compressions to 2 breaths

Infant (person younger than 1 year old)

- 1 rescuer: 30 compressions to 2 breaths
- 2 rescuers: 15 compressions to 2 breaths

Airway:

- Open airway adequately using head tilt-chin lift maneuver or jaw thrust
- For head tilt-chin lift, put the palm of one hand on the person's forehead and the fingers of the other hand under the bony part of the chin
- Tilt the head back and lift the chin to open the airway

- Breathing: when giving rescue breaths, use protective barrier devices to help prevent disease transmission.
- Provide 2 rescue breaths with a barrier device (bag valve mask, pocket mask, face-shield, etc.)
- Create airtight seal with the barrier device around the mouth
- Watch for visible chest rise
 - Give just enough breaths to make the chest rise

AED (automated external defibrillator)

Medical device that can analyze the heart's rhythm and, if necessary, deliver an electrical shock, or defibrillation, to help the heart reestablish an effective rhythm.

- Power on AED and follow the prompts
- Correctly attach adult AED pads
 - Peel away backing from the pads
 - Follow pictures on the pads
 - Attach pads to person's bare chest
 - Ensure pads are not touching
- Allow AED to check heart rhythm
 - Loudly state "Clear" for analysis and make sure no one is touching the person
- Clear and safely deliver shock if needed
 - Loudly state "Clear" and make sure no one is touching the person
- Push the shock "button"
- Immediately resume CPR
- Follow the instructions of the AED prompts

Respiratory Arrest

- Caused by airway obstruction
- Obstruction may be partial or complete

Signs of Respiratory Distress

- Complaining of difficulty in breathing
- Tachypnea
- Abnormal breathing sounds
- Cyanosis

Signs of Respiratory Arrest

- Absence of breathing
- No chest rise and fall
- Progressive color change caused by lack of oxygen

Seizures

- Sudden change of behavior due to abnormal electrical activity in the brain
- Do not try to restrain the patient
- Do not try to move the patient
- Move dangerous objects away from the patient
- Do not place anything in the patient's mouth or try to move the tongue

After Seizure

- Do check breathing
- Do stay and talk to the patient
- Do not offer the patient something to drink or eat

Fainting

- Syncope is the temporary loss of consciousness
- Help person who has fainted to the ground
- Shake and call patient's name
- Check for pulse

Stroke

- Cerebral vascular accident (CVA) occurs when blood supply to part of the brain is disrupted, causing the brain cells to die.

Signs of a Stroke

- Sudden numbness or weakness of the face, arm, or leg on one side
- Sudden confusion or trouble speaking
- Sudden trouble seeing in one or both eyes
- Sudden trouble walking, loss of balance
- Sudden severe headache with no known cause

Choking

- Universal sign of choking is a patient clutching throat with both hands
- When an adult has choking with a severe airway block, give thrusts slightly above the belly button (see [Table 7.6](#))
- Thrusts are called abdominal thrusts or the Heimlich maneuver
- Each thrusts pushes air from lungs to help move or remove an object blocking airway
- When an infant is choking with severe airway block, use back slaps and chest thrusts to help remove object
- Do not give abdominal thrusts to an infant

TABLE 7.6

Adler A, Carlton R. Introduction to Radiologic Sciences and Patient Care. 7th ed. Elsevier; 2019; Washington CM, Leaver D, Trad M. Principles and Practice of Radiation. 5th ed. Mosby; 2021.

Infection Control

Important Terms

Asepsis

- Absence of disease-producing microorganism called pathogens

Medical Asepsis

- Refers to the practice that helps to reduce the number and hinder the transfer of disease-producing microorganisms.
- Also called clean technique

Surgical Asepsis

- Practices that render and keep objects and areas free from *all* microorganisms
- Also called sterile technique

Contamination

- Process by which something is rendered unclean or unsterile

Disinfection

- Process by which pathogenic organisms, but generally spores, are destroyed

Antiseptic

- Inhibits the growth of bacteria

Sterilization

- Process by which *all* microorganisms are destroyed

In order for an infection to manifest:

- Microorganisms require a source and a reservoir
- Reservoir is where microorganisms live, metabolize, and reproduce
- Source of microorganism is site from which it is transmitted to a susceptible host, either directly or indirectly through an intermediary object (indirect transmission)
 1. A germ (microorganism) or pathogen must be present.

Examples include

- Virus
 - Fungus
 - Bacterium
 - Parasite
2. The germ must have a place to live and multiply (reservoir) such as:
 - People
 - Plants
 - Food
 - Soil
 - Water
 3. A susceptible host, specifically a person who does not have immunity to the germ.
 4. A way for the germ to enter the host, such as:
 - Direct contact
 - Touch, sexual contact, kissing, etc.
 - Indirect contact
 - Through contaminated food, water, and feces
 - Water droplets
 - Particles in the air

Removing any one of these four conditions breaks the chain of infection, thus preventing the infection from spreading.

- Breaking the chain of infection
- Practicing good personal hygiene
- Treating all bodily fluids as potentially infectious

- Using protective barriers
- Using gloves, mask
- Maintaining a clean environment
- Practicing hand hygiene (soap and water, antiseptic hand wash, alcohol-based rubs)
- Using alcohol-based rubs, which are quick and effective before and after each patient contact, and before and after using gloves, as long as hands are not visibly soiled or contaminated; if hands are visibly soiled, soap and water is best.

Standard Precautions

- Applies to blood, all body fluids and secretions (except for sweat), broken/nonintact skin, and mucous membranes
- Designed to prevent the transmission of HIV, hepatitis, and other pathogens that are spread through contact with body fluids
- Requires the use of protective barriers
- Gloves, aprons, masks, and protective eyewear

Hospital Isolation

- Barriers in place to stop the spread of infection

Types of Hospital Isolation

Strict isolation

- Designed to prevent transmission of highly contagious infections that can be spread by air or contact
- Gown
- Mask
- Gloves
- Hand washing after leaving room
- Contaminated articles from the room should be labeled and bagged.

Reverse isolation

- Designed to protect immunosuppressed patients from infection
- Patient should be isolated with minimum dust, dirt, and wet areas.
- Sterile gloves
- Gown
- Mask
- Hands washed before entering the room

Contact isolation

- Designed to prevent transmission of infections that do not warrant strict isolation (disease usually spread by direct contact)
- Mask
- Gloves
- Gown
- Hand washing after touching patient
- Contaminated articles from the room should be labeled and bagged.

Respiratory isolation

- Designed to prevent transmission of infection through the air
- Mask
- Hand washed after touching patient
- Contaminated articles from the room should be labeled and bagged.
- Patient in negative pressure and isolated air-flow room (negative air pressure keeps pathogens in)

Drug administration

Seven Rights of Drug Medication Administration

- Identify right patient

- Select right medication
- Give the right dose
- Give the right medication at the right time
- Provide right documentation
- Select the right route of administration
- Confirm right rationale/reason
- Routes of drug administration
- Oral
- Mucous membrane
 - Rectum
 - Sublingual
- Topical
- Parenteral
 - Intradermal (ID)
 - Subcutaneous (SC/SQ)
 - Intramuscular (IM)
 - Intravenous (IV)

Drugs Commonly Used in Radiation Oncology

Antiemetics

- Drugs used to prevent or stop nausea and vomiting
- Can be given by mouth, injection, or suppository
- Reglan (metoclopramide)
- Compazine (prochlorperazine)
- Phenergan (promethazine)
- Zofran (ondansetron)
- Sustol and Sancuso (granisetron)
- Torecan (thiethylperazine)

Antidiarrheals

- Drugs used to treat persistent diarrhea

- Work in various ways to thicken the stool or slow spasms that occur in the intestines
- Lomotil (diphenoxylate)
- Imodium (loperamide)

Antibiotics

- Drugs used to fight bacterial infections
- Penicillin
- Keflex (cefalexin)
- Erythromycin
- Tetracyclines (doxycycline and minocycline)

Pain Medication/Analgesics

- Drugs used to relieve pain
- Opioids

Short-acting opioids (immediate-release)

Narcotics

- Morphine
- Codeine
- Demerol (meperidine)
- Hydrocodone
- Oxycodone
- Fentanyl
- Hydromorphone
- Oxymorphone

Long-acting opioids

- MS-Contin (morphine)
- Methadose (methadone)
- Opana (oxymorphone)
- Nonnarcotics

- Tylenol (acetaminophen)
- Bayer, Zorprin (aspirin)

Nonsteroidal Antiinflammatory Drugs

- Drugs with analgesic, antipyretic, and antiinflammatory effects that reduce pain, fever, and inflammation
- Aleve, Naprosyn (naproxen)
- Advil, Motrin (ibuprofen)
- Clinoril (sulindac)
- Feldene (piroxicam)

Basic Charge Capture Terminology Every discipline plays a role in the charge capture process

- Radiation oncologist, medical physicist, radiation therapist, medical dosimetrist, oncology nurse, and administrative personnel
- Patient Care Service Charges are broken down into: Professional and Technical Charges
- Professional Charges are prompted by the radiation oncologist's involvement into a process designed to provide care for the patient
 - The radiation oncologist's "intellectual" involvement directs not only his or her direct involvement but also the Physics charges that are required for patient care
- Technical Charges are rendered by the treatment center for provision of all the equipment and personnel that the physician must utilize to deliver treatment
 - Technical Charges include treatment unit, examination rooms, simulators, and other procedures not directly supplied by the radiation oncologist but required via the treatment plan.
 - Patients are billed for each treatment
- Documentation for IMRT

Professional and Technical

- Permanent record of inverse/forward plan including 3D tumor volume and critical structures, dose volume histogram (DVH), dose verification, and physician review
- The radiation oncologist must sign the treatment plan
- Technical Only
 - Permanent record of daily treatment by field, unit settings, and dose delivered
 - Verification of images, MLC sequence/field, and physician review
- General Billing Principles—CPT (Current Procedural Terminology)
- Two factors determine which treatment delivery code to select:
 - Energy level used in treatment, in megavolts (MV)
 - Complexity of treatment (number of treatment sites, fields, and devices)
- The patient's medical expenses, including treatments, immobilization devices, and simulations, are billed.
- Patients are billed for immobilization equipment one time only
- Verification imaging (i.e., daily IGRT or weekly MV/EPID portal images) is billed to the patient.
- Positioning aids are devices solely designed for the purpose of providing patient comfort rather than preventing movement during treatment.
- Positioning aids are not customized for the patient.
- Positioning aids are utilized for multiple patient use and cost-effective.
- Patients are not billed for the use of positioning aids.
 - Examples: table pad/mat, prone pillow, knee wedge/sponge, sandbag, head holder, foam neck roll, and a standard pillow
- Billing codes are divided into three groups: simple, intermediate, and complex.
- IMRT plans require advanced treatment planning techniques, are considered complexed, and are billed independently as a separate charge.
- Simple devices can be transferred from one patient setup to another.
 - Examples: masking tape, paper tape, rubber band, prone pillow, safety belts

- Intermediate devices consist of equipment that can be affixed, indexed, or attached to the patient support assembly (PSA).
 - Examples: wing board, breast board, belly board
- Complex devices are customized patient-specific apparatuses made with various products including polystyrene foam, plaster, carbon fiber, and plastic.
 - Examples: Alpha Cradle, vacuum cushions, thermoplastic molds
- Simple simulations consist of one treatment site without custom shielding.
 - Examples whole brain or spine simulation
- Intermediate simulations are described as having more than one treatment site.
- Complex simulations involve three or more treatment sites where treatment planning requires the use of multiple beams
- Simple treatments consist of one treatment area (1 isocenter) with no more than two treatment fields/ports and involve two simple blocks or less for shielding purposes.
 - Examples: whole brain treatment with a face-block or a single field electron
- Intermediate treatments involve two or more treatment areas (two or more isocenters) with at least three treatment fields/ports and require three simple blocks for shielding purposes.
- Complex treatments consist of any area that requires a treatment plan with contouring, DVHs, and designing of multiple beams.

Record Keeping

- EMR (electronic medical record) is the standard communication mechanism for the radiation oncology team.
- Radiation therapists are legally responsible for ensuring accuracy and patient confidentiality of the medical record.
- Accurate and comprehensive records are essential for the entire care team to make appropriate decisions. The radiation therapist, not the equipment, is accountable for maintaining the integrity of the patient's treatment history.

- Patient information is stored on a safe and secured facility/hospital network.
- Patient information is limited to health care providers who are directly involved with the patient's treatment and on a need-to-know basis.
- Safeguarding and protection of the patient record is paramount.
- EMR chart entry and access to patient information require a unique login ID.
- Medical conditions that could impede patient treatment outcomes along with disease staging and diagnostic results are documented in the radiation treatment chart.
- Before any procedure, informed consent must be obtained from the patient.
- Patient reactions to the treatment must be carefully monitored by the radiation therapists daily and documented during and after treatment has concluded.
- Patient reactions to radiation treatment may warrant the need for certain medications, lab work, psychosocial, and nutritional interventions.
- The treatment record, radiation prescriptions, and treatment plan make up the radiation treatment record.
- The radiation treatment prescription must provide clear and sequenced information that supports consistent interpretation by experienced specialists, including the radiation therapist.
- Anatomic treatment site is identified first, followed by method of delivery (minimally, photons, electrons, or identifying an isotope).
- The radiation treatment prescription consists of individual dose per treatment session (fractions), preceded by the total number of fractions, and subsequently the total radiation dose intended to be delivered (fractionation).
- Additional elements of the treatment prescription
 - Beam modifiers—accessories that alter the treatment shape or radiation dose distribution at a certain depth
 - Portal/treatment field sizes
 - Gantry beam angles
 - Collimator angles

- Couch rotations
- Beam energy
- Planning instructions
- Protraction schedule-total duration of treatment (number of days between the first and last sessions)
- Ongoing verification imaging communication between the radiation oncologist and the radiation therapist is essential to confirm treatment localization is exact.
- Each treatment session records the radiation dose and the equipment settings that were used to administer it.
- The treatment history provides the treatment date(s) and increments of the given treatment number, elapsed days (total period over which therapy is delayed), fractional and total dose delivered to the prescribed volume, and pertinent structures around or in the treatment volume.
- Every treatment session records the amount of radiation administered as well as the equipment parameters.
- Procedures done during a treatment session are noted, including additions or deletions of bolus or other beam modifiers, and verification imaging (radiographic or electronic therapy documentation).
- Radiation therapists treating patients must be identified in all treatment record entries.

Verification and Record (V&R) Systems transmit pre-validated treatment plan parameters to the treatment machine for configuration and delivery.

- Actual machine parameters are compared to the most recently prescribed values, and treatment beam start is prevented if they fall outside of a predetermined tolerance range.
- The radiation therapists must confirm the accuracy of the treatment record.
- Observable changes/variations from what occurred must be reported and closely examined.
- Because the chart is the key document used in legal proceedings, revisions must clearly show the original entry.

- Corrections made in treatment chart must be legible and provide explanations for the change.
- If using a paper chart, one line should be drawn through the entry, proceeded by the new notation that includes initials of radiation therapists and date of the revised entry.
- Correction fluid (i.e., Wite-Out) of any kind is never to be used to document changes in a patient's treatment chart.
- Changes to treatment orders or changes to entries must be visible in electronic records, just as they are on paper.
- The Joint Commission mandates that authorized institutions adhere to the following the Time Out and Universal Protocol
 - Verification of procedures (room and chart preparation): ascertain the availability of necessary items, verify the procedure and patient site, and match items to the patient
- Time Out Process—required verification of patient identity before simulation, treatment, clinic visit, or treatment planning session, utilizing at least two methods of identification
 - Before initiating a simulation, the radiation therapist must check for a valid consent for radiation treatment, confirm the simulation order/instructions are correct according to the radiation oncologist, and confirm patient identity using at least two methods.
 - Before initiating treatment delivery, the “5 Rights” must be carried out to assess patients before treatment delivery and treatment planning. Time Out process includes the “5 Rights” which confirms the following: Right Patient, Right, Prescription, Right Dose, Right Treatment Site/Plan/Technique/Field, and Right Time

Review Exercises

1. The cycle of infection can be broken by the:
 1. Destruction of the infectious organism

2. Removal of the source of infection
 3. Preventing the means of transmission
 - a. 1 and 2
 - b. 1 and 3
 - c. 2 and 3
 - d. 1, 2, and 3
2. The normal platelet count for an adult is approximately:
- a. 20,000/mL
 - b. 80,000/mL
 - c. 120,000/mL
 - d. 250,000/mL
3. The most common means by which infections are spread is by:
- a. Airborne particulates
 - b. Indirect contact
 - c. Direct contact
 - d. Endogenous contact
4. For what reason is anaphylactic shock the type of shock most often seen in diagnostic imaging?
- a. Patients who come for diagnostic imaging procedures are weak and debilitated
 - b. Iodinated contrast agents are frequently used
 - c. Patients here have more allergies
 - d. X-radiation causes this problem
5. Symptoms of a partially obstructed airway may include:
- a. Cold, clammy skin; pallor; weakness; anxiety
 - b. Flushed, hot skin; hyperactivity; confusion
 - c. Labored, noisy, breathing, wheezing
 - d. Acetone breath, irregular pulse, noisy respiration
6. Alopecia, nausea, vomiting, stomatitis, and skin reactions are all possible side effects of radiotherapy. The correct response to someone asking whether he will experience them would be:
- a. "Yes, but they'll subside once treatment ceases."
 - b. "No, they rarely occur."
 - c. "The type of side effects that will occur is dependent on the specific treatment site and dose."
 - d. "You'll have to ask your doctor."

7. Radiation recall:
- a. The recurrence of the radiation skin reaction when given certain chemotherapy drugs
 - b. Can occur years after radiation
 - c. The recurrence of all radiation toxicities when given certain drugs
 - d. a and b only
 - e. All of the above
8. A patient with lung cancer has shortness of breath, a cough, facial and arm edema, and neck distention. The therapist suspects that the patient has developed:
- a. Cardiac tamponade
 - b. Superior vena cava syndrome
 - c. Pleural effusion
 - d. Tumor lysis syndrome
9. The care plan for a patient receiving narcotics around the clock for pain control should include which of the following daily measures to prevent constipation?
- a. Digital examination for impaction
 - b. Use of suppositories
 - c. Regular administration of mild laxatives
 - d. Fluid intake of approximately 1500 cc/day
10. A patient receiving treatment for lymphoma reports experiencing numbness and tingling in the feet, weakness when ambulating, and dribbling of urine. The therapist should suspect:
- a. Development of diabetes mellitus
 - b. Development of spinal cord compression
 - c. Peripheral neuropathy
 - d. Production of ectopic hormone
11. The most common clinical manifestation of infection in patients with cancer who are neutropenic is:
- a. Fever
 - b. Positive blood cultures
 - c. Dysuria
 - d. Redness at the catheter site

12. If an area must be kept completely free of pathogens, you should follow:
- a. Surgical asepsis
 - b. Gloved technique
 - c. Medical asepsis
 - d. Clean technique
13. If a patient appears to be fainting, the first thing that you should do is:
- a. Assist the patient to a safe position and call for help
 - b. Give smelling salt
 - c. Get crash cart
 - d. Prepare to administer oxygen
14. All drugs given by parenteral routes are given by:
- a. Medical aseptic techniques
 - b. Surgical aseptic techniques
15. The range for normal respiration for adults is:
- a. 20 to 30
 - b. 80 to 90
 - c. 10 to 20
 - d. 8 to 10
16. Within 30 minutes of receiving the first dose of asparaginase, a patient with acute lymphatic leukemia experience tightness of the chest, dyspnea, and nausea. These symptoms suggest that the patient is experiencing:
- a. An anaphylactic reaction
 - b. Cardiac toxicity
 - c. Pulmonary fibrosis
 - d. Anxiety
17. The practice that helps reduce the spread of microorganisms is termed:
- a. Lethargy
 - b. Contracture
 - c. Asepsis
 - d. Isolation
18. In general, the best method for a therapist to maintain medical asepsis and prevent the spread of infection is by frequent and

proper:

- a. Mask usage
- b. Hand washing
- c. Isolation usage
- d. Personal hygiene

19. The patient has the right to:

- a. Refuse medical treatment
- b. Know the qualifications of the medical personnel
- c. Confidential treatment of his or her records:
 - a. a and b
 - b. a and c
 - c. b and c
 - d. a, b, and c

20. A patient that is said to be experiencing dyspnea has:

- a. Breathing difficulties
- b. High blood pressure
- c. A fever
- d. A urinary problem

21. The loss of hair after exposure to radiation is termed:

- a. Epistaxis
- b. Epilation
- c. Erythema
- d. Elation

22. A drug used to relieve symptoms of nausea and vomiting due to irradiation is a/an:

- a. Laxative
- b. Analgesic
- c. Antiemetic
- d. Antidiarrheal

23. Complete the chart of common radiation side effects to include anticipated onset dose and appropriate interventions.

	Onset Dose	Intervention
Skin Reaction		
Diarrhea		
Fatigue		
Pain		
Nausea		
Weight Loss		
Mucositis		
Alopecia		
Cystitis		
Esophagitis		

24. An adult patient who has tachycardia would have a pulse higher than:
- 60 beats/min
 - 90 beats/min
 - 80 beats/min
 - 100 beats/min
25. A drug that would increase the flow of urine is a:
- Derivative
 - Diuretic
 - Diarrheal
 - Antiemetic
26. Refusing to care for a patient who has different religious beliefs from your own would be violation of:
- Criminal law
 - Ethical code
 - Administrative law
 - Personal law
27. Professional ethics are:
- A set of principles that govern a course of action
 - Values of any professional person
 - The same as federal law
 - A set of rules and regulations made up by the facility manager
28. Information about a patient's condition:

- a. May be discussed with close relatives only
 - b. Must always remain confidential
 - c. Is open for discussion if their condition is discussed in medical rounds
 - d. Can be shared with other medical professionals only
29. If your manager asks you to perform a duty outside of your scope of practice, the best course of action would be to:
- a. Proceed as best as you can
 - b. Ask a colleague for directions and then proceed
 - c. Explain that you do not have the education required and feel uncomfortable
 - d. State that you are ill and retreat
30. A persistent threat for HIV or HBV infection for the health care provider is:
- a. The water supply
 - b. Careless patients who do not reveal their status
 - c. Needle-stick injuries
 - d. Tuberculosis exposure
31. An example of a potential source of infection would be:
- a. A co-worker with a cold
 - b. A visitor with a “fever blister” on the mouth
 - c. A patient with pneumonia
 - d. All of the above
32. The method by which all health care providers can control the transmission of blood-borne disease transmission is:
- a. Enteric precautions
 - b. Universal precautions
 - c. Strict isolation
 - d. Reverse isolation
33. The “scope of practice” for the radiation therapist
- a. Could never be used in a court of law
 - b. Describes the responsibilities of the therapist
 - c. Can be used to defend the actions of a nurse
 - d. Can be used to defend the actions of a physician

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Clinical Applications in Radiation Therapy

Leia Levy and Lisa Bartenhagen

Focus Questions

- What epidemiologic and etiologic information is pertinent to each anatomic site?
- How are basic anatomy, physiology, and lymphatic nodal drainage related to disease spread and radiation therapy management?
- Describe the observable clinical presentation of disease associated with each site.
- Compare the detection and diagnosis mechanisms used to classify various neoplastic diseases.
- What is the pathology associated with certain malignancies?
- Apply the appropriate grading and/or staging system associated with each disease site.
- Describe the spread patterns of disease.
- Analyze the principle and practice of simulation and treatment as they apply to each disease site.
- Describe the treatment regimens and fractionation schemes used in disease management.
- Interpret acute and chronic side effects and/or complications encountered during and after a course of therapy.

Head and Neck Cancers

General Facts, Epidemiology, and Etiology

- Represents about 4% of cancers in the United States
- Depending on size, site, and pattern of spread, they can cause varying degrees of structural deformities and functional disabilities
- Tobacco and alcohol use are recognized risk factors
- Epstein-Barr virus (EBV) associated with cancers of the nasopharynx
- Recent study of human papillomavirus (HPV) and associations with carcinomas of the tongue, floor of the mouth, and tonsils
- Prognosis is good for those compliant with aggressive treatment regimens and high-dose chemotherapy and radiation
- Prevention of regional recurrence has long been a challenge due to dose-limiting factors
- Anatomic subdivisions of the upper aerodigestive tract include:

Oral Cavity

- Anterior two-thirds of the tongue, lip, buccal mucosa, retromolar trigone, floor of the mouth, hard palate

Nasopharynx

- Posterosuperior pharyngeal wall and lateral pharyngeal wall, eustachian tube orifice, and the adenoids

Oropharynx

- Base of tongue, tonsils (fossa and pillars), soft palate, and oropharyngeal walls

Hypopharynx

- Pyriform sinuses, postcricoid, and lower posterior pharyngeal walls below base of tongue

Larynx

- Glottis, supraglottis, subglottis

Oral Cavity

Extends from the skin–vermilion junction of the lip to the posterior border of the hard palate superiorly and to the circumvallate papillae inferiorly

Clinical Presentation

- Poor oral and dental hygiene
- Plummer-Vinson syndrome (iron deficiency)
- Leukoplakia/erythroplasia (severe dysplastic changes)
- Nonhealing ulcers
- Squamous cell carcinoma common

Detection and Diagnosis

- Oral inspection and palpation
- Biopsy
- Computed tomography (CT)/magnetic resonance imaging (MRI)
- Positron emission tomography (PET) helps with delineation of GTV (gross tumor volume), CTV (clinical target volume)

Lymphatic Drainage by Site

- Lips to submandibular, preauricular, and facial nodes
- Buccal mucosa to the submaxillary and submental nodes
- Gingiva to the submaxillary and jugular nodes
- Retromolar trigone to the submaxillary and jugulodigastric nodes
- Hard palate to the submaxillary and upper jugular nodes

- Floor of mouth to the submaxillary and jugular (middle and upper nodes)
- Anterior two-thirds of the tongue to the submaxillary and upper jugular nodes

Treatment

- Surgical removal when tumors are small (<1 to 1.5 cm)
- Radiation—5000 to 7000 cGy to GTV and margin; both positive and negative regional lymphatics included in the ITV (irradiated target volume)
 - Hyperfractionated radiation therapy and use of radiosensitizers or radioprotectors possible
 - High-precision radiation therapy using IMRT (intensity-modulated radiation therapy) with IGRT (image-guided radiation therapy) techniques to escalate dose
- Cytotoxic chemotherapy drugs are often used in combination and may be given in sequence or concurrent with radiation

Radiation treatment borders

- Anterior—anterior portion of the mandible
- Posterior—behind vertebral bodies or spinous processes
- Superior—1.5 cm above the tongue
- Inferior—thyroid notch or just below the clavicles when lower jugular and supraclavicular nodes included in the ITV

Nasopharynx

Cuboidal structure lying on a line from the zygomatic arch to the external auditory meatus (EAM), extending inferiorly to the mastoid tip. Nasopharynx is located behind the nose and extends from the posterior nares to the level of the soft palate.

Clinical Presentation

- Bloody discharge
- Auditory dysfunction
- Respiratory dysfunction
- Cranial nerve involvement (III, V, VI, IX, XII)
- Squamous cell carcinoma common

Detection and Diagnosis

- History and physical
- Inspection—indirect mirror examination
- Palpation
- Biopsy
- Fiber optic endoscopy
- CT and MRI
- PET
- Chest x-ray
- EBV—specific serologic tests
- Liver function test/bone scans with advanced disease

Lymphatic Drainage

- Retropharyngeal nodes into the superior jugular and posterior cervical nodes
- Lateral retropharyngeal node (node of Rouvière)

Treatment

- Radiation therapy for early-stage disease
- Concurrent chemoradiotherapy for locally advanced disease
- Radiation to the GTV and margin plus any positive or negative lymph nodes at risk 5000 to 7000 cGy
- IMRT with IGRT techniques to escalate dose

Radiation treatment borders

- Superior—2 cm beyond tumor (seen on CT) to include base of skull and sphenoid sinuses
- Posterior—2-cm margin beyond mastoid process, or posterior margin may extend further to allow a 1.5-cm margin on enlarged nodes
- Anterior—to include the posterior third of the maxillary sinus and nasal cavity, careful attention to adequate margin (2 cm) for more anterior tumors
- Inferior—thyroid notch to allow sparing of larynx
- Lower neck—anterior supraclavicular fossa
- Brachytherapy can be used to deliver boost to small lesions

Oropharynx

Clinical Presentation

- Sore throat
- Pain on swallowing
- Upper spinal nodal swelling
- Referred otalgia
- Squamous cell carcinoma common

Detection and Diagnosis

- Direct inspection
- Palpation
- Biopsy

Lymphatic Drainage

- Base of tongue into jugulodigastric, low cervical, and retropharyngeal nodes
- Tonsillar fossa into jugulodigastric and submaxillary nodes
- Soft palate into jugulodigastric, submaxillary, and spinal accessory nodes

- Pharyngeal walls into retropharyngeal nodes, pharyngeal nodes, and jugulodigastric nodes

Treatment

- T1-T2 soft palate, tonsil, pharyngeal wall, tongue; conventional 66 to 70 Gy
- T3-T4 oropharyngeal and T2 base of tongue; 70 to 81.6 Gy
- Hyperfractionation—70 Gy
- Clinically negative nodes—50 to 54 Gy
- With node dissection—60 Gy
- IMRT (major salivary glands and oral mucosa are spared, less trismus and xerostomia)

Radiation treatment borders

- Anterior—2 cm from known tumor
- Superior—1.5 to 2.0 cm superior to the soft palate
- Posterior—posterior spinous processes
- Inferior—level of the hyoid

Hypopharynx

The inferior portion of the pharynx extends from the hyoid bone superiorly to the cricoid inferiorly. Divided into three components: pharyngeal walls, pyriform sinus, and postcricoid pharynx

Clinical Presentation

- Sore throat
- Odynophagia
- Neck mass
- Dysphagia (hallmark of postcricoid carcinoma)
- Weight loss
- Squamous cell carcinoma common

Detection and Diagnosis

- Inspection
- Palpation
- Biopsy
- Fiber optic endoscopy
- CT/MRI
- PET

Lymphatic Drainage

- Superior deep, middle, and low jugular nodes
- Lateral retropharyngeal lymph nodes at base of skull (Node of Rouviere)

Treatment

- T1-2 (rare) could be treated with radiation or surgery
- T2-4 surgery and radiation therapy
- Chemotherapy may be added
- Large radiation treatment fields to include GTV, positive and negative nodes; GTV to 64 to 70 Gy; standard fractionation includes 2 Gy per fraction; hyperfractionation may be 1.2 Gy per fraction twice daily to higher total dose in the range of 70 to 78 Gy

Radiation treatment borders

- Superior—inferior border of mandible and mastoid process, to the base of skull
- Inferior—lower border of the cricoid cartilage; 1.5- to 2.0-cm margin to cover the retropharyngeal nodes
- Anterior—in front of the thyroid cartilage “shine off” (fall off) if larynx involved
- Posterior—behind the spinous processes

Larynx

- Glottis
- Supraglottis
- Subglottis

Clinical Presentation

- Persistent sore throat
- Hoarseness and stridor
- Voice changes
- Enlarged cervical lymph nodes—supraglottic lesions especially
- Squamous cell carcinoma common

Detection and Diagnosis

- Palpation
- Direct inspection
- Laryngoscopy
- CT and MRI
- PET
- Barium swallow (optional)
- Biopsy

Lymphatic Drainage

- Glottis—extremely rare for nodal involvement
- Subglottis—into the peritracheal and low cervical nodes
- Supraglottis—into the peritracheal, cervical, and submaxillary nodes

Treatment

- Early lesions—surgery or radiation
- Advanced lesions—surgery and postoperative radiation

- Helophytic lesions—more responsive to radiation than infiltrative lesions
- Poorly differentiated carcinoma—radiation alone or concurrent with chemotherapy
- Veracious carcinoma—conservative surgery

Radiation treatment borders

Glottis

- Superior—upper thyroid notch
- Inferior—cricoid cartilage (lower border of C6)
- Anterior—1- to 1.5-cm shine over (flash) over the skin surface at the level of the vocal cords
- Posterior—just anterior to the vertebral body, including the anterior portion of the posterior pharyngeal wall
- 60 to 70 Gy in 2-Gy fractions; higher dose for those with bulky disease

Supraglottic and Subglottis

- Often much larger fields
- Fields should include jugulodigastric, anterior and posterior cervical, and supraclavicular lymph nodes
- 60 to 70 Gy to GTV in 2-Gy fractions or hyperfractionation with 1.2 Gy per fraction twice daily to total 76.8 Gy; negative nodes to 45 Gy
- Postoperative radiation therapy (RT) 60 Gy to tumor bed

Salivary Glands—Parotid

- Play a role in digestion and tooth protection
- Parotid gland is the largest of all salivary glands and located superficial to and partly behind the ramus, covering the masseter muscle

- Two-thirds of tumors are benign; salivary gland malignancies are rare
- Majority of salivary gland malignancies occur in the parotid gland

Clinical Presentation

- Asymptomatic parotid mass lasting 4 to 8 months
- Pathology-adenoid cystic, mucoepidermoid and adenocarcinoma
- Extensive lymphatic capillary plexus
- Localized swelling of face, pain, facial palsy
- Rapidly growing
- Facial nerve involvement—causing paralysis

Detection and Diagnosis

- Full oral cavity inspection
- Flexible fiberoptic nasopharyngolaryngoscopy
- Assessment of cranial nerves
- US-guided fine needle aspiration or core needle biopsy
- CT and MRI
- PET

Lymphatic Drainage

- Intraglandular and extraglandular parotid nodes
- Submandibular nodes

Treatment

- Surgery for complete resection
- Radiation postoperatively for residual, recurrent, or inoperable lesions
- Systemic chemotherapy used palliatively
- Local recurrent disease can receive low to moderate dose external beam RT plus hyperthermia

Radiation treatment borders

- Superiorly—zygomatic arch or higher
- Anteriorly—anterior edge of the masseter muscle
- Inferior—thyroid notch
- Posterior—just behind mastoid

Treatment delivery

- Treatment delivered by conventional wedged field technique superior and inferior oblique combination; opposed lateral fields if target extends beyond midline
- Doses: postoperative case—60 to 66 Gy; 70 to 75 Gy if gross residual disease with standard fractionation
- Target volume will include local invasion and lymphatics involved
- IMRT with IGRT to escalate dose
- Concern—preservation of salivary function by sparing at least one parotid gland has been a primary objective of head and neck IMRT
- Submandibular and sublingual only account for 2% to 3% of all head and neck cancers
- Neutron or proton therapy possible; 70 to 75.9 cobalt-gray equivalent
- Stereotactic radiosurgery with hypofractionation to total 12 Gy

Maxillary sinus

- Pyramid-shaped cavity lined by ciliated epithelium
- Carcinomas arise from the ciliated epithelium or mucous glands
- Roof of the maxillary sinus is the floor of the orbit
- Alveolar process and hard palate separate the maxillary sinus from the oral cavity
- Ohngren's line is a theoretical line passing from the medial canthus of the eye to the angle of the mandible and divides the maxillary sinus into a superior and inferior portions

- Maxillary sinus disease accounts for 80% of all sinus cancer with 2:1 male prevalence
- Although lymphatics are in the region, maxillary sinus tumors rarely involve regional lymphatics
- Adenocarcinoma of nasal cavity and ethmoid sinus has been associated with

wood dust exposure

- Squamous cell carcinomas of the maxillary sinus and nasal cavity are associated with

chemical agents found in nickel refinery and leather tanning

Clinical Presentation

- Tumors may involve the trigeminal branches of the cranial nerves.
- Displacement of the eye

Detection and Diagnosis

- Most useful studies—CT to define early cortical bone erosion and MRI delineates soft tissue and can differentiate among opacification of the sinuses due to fluid, inflammation, or tumor. MRI can also demonstrate subtle perineural spread and involvement of the cranial nerve foramen and canals.

Lymphatic Drainage

- Lymph involvement is rare
- Submaxillary, upper jugular, and posterior cervical are commonly found positive in recurrent disease

Treatment

- Surgery—only for small lesions of nasal septum or those limited to the infrastructure of the maxillary sinus

- Surgery and

postoperative radiation—advanced stages

- Radiation may be used when a massive tumor exists that involves the nasopharynx, base of skull, sphenoidal sinuses, brain, or optic chiasm.
- Postoperative radiation (

Figure 8.1)—60 to 63 Gy (1.8–2.0 per fraction), external beam, wedged pair technique with coned down boost; 70 Gy recommended for unresectable tumors; orbit block if not involved; care taken in order to miss the cord and contralateral lens; IMRT offers a more therapeutic ratio for tumor over conventional treatment

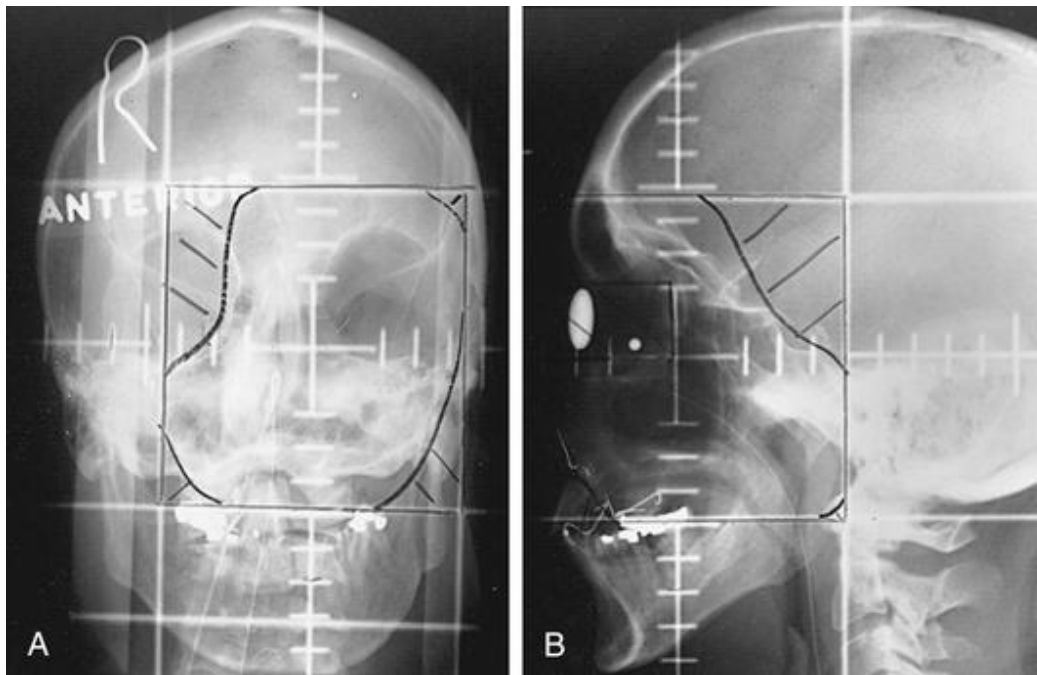


FIG. 8.1 A , Anterior left maxillary sinus portal.

B , Left lateral maxillary sinus portal.

Treatment delivery and considerations for head and neck

-

Table 8.1 lists typical curative radiation doses for head and neck lesions;

Table 8.2 includes an approximate dose–tissue response schedule.

- Periodontal disease and caries—Teeth extractions should be done before radiation treatment.
- Maintaining adequate nutrition is a major problem for these patients
- Mucositis/stomatitis—inflammation of the oral mucous membranes with edema and tenderness (3000 cGy)
- Xerostomia—dry mouth may be seen after 1000 to 2000 cGy and may be permanent after 4000 cGy. Poses risk for dental caries and oral infections
- Cataract formation if lens is treated; doses as low as 1000 cGy
- Lacrimal glands—dry painful eye (severe dry eye syndrome reported in 100% of patients receiving more than 5700 cGy)
- Taste changes—taste buds are radiosensitive and atrophy and degeneration are noted at 1000 cGy
- Skin reactions—usually acute and depending upon dose, energy of beam, and use of radiosensitizing chemotherapy drugs
-

Box 8.1 describes an oral hygiene program;

Box 8.2 lists a skin care program.

- Many head and neck protocols incorporate the use of radioprotectors and/or concurrent chemotherapy; be mindful of treatment delivery time.
- It is important to be mindful of specific protocol instructions regarding documentation of daily treatments, portal verification, monitoring of progress, and side effects.
- Standard fractionation schemes may be used but hyperfractionation schemes are not uncommon.

- High total doses require extensive treatment planning and application of IMRT, PET/CT image fusion planning, complex immobilization systems, and use of accessories such as wedges, bolus, and/or compensators.
- Simulation, planning, and daily treatment billing should be at the complex level.

TABLE 8.1

Typical Curative Radiation Doses for Head and Neck Lesions

5000 cGy	Nodes
5000 cGy	Any subclinical disease
6000–6500 cGy	T1 lesions
6500–7000 cGy	T2 lesions
7000–7500 cGy	T3-4 lesions

From Washington CM, Leaver D.

Principles and Practice of Radiation Therapy . 3rd ed. Mosby; 2010.

TABLE 8.2**Approximate Dose–Tissue Response Schedule for a Conventional Fractionation Scheme**

Response	Dose (cGy)
Dry mouth	2000
Erythema	2000
Brachial plexus	5500
Spinal cord	4500
Lhermitte sign	2000–3000
Mandible, teeth and gums	5000–6000
Mucositis	3000
Ears	4000
Cataracts	500–1000
Dry eye	4000
Optic nerve	5000
Retina	5000
Trismus	6000
Laryngitis	5000

From Washington CM, Leaver D.

Principles and Practice of Radiation Therapy . 3rd ed. Mosby; 2010.

BOX 8.1

Recommended Oral Hygiene Program

- Clean teeth and brush gums after meals.
- Use fluoride toothpaste or fluoride rinses daily.
- Floss daily.
- Rinse the mouth with salt and a baking-soda solution (1 qt water, 1/2 tsp salt, 1/2 tsp baking soda).
- See a dentist regularly during treatment for a teeth and gum examination.
- To reduce the severity of any head and neck complication, the patient should be encouraged to avoid the following:
 - Spicy hot foods, coarse or raw vegetables, dry crackers, chips, and nuts
 - Smoking, chewing tobacco, and alcohol
 - Sugary snacks
 - Commercial mouthwash that contains alcohol because it dries the mouth
 - Cold foods and drinks

From Washington CM, Leaver D.

Principles and Practice of Radiation Therapy . 3rd ed. Mosby; 2010.

BOX 8.2

Recommended Skin Care Program

- Wash the skin with lukewarm water, pat dry, and do not wash off marks.
- Use mild soaps (e.g., Basis, Neutrogena).
- Use water-based lotions or creams (e.g., Aquaphor, Eucerin).
- Avoid lotions with perfume and deodorants.
- Avoid direct sunlight.
- Do not use straight razors.
- Avoid tight-fitting collars and hat brims.
- Do not use aftershave lotions or perfumes.
- Apply only nonadherent, hydrophilic dressings to wounds.

From Washington CM, Leaver D.

Principles and Practice of Radiation Therapy . 3rd ed. Mosby; 2010.

Head and neck review exercises

1. List clinical detection for each of the following sites.
 - a. Oral cavity
 - b. Oropharynx
 - c. Hypopharynx
 - d. Nasopharynx
 - e. Larynx
 - f. Maxillary sinus
2. Label

Figure 8.2 (12 answers).

3. Match the landmark to the description.

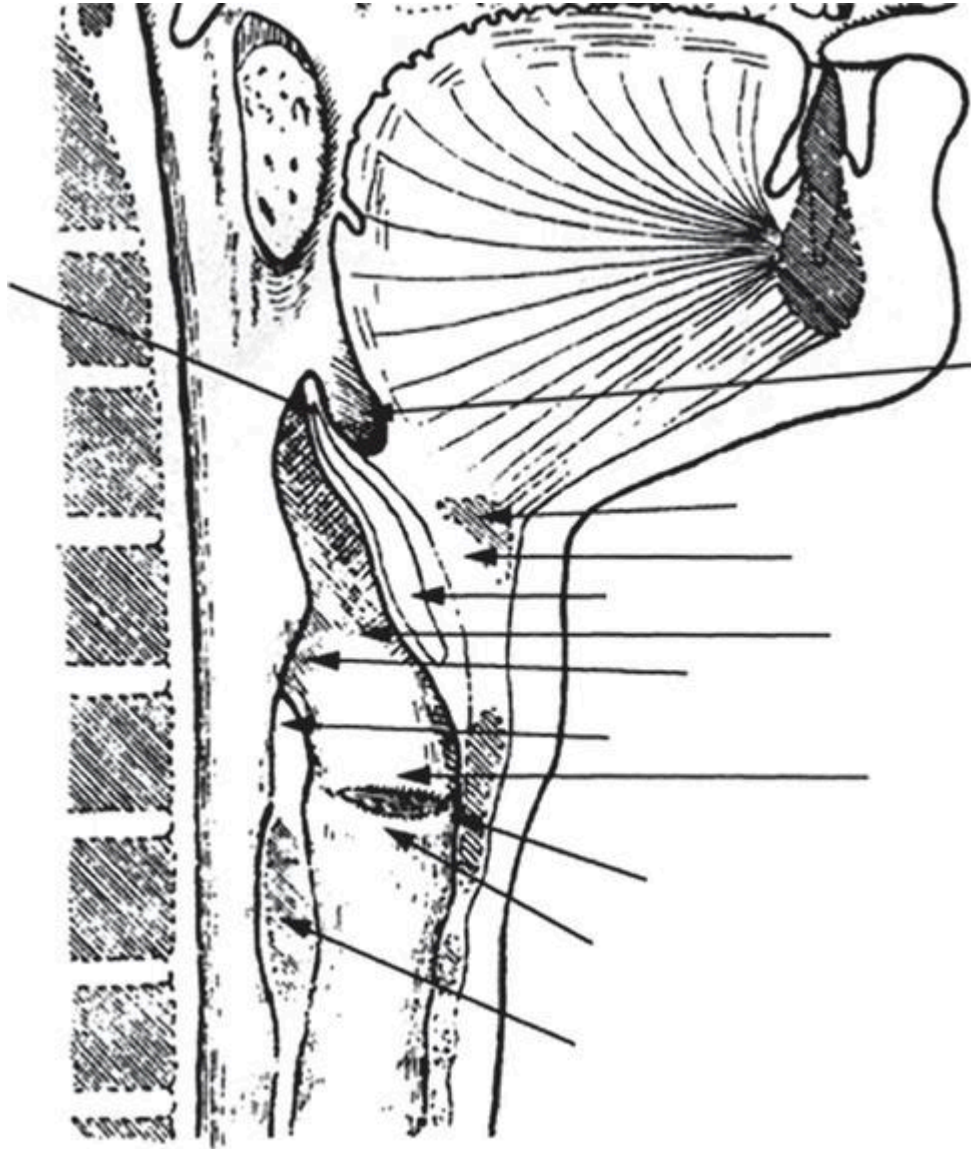


FIG. 8.2 For anatomical labeling.

Superior orbital margin (SOM)

Inferior orbital margin (IOM)

External occipital protuberance (EOP)

Mastoid process

Zygomatic arch

Glabella

Nasion

Inner canthus (IC)

Outer canthus (OC)

Tragus

Commissure of the mouth

C1

C2

C3

C4

C6

C7

Sternocleidomastoid muscle

- a. Located at the outer aspect of the eye where the upper and lower eyelids meet
 - b. Lies inferior to the mastoid process
 - c. The depression at the base of the nose
 - d. The first prominent process of the cervical vertebrae
 - e. Located at the level of the angle of the mandible
 - f. The roof of the orbit
 - g. A thick band attached to the mastoid and occipital bones superiorly and sterna and clavicular heads inferiorly
 - h. Corresponds to the level of the thyroid cartilage
 - i. The bony prominence of the cheek
 - j. Located between the orbits
 - k. Located at the junction of the upper and lower lip
 - l. Located at the level of the cricoid cartilage
 - m. Lies at the level of the hyoid bone
 - n. Forms the lateral margin of the bony orbit
 - o. Located at the medial aspect of the eye where the upper and lower eyelids meet
 - p. The central prominence in the occipital bone
 - q. Located near the external auditory meatus
 - r. The most lateral and inferior extension of the temporal bone
4. Fill in the function of each of the cranial nerves:

Olfactory	I	_____
Optic	II	_____
Oculomotor	III	_____
Trochlear	IV	_____
Trigeminal	V	_____
Abducens	VI	_____
Facial	VII	_____
Acoustic	VIII	_____
Glossopharyngeal	IX	_____
Vagus	X	_____
Spinal accessory	XI	_____
Hypoglossal	XII	_____

5. About _____ of the body's lymph nodes are located in the head and neck area.
 - a. one-fourth
 - b. one-third
 - c. two-thirds
 - d. one-half
6. How many cartilages make up the larynx?
 - a. 3 pair
 - b. 6 pair
 - c. 9
 - d. 12
7. What muscle divides the neck into anterior and posterior triangles?
 - a. Trapezius

- b. Pterygoid
 - c. Longissimus dorsi
 - d. Sternocleidomastoid
8. The _____ nodal group, below the mastoid tip, receives nearly all of the lymph from the head and neck area and is often included in the treated area.
- a. Submandibular nodes
 - b. Carotid nodes
 - c. Jugulodigastric nodes
 - d. Rouvière nodes
9. What is the function of the hyoid bone?
- a. Acts as an attachment site for muscles associated with swallowing
 - b. Prevents food from entering the trachea
 - c. Protects the delicate vocal cords
 - d. Acts as a base for the laryngeal cartilages to rest on
10. Which of the following is typically the largest vascular structure located in the neck?
- a. Common carotid artery
 - b. Internal jugular vein
 - c. Internal carotid artery
 - d. External carotid artery
11. The jugulodigastric node may also be referred to as:
- a. Node of Rouvière
 - b. Subdigastric node
 - c. Retropharyngeal nodes
 - d. Circle of Willis
12. Postcricoid and pyriform sinuses are located in which of the following?
- a. Oropharynx
 - b. Hypopharynx

- c. Ethmoid sinuses
 - d. Maxillary sinuses
13. Which of the following is not considered part of the oral cavity?
- a. Buccal mucosa
 - b. Hard palate
 - c. Floor of the tongue
 - d. Soft palate
14. The tonsils are the most common site of disease in which of the following area?
- a. Oral cavity
 - b. Oropharynx
 - c. Nasopharynx
 - d. Hypopharynx
15. Many structures and soft tissue of the aerodigestive track within the facial/cervical regions can be directly examined by means of:
- 1. Palpation
 - 2. Direct inspection
 - 3. Biopsy
- a. 1, 2
 - b. 1, 3
 - c. 2, 3
 - d. 1, 2, 3
16. Which of the following lymph node area is a very high risk for dissemination of disease, is inaccessible for surgery, and therefore must be included as the minimum target volume when treating the nasopharyngeal area?
- a. Waldeyer ring
 - b. Rouvière nodes
 - c. Circle of Willis
 - d. Jugulodigastric nodes

Define the Following Symptoms Often Indicated in Specific Areas of Head and Neck Cancers.

List the Specific Areas Where They Often Occur

17. Otalgia
18. Dysphagia
19. Stridor
20. Diplopia
21. Erythroplasia
22. Leukoplakia
23. Keratosis
24. Dysplasia
25. Odynophagia
26. The majority of head and neck cancers arise from epithelial surfaces and mucosal linings of the upper digestive tract and are mostly:
 - a. Adenocarcinoma
 - b. Squamous cell carcinoma
 - c. Lymphomas
 - d. Keratinized carcinoma
27. The two most common etiologic factors contributing to head and neck cancers are:
 1. Smoking
 2. Heredity
 3. Alcohol
 4. Environmental
 - a. 1, 2
 - b. 1, 3

c. 2, 3

d. 2, 4

28. The main goals in treating head and neck cancers and determining the best modality of treatment are:

1. Eradication of disease

2. Maintenance of physiologic function

3. Preservation of social cosmesis

a. 1, 2

b. 1, 3

c. 2, 3

d. 1, 2, 3

29. Plummer-Vinson syndrome (iron deficiency anemia), often seen in females, is considered an important etiologic factor in which of the following cancers?

a. Oral cavity

b. Oropharynx

c. Nasopharynx

d. Hypopharynx

30. In some head and neck cancers, the supraclavicular area is often treated if there is advanced disease or lower involved nodes. The normal dosage of irradiation to this area:

a. 2500 cGy

b. 3000 cGy

c. 5000 cGy

d. 6500 cGy

31. Which of the following is found at the base of the tongue?

a. Uvula

b. Vallecula

c. Tonsillar fossa

d. Posterior pillar

32. The treatment field for a primary tumor in the hypopharynx includes the node of Rouvière. A sharp field edge is necessary to avoid and protect the:
- a. Spinal cord
 - b. Base of the brain
 - c. Larynx
 - d. Epiglottis
33. The highest rate of nodal metastases in all head and neck cancers is found with cancers in the:
- a. Oropharynx
 - b. Hypopharynx
 - c. Nasopharynx
 - d. Maxillary sinus
34. Tumors of the head and neck may involve the cranial nerves that control our major senses. This may lead to signs and symptoms that can point to a possible location of the tumor. Which area would be the most common for involvement of cranial nerves?
- a. Oral cavity
 - b. Oropharynx
 - c. Hypopharynx
 - d. Nasopharynx
35. A mouth stent or tongue blade may serve more than one purpose when used during irradiation treatments to head and neck cancers. They may serve to separate or _____ the palate.
- a. Moisten
 - b. Displace
 - c. Immobilize
 - d. Sterilize
36. Which of the following is considered at the most risk when treating the maxillary antrum with radiation?
- a. Brain

- b. Eye
 - c. Skin
 - d. Pituitary
37. The most common site of distant metastatic disease from the head and neck area is the:
- a. Brain
 - b. Bone
 - c. Lungs
 - d. Liver
38. More than 80% of head and neck cancers arise from the surface epithelium of the mucosal linings of the upper digestive tract and are:
- a. Adenocarcinomas
 - b. Squamous cell carcinomas
 - c. Transitional cell carcinomas
 - d. Seminoma cancer
39. The usual wedge-pair technique often used in treatment of the parotid gland is:
- a. Superior/inferior oblique combination
 - b. Anterior/posterior oblique combination
 - c. Anterior/posterior combination
 - d. Anterior/inferior oblique combination
40. The most commonly involved site for malignancy of the sinuses would be:
- a. Ethmoid
 - b. Maxillary
 - c. Sphenoid
 - d. Frontal

Lung

General Facts and Epidemiology

- Men have slightly higher incidence than women
- Incidence is decreasing in the US while increasing worldwide per 2019 reports
- Mortality rates have increased greatly in women over the past half-century
- More cigarettes consumed daily increases risk
- Most cases caused by habitual or environmental exposure to tobacco smoke
- Non-tobacco-associated lung cancer represents 10% to 20% of lung cancers in men and women, respectively
- Average age for onset is 60 years
- Smoking cessation decreases risk over time

Etiology

- Smoking
- Exposure to combustion by-products
- Asbestos
- Pollution
- Pitchblende
- Chemicals such as arsenic
- Metals such as cadmium and chromium
- Ionizing radiation

Clinical Presentation

Signs and symptoms

- History of smoking
- Persistent, unproductive cough
- Hoarseness
- Hemoptysis
- Weight loss
- Dyspnea

- Unresolved pneumonitis
- Chest wall pain
- Apical tumors: weakness in arm, swelling in neck
- Atelectasis
- Pleural effusion

Histology

- Small cell/oat cell-high mortality; very aggressive
- Large cell
- Squamous cell
- Adenocarcinoma
- Adenosquamous
- Mesothelioma
- Carcinosarcomas
- Carcinoid

Lymphatic Drainage and Spread Patterns

- Mediastinal and supraclavicular lymph nodes (

[Figure 8.3](#)) are regional drainage.

- Paratracheal, subcarinal, interlobar, paraesophageal, upper aortic are mediastinal nodes.
- Regional spread may be to adjacent lobe (considered metastatic).
- Blood metastasis to liver, brain, bone, bone marrow.
- Small cell cancer has high risk for brain metastasis early.

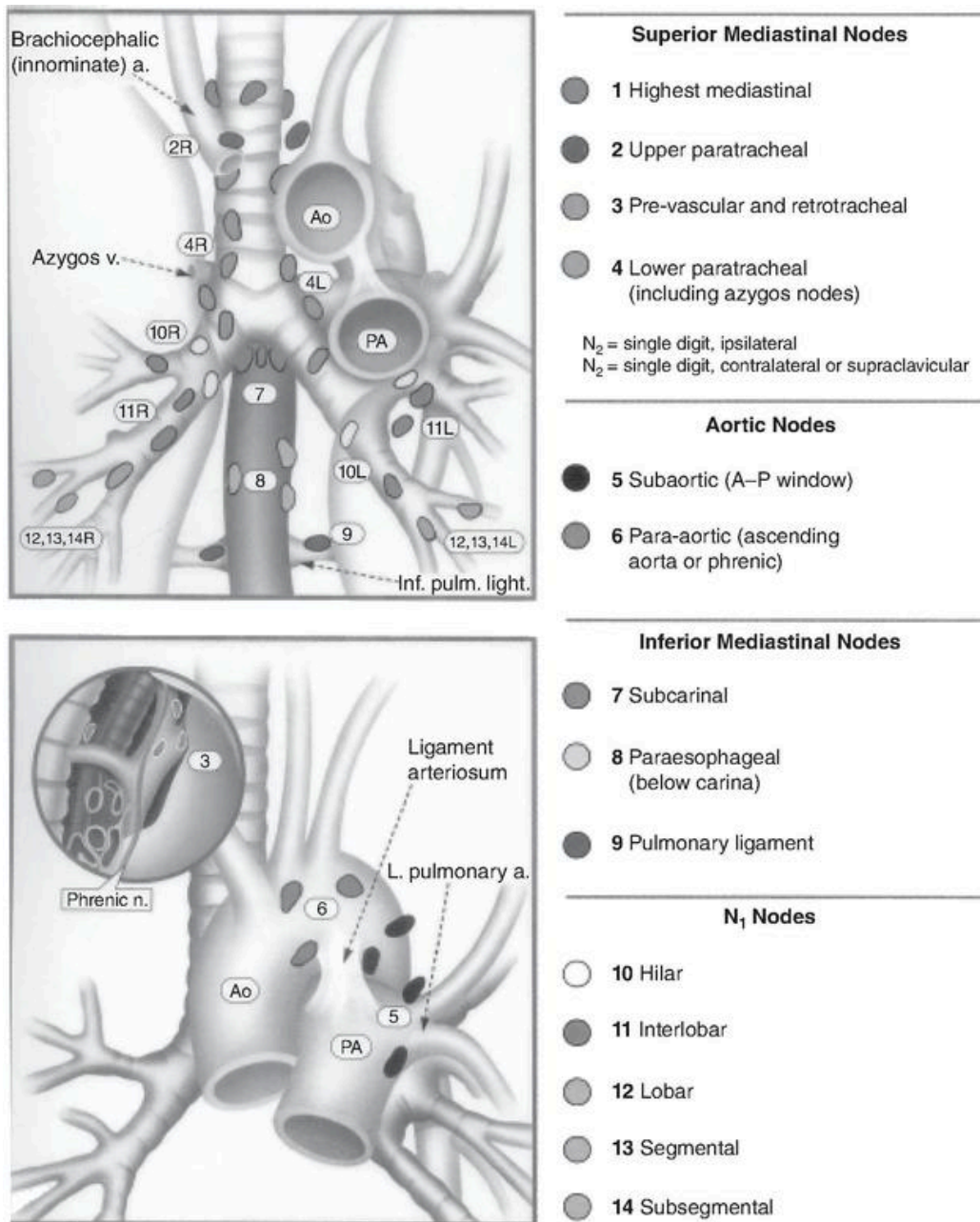


FIG. 8.3 Mediastinal lymph nodes.

Detection and Diagnosis

- Physical examination
- Chest x-ray
- CT of the thorax and abdomen
- Needle biopsy

- Sputum cytology
- Bronchoscopy with biopsy
- Bone and liver scan to rule out metastasis
- CT of the brain if small cell
- PET-CT fusion
- Blood markers: carcinoembryonic antigen (CEA), neuron-specific enolase for small cell especially, RAS oncogene, TP53 tumor suppressor gene
- Staging—TNM

Treatment

- Patient performance must be evaluated using a tool such as Karnofsky scale.
- Surgery is the treatment of choice for early disease with a lobectomy or segmentectomy.
- Unresectable patients may be those with confirmed distant metastasis, pleural effusion, superior vena cava obstruction, tracheal wall invasion, and/or small cell histology.
- Radiation may be used definitively if unresectable or adjuvant to surgery and chemotherapy; for recurrent disease; emergently for relief of superior vena cava (SVC) syndrome or prophylactic

to the central nervous system (CNS) in small cell carcinoma; palliatively

- Chemotherapy under investigation for more substantial adjuvant role in management of non-small cell carcinomas
- Chemotherapy primary treatment for small cell carcinomas
- Small cell carcinomas very sensitive to chemotherapy

Radiation treatment borders

- Radiation treatment fields may include lesion and margin and regional lymph nodes or exclude nodes
- Stereotactic Body Radiation Therapy Under Study

- Lesions (GTV)—tumor and margin, along with mediastinal and supraclavicular nodes is conventional; inoperable stage I-III may be treated with smaller fields and escalated doses
- Prophylactic cranial fields for small cell include the entire brain with sufficient margin on the fourth ventricle
- PET/CT fusion helpful in defining region of interest

Treatment delivery

- Total dose to lung lesion and margin typically 50 Gy if radiation is adjuvant to surgery or chemotherapy
- Total dose to lung for palliative intent typically 45 Gy
- Total dose to lung and margin typically 60 Gy if radiation used alone with standard fractionation
- Stereotactic body radiation (SBRT) and IMRT techniques may escalate dose to 70 Gy
- SBRT regimens may involve 3 to 5 fractions or more protracted over 8 to 10 fractions to doses ranging 54 to 72 Gy
- Protocols for small cell lung carcinomas may require hyperfractionation; 1.5-Gy fractions twice daily to 24 Gy, then 2-week break before receiving an additional 24 Gy
- Critical organs in thorax have low tolerance to radiation, so complex strategies are used; often oblique off-cord and boost fields incorporated
- Patient should be positioned to accommodate complex portal arrangements; arms elevated in reliable positioning and immobilization device
- Prone position for posterior, middle/lower lobe lung lesions facilitates easy daily setup for off-cord and boost fields
- Wing boards, prone pillows are intermediate positioning aids
- Use of alpha cradle or vac lock for daily positioning and immobilization are complex aids
- Advanced internal volume localization such as breath-hold, respiratory gating, and CT simulation at full inspiration and full expiration are helpful in planning

- As tissue densities vary greatly in the thorax, modifiers will likely be used such as wedges or tissue compensators

or unequal beam weighting techniques

- Small, localized lesions may be treated with dynamic therapy such as IMRT, and stereotactic or tomotherapy
- Prophylactic cranial irradiation for small cell lung carcinoma typically given in 18 fractions to 36 Gy
- Emergency treatment of superior vena cava typically in 300 to 400 cGy per fraction; three or four consecutive treatments for quick response then complete workup is needed
- Slight incline helps facilitate easier breathing for short-course treatment plans such as SVC syndrome palliation
- Remind patient of the importance of nutrition despite esophagitis/mucositis caused by radiation or chemotherapy; avoid alcohol, smoking, and acidic and spicy foods that would further irritate the trachea and esophagus
- Skin care: keep area clean and dry, no deodorants if axillary areas treated, no commercial lotions or creams on irritated areas; protect chest from sun exposure and extreme temperatures

Lung review exercises

1. Define the following:

Odynophagia

Hemoptysis

Dyspnea

Atelectasis

2. List all mediastinal lymph nodes.

3. Using the cross-sectional images in

Figure 8.4 below, complete the following:

a. Outline the gross tumor volume.

- b. Outline the critical structures and list tolerance doses for each.
 - c. Diagram possible directions for off-cord and boost treatment fields.
4. List four etiologic factors for lung cancer.
 5. Note common anatomic locations and physical characteristics for the manifestations of the following lung tumors:

Adenocarcinoma:

Squamous cell carcinoma:

Pancoast tumor:

Mesothelioma:

Large cell carcinoma:

6. The histologic type of lung cancer seen in patients with no history of smoking is:

- a. Adenocarcinoma
- b. Small cell carcinoma
- c. Large cell carcinoma
- d. Squamous cell carcinoma

7. “Clubbing” of the fingers is one physical symptom of:

- a. Chronic obstructive pulmonary disease
- b. Pleurisy
- c. Atelectasis
- d. Pneumonitis

8. The histologic type assumed to indicate that there is already distant disease at the time of diagnosis is:

- a. Oat cell carcinoma of the lung
- b. Squamous cell carcinoma of the lung
- c. Adenocarcinoma of the lung
- d. Large cell lung carcinoma

9. A patient with a middle lobe posterior lung tumor may be positioned prone to facilitate:

- a. Easier breathing

- b. Clinical verification of spinal alignment
- c. Easier alignment of off-cord obliques and boost fields directed posteriorly
- d. Easier alignment of off-cord obliques and boost fields directed anteriorly

10. Using

Figure 8.5 , draw the likely emergency treatment field for the patient diagnosed with superior vena cava syndrome caused by right Pancoast tumor.

11. Total dose for prophylactic cranial irradiation is typically:

- a. 2000 cGy
- b. 3000 cGy
- c. 3600 cGy
- d. 4500 cGy

12. To verify the histology of a suspected lung cancer, all of the following could be helpful except:

- a. Excisional biopsy
- b. CT scan
- c. Bronchoscopy with biopsy
- d. Sputum cytology

13. How many lobes does the right lung have?

- a. 2
- b. 3
- c. 4
- d. 5

14. Target volume delineation for lung tumors may involve cardiac or respiratory gating procedures. The rationale for this is that lung tumors:

- a. Are often metastatic
- b. Are difficult to image

- c. Move with cardiac and respiratory motion
 - d. Change shape with cardiac and respiratory motion
15. The histologic type of lung cancer most closely associated with asbestos exposure is:
- a. Adenocarcinoma
 - b. Mesothelioma
 - c. Squamous cell carcinoma
 - d. Oat cell carcinoma

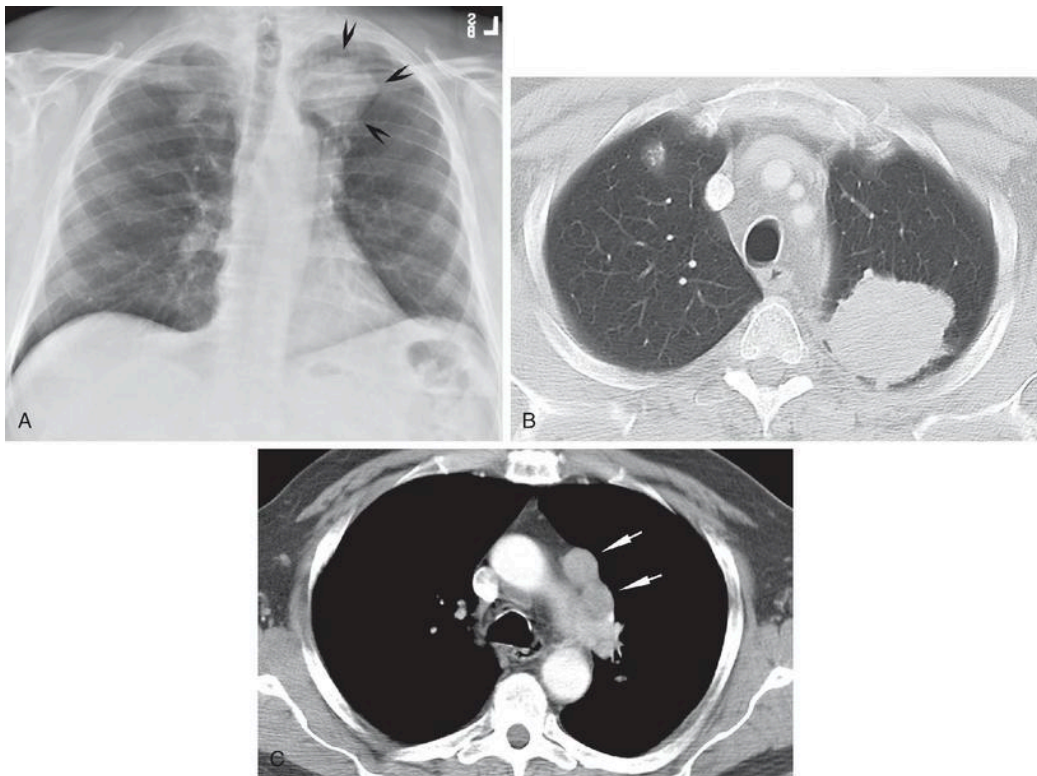


FIG. 8.4 A , Anterior chest x-ray.

B , CT lung window axial.

C , CT axial chest.

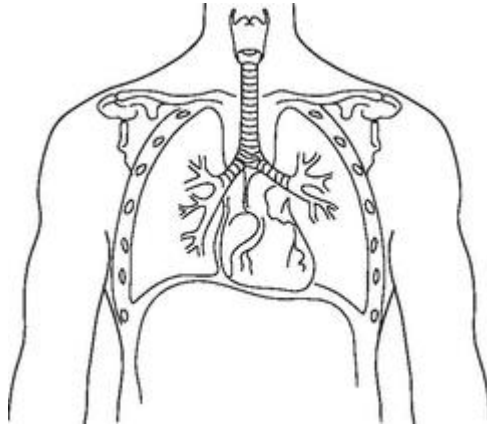


FIG. 8.5 Anterior chest.

Alimentary canal: esophagus, stomach, small bowel, colon, anus

General Facts and Epidemiology

- Cancer of the digestive tract is very common.
- Most common location is the colorectal area.
- Men affected more frequently than women in all areas except small bowel, then incidence is 1:1.
- These tumors often present late due to vague symptoms. Symptoms may mimic several benign conditions of the digestive tract. By the time there is a palpable mass in the abdomen or there is hemorrhaging, the tumor is quite large.
- Grow from inner layers of the organ to the outside; from mucosa out to the serosa.
- Incidence for esophageal cancer is higher in African Americans; China, Japan, Finland, Iran are high-risk locations; average age of onset is 60.
- Incidence for stomach cancer is higher in African Americans and Native Americans; higher risk in low socioeconomic groups; Japan, Chile, Costa Rica are high-risk areas; average age of onset is 55.

- Small bowel cancer is very rare; only make up 5% of gastrointestinal cancer cases; average age is 59.
- Colon/rectum cancers are second in incidence for men and women in the United States.
- Risk increases with age, male sex, family history, and increased body mass index for colon/rectum. The risk is strongly related to diet. Adenomas and polyps are precursors; average age is 50.
- The anus is generally a rare site for cancer; however, there has been an increased incidence in the past 30 to 40 years.
- Risk factors for anal cancers include HPV infection, HIV infection, chronic immunosuppression, smoking, and benign anal conditions.

Esophagus

The esophagus can be divided into two, three, or four divisions (

[Table 8.3](#)).

TABLE 8.3

Divisions of the Esophagus

Two Divisions	Three Divisions	Four Divisions
Cervical	Upper $\frac{1}{3}$	Cervical: C6-SSN
Thoracic	Middle $\frac{1}{3}$	Upper thoracic: SSN-carina
Lower $\frac{1}{3}$	Mid thoracic: carina-esophagogastric junction	Lower thoracic: at the cardia

Etiology

Direct causes unknown

Associated conditions:

- Chronic consumption of hot, highly seasoned foods
- Alcohol (especially for squamous cell type)
- Smoking
- Chemical exposure
- Obesity
- Short esophagus
- Tylosis (genetic disorder involving hyperkeratosis of palms and soles of the feet)
-

Helicobacter pylori infection

- Barrett's disease

Clinical Presentation

Signs and symptoms

- Dysphagia and weight loss most common
- Chest pain
- Odynophagia
- Hoarseness if laryngeal nerve compressed
- Superior vena cava syndrome
- Hematemesis

Histology

- Squamous cell found mostly in proximal and mid-esophagus
- Adenocarcinoma found in distal esophagus and gastroesophageal junction
- Three-fourths of those diagnosed in the United States will have adenocarcinoma of the distal esophagus

Detection and Diagnosis

- History and physical
- Barium swallow under fluoroscopy
- Esophagoscopy with biopsy
- Ultrasound shows depth of invasion through organ layers
- CT of chest and abdomen
- PET
- Complete blood count (CBC) and liver function

Spread Patterns

- Rarely localized at the time of diagnosis
- High incidence of local and distant spread
- Local → trachea, mediastinum, lung, pleura, aorta, heart
- Distant → liver, lung, bone, adrenals, brain
- Lymph node drainage (

Figure 8.6) to low cervical, supraclavicular, paraesophageal, celiac axis, common hepatic, and perigastric

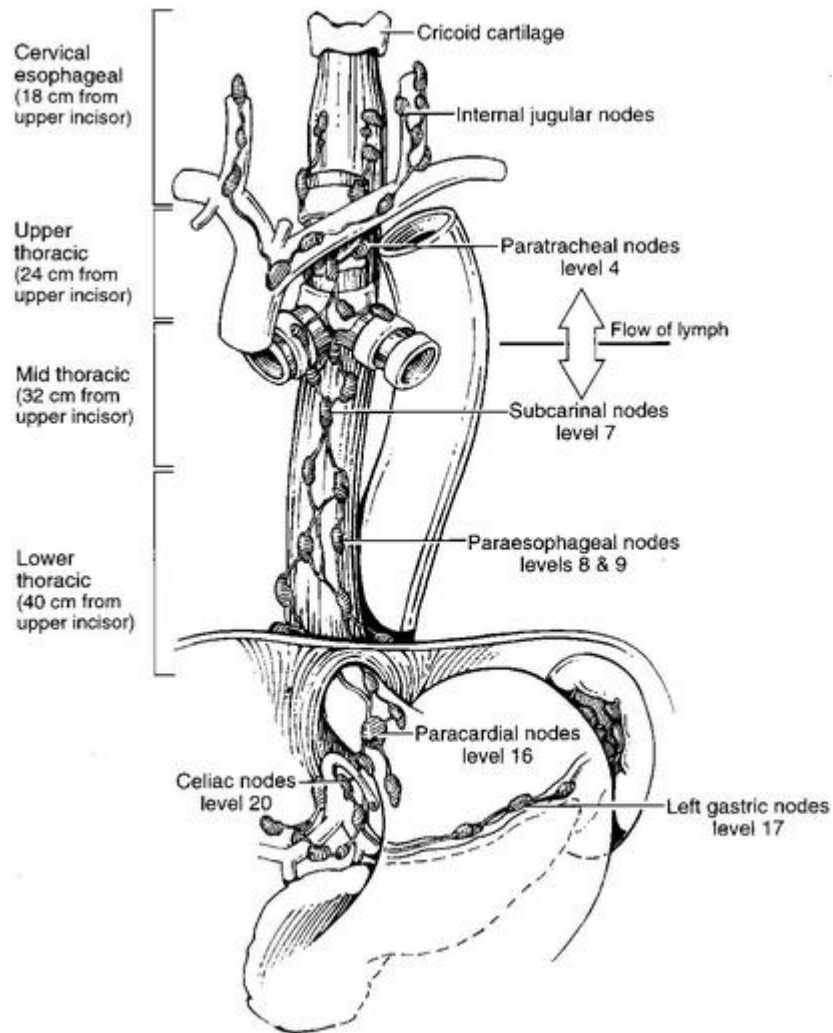


FIG. 8.6 Esophagus with divisions and lymphatics.

Staging

- American Joint Committee on Cancer (AJCC) staging system using TNM

Treatment

- Surgery is standard whenever possible with anastomosis (reconstruction).
- Complications from surgery include anastomosis leak, respiratory failure, motility disorders, and reflux.

- Local control and survival improve with radiation and concurrent chemotherapy.
- Upper esophagus lesions best managed with chemoradiation due to high mortality with surgery.
- Preoperative or postoperative radiation dose to 45 to 50 Gy.
- Radiation dose to 50 to 70 Gy depending on whether previous surgery or concurrent chemotherapy has occurred.
- Radiation alone total dose 60 to 70 Gy; IMRT techniques assist in dose escalation.
- Intraluminal high dose rate (HDR) brachytherapy is controversial.
- Chemotherapy drugs may include 5-FU, cisplatin, bleomycin, methotrexate, mitomycin, ifosfamide, VP-16, and several others.
- Complications from chemotherapy depend on the combination of drugs.
- Trials underway for targeted and immunotherapy.

Radiation treatment borders

- GTV plus generous margin of about 5 cm above and below tumor plus regional lymph nodes; regional lymphatics at risk should be included; tumors in the cervical, upper and middle esophagus, the mediastinal, supraclavicular and low cervical nodes should be included; tumors in the lower esophagus and GE junction should include mediastinal and celiac axis
- Prescribed dose above tolerance of organs at risk such as the spinal cord, kidneys, and liver may be delivered using oblique fields, opposed laterals, four-field box technique or AP, and posterior obliques to spare spinal cord; multifield IMRT fields can help conform high dose and spare organs at risk

Treatment delivery

- After surgery, enteral nutrition may be necessary via feeding tubes.
- Nutritional support very important as nutritional status was likely marginal before the start of therapy. Offer the patient

hyperalimentation products if still taking food orally.

- Take care not to dislodge feeding tubes when transferring/transporting patients.
- Patient may be positioned supine or prone; slight displacement of esophagus away from the thoracic spine in the prone position
- Arms should be raised to accommodate lateral or posterior oblique fields for spinal cord sparing.
- Prone position is accomplished with a prone pillow or Duncan mask with arms up around pillow or mask.
- Supine with both arms up on a wing board, alpha cradle, or vac lock system.
- All treatment fields will need beam shaping to spare lung, heart, spinal cord.
- Positioning aids such as prone pillow, Duncan mask, and wing board are billable as simple treatment devices; vac lock is complex.
- Daily delivery is complex due to field shaping and the use of modifiers such as wedges on oblique/lateral fields.
- May have special protocols, stay abreast of required documentation if participating in protocol.
- Acute reaction to radiation is mainly dysphagia; onset at about 20 Gy.
- Educate patient on starting a soft, bland diet for dysphagia; esophagitis cocktails.
- Chemoradiation intensifies dysphagia and lowers onset dose.
- Late complications from radiation therapy include perforation, hemorrhage from tumor dissolution, stricture, lung necrosis, and pneumonitis.

Stomach

Sections of the stomach:

- Cardia
- Fundus
- Body
- Antrum

- Greater curvature
- Lesser curvature
- Pylorus

Etiology

- Diet (red meat, spices, fish, smoked foods, heavily salted)
- Coal mining
- Rubber working
- Asbestos exposure
- Gastric ulcers/polyps
- Alcohol/tobacco
- Poor nutrition
- Inadequate sanitation of consumables
-

H. pylori infection

Clinical Presentation

Signs and symptoms

- Vague epigastric discomfort is the #1 symptom
- Loss of appetite
- Weight loss
- Nausea, vomiting
- Palpable, epigastric mass
- Ascites
- Jaundice, left supraclavicular adenopathy (Virchow node)
- Left axillary adenopathy (Irish node)

Histology

- Adenocarcinoma 90% to 95%
- Leiomyosarcomas and lymphomas 5% to 8%

Detection and Diagnosis

- CBC (most have anemia)
- Guaiac stool test
- Upper gastrointestinal series with contrast
- Endoscopy with biopsy
- CT scan of abdomen and chest
- Laparoscopy

Spread Patterns

- One-third have distant metastasis at diagnosis
- May spread through lymph, blood, or direct to any organ
- More than likely spread to bowel, omenta, pancreas, colon, regional nodes
- Will take the blood route to the liver and lung since the portal system is in close proximity
- Peritoneum is a likely site for metastasis too; invasion is often diffuse.
- There are abundant lymphatic channels within the layers of submucosa and subserosa.
- Initial drainage is to the nodes along the greater and lesser curvatures (channels present in the layers of the gastric wall), then splenic, celiac, and hepatic nodes

Staging

- TNM system used

Treatment

- Surgery is the primary therapy for potentially curable stomach cancers
- Radical distal subtotal gastrectomy is common; removes 80% of stomach

- Radiation therapy is used adjuvantly along with multiagent chemotherapy; intraoperative investigational
- Postoperative or preoperative radiation dose 45 to 50 Gy; radiation alone totals 60 Gy
- Chemotherapy is integral for improved outcomes
- Drugs may include etoposide, 5-FU, methotrexate, cisplatin, Adriamycin, leucovorin, biologic modifier-interferon

Radiation treatment borders

- Unresectable disease or tumor bed plus regional lymphatics: lesser and greater curvature, celiac axis, pancreatic, splenic, and porta hepatis
- Paraesophageal nodes and lower third of the esophagus should be included if disease was in the proximal portion of the stomach
- Dose-limiting organs are kidneys, liver, and bowel
- Field shaping to spare as much liver, kidney, and bowel as possible; some portion of the left kidney cannot be avoided

Treatment delivery

- Could use four-field box technique with beam shaping on all fields
- IMRT produces the best dose distributions
- Pay close attention to nutritional support, especially in postoperative patients
- Most will not be able to manage three full meals a day; advise patients to eat small meals more frequently
- Those on chemoradiation may also have feeding tubes
- Multiple fields will incur complex daily treatment charges

Small Bowel

Divisions of the small bowel:

- Duodenum
- Jejunum

- Ileum

Etiology

- May be inherited connected to disorders such as polyposis, Crohn disease, Gardner syndrome

Clinical Presentation

Signs and symptoms

- Abdominal pain, cramping
- Abdominal hemorrhage
- Weight loss
- Abdominal mass, usually movable
- Occult or gross rectal bleeding
- Watery diarrhea

Histology

- Adenocarcinoma (in duodenum and jejunum)
- Sarcomas
- Lymphomas (mucosa-associated lymphoid type [MALT])
- Carcinoid (no. 1 in ileum)

Workup

- Upper gastrointestinal series with small bowel follow-through
- Small bowel enema
- Flexible endoscopy with biopsy
- CBC for anemia, liver function (bilirubin, amylase)
- CT scan of abdomen, pelvis
- CT-guided biopsy

Spread Patterns

- Regional lymph node review
- Neighboring organs are possibility

Staging

- Classification of these tumors correlates to the histologic type. TNM system is also used.
- Grading is a good indicator for prognosis and guides treatment.

Treatment

- Surgery is standard.
- Postsurgical complications would include anastomosis leak, adhesions, and obstructions.
- Generally recognized as radioresistant; sarcomas respond
- If unresectable, radiation and chemotherapy will be considered.
- Radiation can be given preoperatively or concomitant to chemotherapy.
- Chemotherapy is 5-FU or cisplatin-based.

Radiation treatment borders

- Irradiation of whole abdomen for lymphomas, carcinoids that are unresectable or partially resected
- Total abdominal radiation puts low-tolerance organs at risk such as the kidneys
- Adjuvant radiation for the tumor bed plus nodal areas can be considered following complete resection of most histologies

Treatment delivery

- Whole-abdomen RT postoperatively to dose of 20 to 25 Gy in 1- to 1.25-Gy fractions
- This low-dose limits the risk of low tolerance tissues in the abdomen

- Bowel irradiation will lead to acute nausea, vomiting, diarrhea; late effects may include perforation
- For nausea and vomiting recommend clear liquids, no strong odiferous foods, drink plenty of fluids to prevent dehydration; keep ice chips available
- For diarrhea recommend low fiber diet and plenty of fluids
- Beam shaping for the whole abdomen using AP/PA fields will incur complex billing charges

Colon/Rectum

Divisions include:

- Cecum
- Ascending colon
- Transverse colon
- Descending colon
- Sigmoid
- Rectum

Etiology

Associated risk factors

- Diet (red meat, processed meats, low fiber, high fat)
- Alcohol
- Genetic polyposis
- Crohn disease
- Diverticulosis

Clinical Presentation

Signs and symptoms

- Blood in stool (microscopic or visible)

- Diarrhea
- Palpable mass in right lower quadrant
- Rectal bleeding
- Pencil stools

Histology

- Adenocarcinomas 90%
- Leiomyosarcomas
- Lymphomas
- Carcinoids

Workup

- Liver function, CBC
- Renal function
- CEA tumor marker
- Digital rectal examination
- Sigmoidoscopy; colonoscopy with biopsy
- Barium enema
- Endorectal ultrasound or coil MRI
- CT of pelvis and abdomen

Spread Patterns

- Local invasion out through the mucosal walls, then pelvic lymph nodes (

[Figure 8.7](#)) and finally distant metastasis to lung, liver, bone, ovaries, adrenal

- There is very little propensity for colon cancers to creep longitudinally in contrast to esophageal and gastric cancers

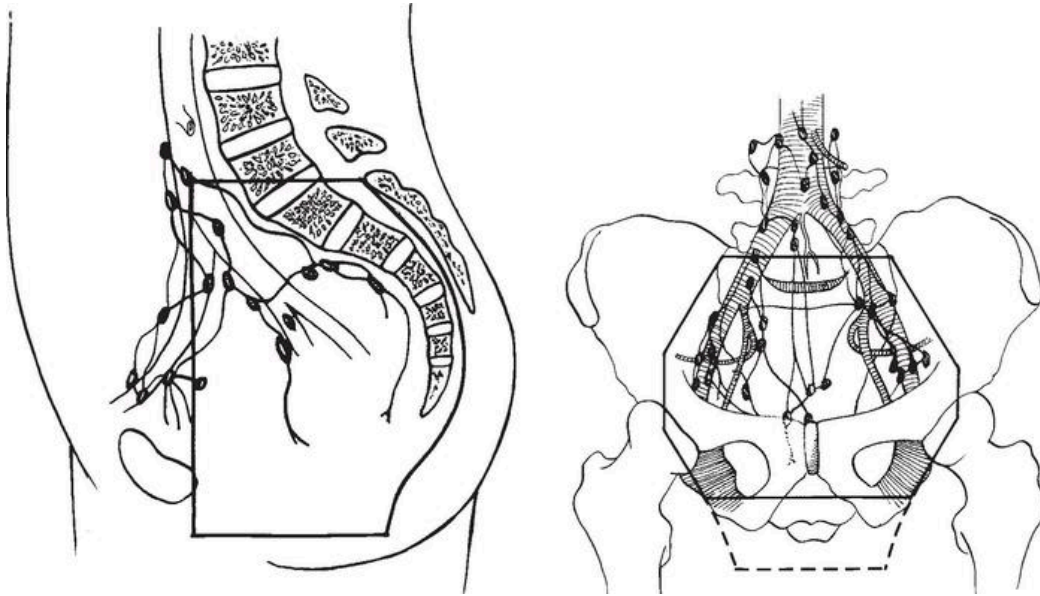


FIG. 8.7 Pelvic lymph nodes.

Staging

- TNM and modified Astler-Coller ([Table 8.4](#))

TABLE 8.4**Comparison of Staging Systems for Colorectal**

AJCC TNM	Modified Astler-Coller
I	A
Tis, N0, M0	A
T1-2, N0, M0	B1
II	B
T3-4, N0, M0	B2
T4b, N0, M0	B3
III	C
T1-2, N1-2, M0	C1
T3-4a, N1-2, M0	C2
T4b, N1-2, M0	C3
IV	D
Any T, Any N, M1	D

Treatment

- Early lesions should have total resection; surgical resection remains primary treatment
- Surgical complication include fistula, abscess, hemorrhage, stomal issues, obstruction
- Beginning of the colon not routinely treated with radiation
- Surgery and multiagent chemotherapy used for colon above sigmoid

- Pelvic floor needs reconstruction after lower bowel resection to minimize small bowel within the true pelvis
- Abdomino-perineal resection (APR) removes the terminal end of the colon and inserts an abdominal colostomy
- A re-anastomosis (reverse of colostomy) can be safely performed after moderate doses of radiation 45 to 50 Gy. An unirradiated section of bowel can be used for this
- Radiation may be used without APR for rectal cancers to preserve the sphincter
- Adjuvant radiation therapy doses 50 to 54 Gy; up to 60 Gy if late stage
- Colorectal cancer traditionally regarded as chemoresistant
- 5-FU therapy is the backbone for adjuvant chemotherapy of resected colorectal tumors; other drugs may be useful, such as Oxaliplatin, Irinotecan, and Leucovorin
- Targeted therapy agents may be used in combination with cytotoxic chemotherapy agents

Radiation treatment borders

- Pelvic lymph nodes should be included in treatment fields for the rectum.
- Lymphatic drainage follows the inferior mesenteric vein in the upper rectum, whereas the middle and lower third rectal lymphatic drains to the internal iliac and presacral nodes.
- AP/PA fields should cover the pelvic inlet with margin on the pelvic nodes up to the common iliac.
- Lower border has to leave 2.0-cm margin on the tumor; attempt to spare the anus if sphincter preserved.
- Four field techniques, three field techniques, or IMRT techniques assist in sparing organs at risk such as the small bowel.

Treatment Delivery

- Patient may be positioned supine or prone

- Prone allows positional shift of small bowel up and away from the pelvis; also allows gluteal fold to decrease; belly board may help avoid small bowel on lateral fields
- Conventional three field-technique common PA/RT/LT for rectum sparing the bowel anteriorly
- Field shaping to protect remaining bowel, bladder, bone marrow
- Positioning aids and immobilization devices may range from the simplest block between the feet with Velcro to complex lower pelvis and extremity vac-lock or Aquaplast systems
- Beam shaping and modifiers on the lateral fields will incur complex daily treatment charges
- Desquamation in the gluteal fold probable; advise patient to keep fold clean and dry, pat after toilet, avoid extreme temperatures during bathing
- Radiosensitizing chemotherapeutic agents might yield intensive desquamation
- If diarrhea, advise patient to begin low residue diet with plenty of fluids

Anus

Etiology

- Exact cause unknown
- Associated with HPV
- Associated with fissures, leukoplakia, and Bowen disease
- Chronic genital infections and smoking risk factors
- Incidence higher in homosexual males
- High incidence in men and women with AIDS

Clinical Presentation

Signs and symptoms

- Bleeding

- Rectal pain
- Palpable mass
- Rectal discharge

Histology

- Most true anal cancers are squamous cell.
- Adenocarcinomas are likely rectal tumors that have extended.

Detection and Diagnosis

- Digital anorectal examination
- Proctoscopy with biopsy
- Colonoscopy
- Transluminal ultrasound
- CBC, creatinine, liver function
- CT of pelvis and abdomen

Spread Patterns

- Local spread is common; this is considered a locoregional disease.
- There can be lymphatic involvement in superficial inguinal nodes, perirectal, internal iliac, and inferior mesenteric nodes.
- Invasion through the rectum into the prostate or vaginal space.

Staging

- TNM system works—T categories are quantified by the size (diameter) of the tumor and depth of invasion

Treatment

- Early disease can be managed with surgery APR.
- RT can be used when disease is bulky as definitive or when no surgery.

- Chemotherapy can also be used; chemoradiation has become the standard of care using radiosensitizing 5-FU and/or mitomycin C.

Radiation treatment borders

- Pelvis treated with upper border up to internal iliac nodes
- Lower border margin on anal sphincter/tumor
- Width must be wide enough for margin on internal iliac and include superficial inguinal lymph nodes

Treatment delivery

- Radiation without previous surgery dose ranges from 45 to 65 Gy
- Radiation along with chemotherapy dose ranges from 45 to 50 Gy
- 45 Gy may be administered to the large pelvic fields; AP/PA to start with inguinal nodes included
- Fields reduced and anal canal boosted to total 65 Gy; PA/RT/LT fields; final anal boost possible with electron beam with patient in lithotomy position or prone position
- Positive inguinal nodes may also need to be boosted using electron beams
- If inguinal node boost anticipated, supine position is desired
- If no inguinal node boost, patient may be positioned prone to open the gluteal fold and decrease skin reaction in the area; facilitates final anal boost with electron beam if elected
- Desquamation may also be realized in the genital area
- Advise patients to keep skin clean and dry; pat after toilet and no extreme temperatures during bath
- If diarrhea, low fiber diet with plenty of fluids
- Treatment fields with beam shaping, electron boosts incur complex treatment charges

Alimentary canal section review exercises

1. The esophagus is located _____ to the trachea.
2. The junction of the transverse and descending colon takes place at the _____.
3. An out pouching or weakening of the intestinal wall most commonly seen in the large intestine is termed:
 - a. Diverticulum
 - b. Aneurysm
 - c. Calculus
 - d. Fistula
4. The first portion of the small intestine, which is about 25 cm long, is the _____.
5. The longest segment of the normal human intestinal tract is the _____.
6. Using

Figure 8.8 , draw conventional typical AP/PA field borders for upper one-third esophagus squamous cell carcinoma.

7. Complete

Table 8.5 :

8. The most common histologic type for small bowel cancer is:
 - a. Squamous cell
 - b. Hepatic sarcoma
 - c. Adenocarcinoma
 - d. Small cell carcinoma
9. The most common histologic type for cancer of the stomach is:
 - a. Squamous cell
 - b. Adenocarcinoma

- c. Lymphoma
- d. Transitional cell

10. The curative treatment of choice for gastric carcinomas is:

- a. Chemotherapy
- b. Radiation therapy
- c. Surgery
- d. Cryotherapy

11. The most common presenting symptom of cancer of the stomach among the following is:

- a. Severe pain
- b. Hematemesis
- c. Vague epigastric discomfort
- d. Palpable mass

12. Define the following:

Cachexia:

Hematemesis:

Dysphagia:

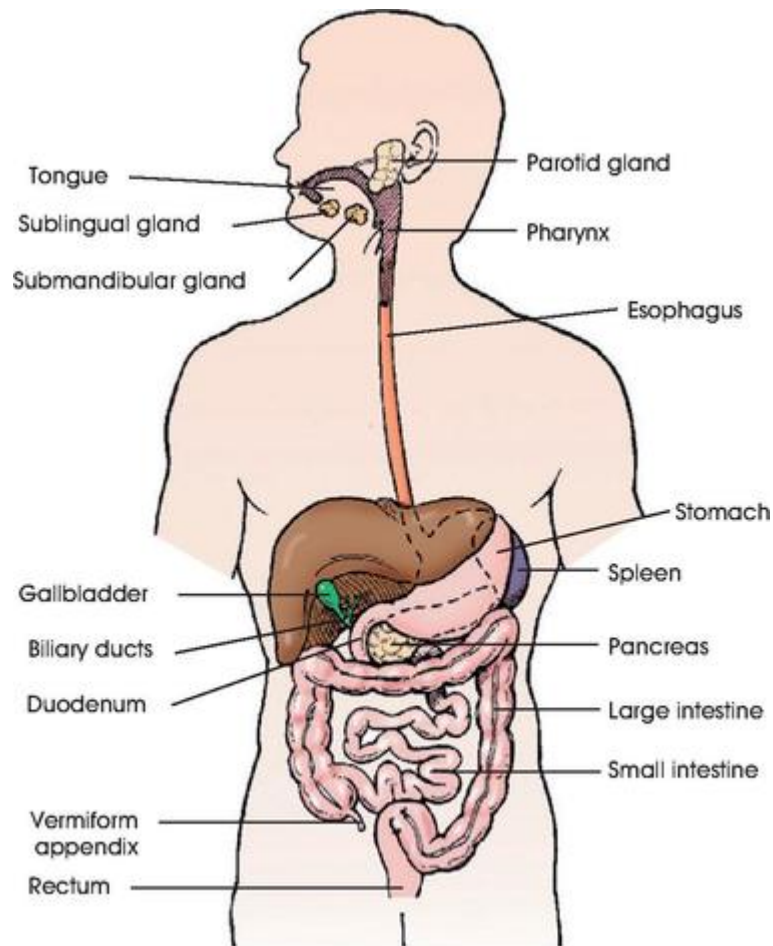


FIG. 8.8 Alimentary canal.

TABLE 8.5

Treatment Site	Anatomy Included in Typical Treatment Fields	Critical Tissues in the Area	Optimal Position/ Immobilization
Rectum			
Anus			

For Questions 13 to 15, Indicate Whether the Statement Is True or False

13. Dysphasia is a common complaint of patients with esophageal carcinoma. _____
14. Adenocarcinomas of the esophagus are more frequently found in the lower one-third of the esophagus. _____
15. The surgical procedure in which an incision is made through the abdominal wall to examine lymph nodes and establish disease extent is called an APR. _____
16. Common sites of metastasis for colon cancer are:
1. Liver
 2. Lung
 3. Peritoneum
 4. Bone
- a. 1, 3
 - b. 2, 3
 - c. 2, 3, 4
 - d. 1, 2, 3
17. Dietary factors associated with increased risk of gastric cancers are:
- a. Low consumption of fruits and vegetables
 - b. Low consumption of salted and smoked foods
 - c. High consumption of salted and smoked foods
 - d. a and c
18. Radiation treatment fields for cancer of the _____ should include inguinal lymph nodes.
- a. Small bowel
 - b. Anus
 - c. Sigmoid colon
 - d. Rectum

19. Intense desquamation may occur in the gluteal fold during radiation therapy to the lower pelvis. Patients should be advised to:
- a. Use cold packs in the folds twice daily
 - b. Take hot baths daily
 - c. Apply Vaseline every other day
 - d. Gently pat the area dry after each toilet
20. A risk factor associated with colon cancer is:
- a. Exposure to ultraviolet radiation
 - b. Diet high in salty foods
 - c. History of colon polyps
 - d. Human papilloma virus
21. Patients scheduled for radiation therapy to the lower esophagus will likely experience:
- a. Diarrhea
 - b. Diplopia
 - c. Diverticulitis
 - d. Nausea
22. Patients scheduled for radiation therapy to the upper esophagus will likely experience:
- a. Diarrhea
 - b. Dysphagia
 - c. Abdominal distention
 - d. Nausea
23. Intestinal tumors grow progressively through the layers of the intestines in the following order:
- a. Serosa, submucosa, mucosa, muscularis
 - b. Muscularis, serosa, submucosa, mucosa
 - c. Mucosa, submucosa, muscularis, serosa
 - d. Submucosa, mucosa, serosa, muscularis
24. Which patient position helps reduce the volume of small bowel in the pelvis?

- a. Supine
 - b. Prone
 - c. Lateral
 - d. Lithotomy
25. MAC stage A for colorectal cancer correlates to the TNM system stage _____:
- a. 0
 - b. I
 - c. II
 - d. III

Pancreas, liver, and gallbladder

Pancreas

General Facts and Epidemiology

- Twelfth most commonly diagnosed cancer in the United States (2018); Fourth leading cause of cancer-related death in men and women in the United States (2018)
- Most occur in the head, neck, or uncinate process-periampullary region
- Prognosis depends on resectability
- Rarely localized at the time of diagnosis
- Surgery is the best chance for cure
- Relapse occurs in the liver, regional nodes and tissues, peritoneum and lung
- If there is metastasis to the liver, lung, or peritoneum, median survival is 3 to 6 months (majority have subclinical disease in the liver at the time of diagnosis)
- Increased incidence in Western and industrialized countries
- In the United States, Japanese-Americans have a lower incidence
- TP16 tumor suppressor has been found to be inactivated in 95% of cases

- Average age at onset is early 70s (United States)

Etiology

- Smoking is the strongest factor
- High fat diet increases risk
- Diabetes increases risk
- Chronic pancreatitis increases risk
- Previous radiation therapy to the abdomen increases risk
- Alcohol consumption
- Hepatitis B or C infection
- History of cholecystectomy
- Cystic fibrosis
- Ten percent may be familial with first-degree relatives diagnosed with pancreas, ovarian, or breast carcinoma

Clinical Presentation

- Symptoms depend on location (

[Table 8.6](#))

TABLE 8.6

Pancreatic Cancer Symptoms

Head, Neck, Uncinate Process	Body and Tail
Obstructive jaundice	Back pain
Dark urine, clay-colored stools	Upper gastrointestinal bleeding
Abdominal pain	Splenomegaly
New diagnosis of diabetes	Jaundice (late)

Histology

- Infiltrating ductal adenocarcinoma No. 1
- Pancreatic neuroendocrine tumors (PanNET)
- Adenosquamous carcinoma
- Anaplastic carcinoma
- Acinar cell carcinoma (associated with subcutaneous pathways and fat necrosis, usually tumors are large and occur in the head mostly)
- Giant cell carcinoma (present large; very aggressive)
- Mucinous and serous cystic epithelial
- Intraductal papillary mucinous neoplasm (good prognosis)
- Pancreatoblastoma (occurs in childhood)
- Pseudopapillary neoplasms (Hamoudi tumors)

Lymphatic Drainage and Spread Patterns

- Area lymph nodes include pancreaticoduodenal, superior pancreatic, inferior pancreatic, porta hepatic nodes, paraaortic nodes, and celiac axis
- Venous drainage of the pancreas is to the liver through the portal vein; easy metastasis to the liver
- Local metastasis to the peritoneum and neighboring abdominal tissues
- If liver is positive for metastasis, distant metastasis is assumed
- Lung is the most likely extraabdominal site for metastasis

Diagnosis and Detection

- History and physical
- CBC
- Blood chemistry
- Chest x-ray
- CT/MRI abdomen and chest
- PET
- Endoscopic ultrasound
- CA 19-9 (elevation may also indicate a benign condition)
- Fine needle aspiration biopsy

Staging

- TNM system is used, although system slightly different for ampulla of Vater

Treatment

- Surgery is the mainstay—pancreaticoduodenectomy, also known as the Whipple procedure, is classic for pancreatic cancer located in the head
- With Whipple, consider possibility of leaks, infections, delayed gastric emptying, pancreatic fistula
- Chemoradiation versus surgery alone still under investigation (recall that most are unresectable)
- Debate regarding preoperative chemoradiation because after surgery there is devascularization of the area leading to low oxygen concentration
- Intraoperative RT possible option
- Brachytherapy is another possibility with I

^{125}I and Pd

103

- Radiation therapy can be split course or continuous to a total of 40 to 60 Gy. Fractions are at 160 to 180 for continuous or split course.
- SBRT and IMRT escalate doses
- Locally advanced cancers may use radiation + 5-FU (radio-sensitizer)

Radiation treatment borders

- Conventional radiation treatment fields were typically three or four fields (AP/RT/LT or AP/PA/RT/LT with wedges on the lateral fields) to include tumor bed, peripancreatic lymph nodes,

para-aortic lymph nodes between T11 and L3 (be careful of kidney tolerance).

- Upper border—T10
- Lower border—L3
- Anterior lateral borders give margins on tumor and include para-aortic nodes (

[Figure 8.9](#)); may extend more into the left abdomen if tumor is in the body

- For lateral fields, posterior border should be anterior to the kidneys and anterior border margin on the tumor
- IMRT fields spare organs at risk and delivers 55 Gy to PTV with possible boost doses to 65 Gy at the GTV
- Hypofractionation using SBRT in 1 to 5 fractions to 33 to 40 Gy (maybe higher total doses for better local control such as 75 Gy in 15 fractions)
- Proton therapy promising as doses to gastrointestinal (GI) organs at risk may be decreased
- Intraoperative RT with single fraction dose of 15 to 20 Gy (role is still being evaluated)
- Treatment delivery
- Interfractional and intrafractional variations are important in setting margins
- Respiratory motion may lend the use of tumor immobilization techniques via abdominal compression or breath-hold
- Pancreatic motion may also be influenced by motion in the GI tract; control of gastric volume via injection of 500 to 900 mL of fluid

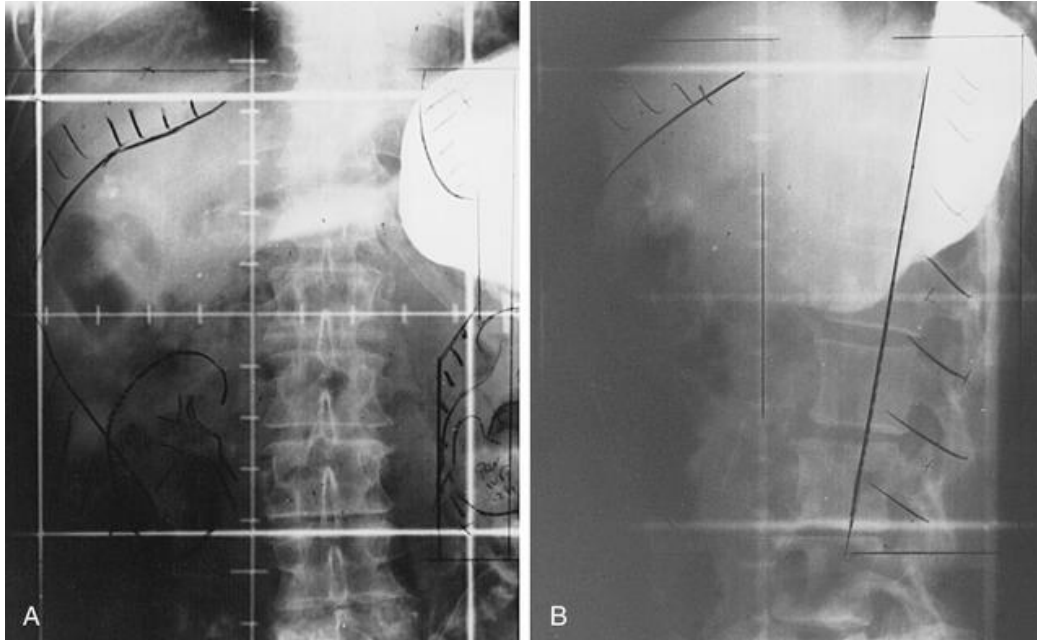


FIG. 8.9 AP and lateral fields for pancreas radiation.

A , Anteroposterior (AP) field for pancreas radiation.

B , Lateral field for pancreas radiation.

Hepatobiliary Tumors

General Facts and Epidemiology

- Linked to hepatitis B, hepatitis C, liver cirrhosis, aflatoxin ingestion
- Gallbladder and biliary cancers related to cholelithiasis
- Primary therapy is surgical resection
- 5-year survival is 30% to 50%
- Radiation via external beam is challenging because high doses to whole liver will cause radiation-induced liver disease. The advanced treatment planning in RT is opening doors for volume control.
- Hepatocellular carcinoma (HCC) is increasing in incidence in the United States as result of hepatitis C epidemic, although it is still rare in relation to other cancer types

- Currently no accepted standard for the management of these but may combine systemic and/or regional chemotherapy—chemoembolization, immunotherapy
- Histologic types include HCC, intrahepatic cholangiocarcinoma (IHCC), extrahepatic cholangiocarcinoma (EHCC), adenocarcinoma, and mucinous carcinoma of the gallbladder
- HCC 2:1 men: women; high incidence in black men versus white women; high incidence in Asia and Africa due to high incidence of hepatitis B
- IHCC 3:1 men: women; Southeast Asia high incidence
- EHCC 1:1 men: women
- Gallbladder 1:3 men: women; high incidence in Northeastern Europe

Etiology

Liver

- Hepatitis B
- Hepatitis C
- Cirrhosis
- Aflatoxin B (toxic metabolite of fungi that can grow in stored grain and peanuts)

Gallbladder

- Cholelithiasis (stones irritate or bile acid is carcinogenic)

Cholangiocarcinoma

- Liver fluke infestation
- Hepatolithiasis
- Congenital bile duct cysts
- Ulcerative colitis

Clinical Presentation

- Symptoms depend on location (

[Table 8.7](#))

TABLE 8.7

Symptoms for Hepatobiliary Cancers

HCC/IHCC	EH/Cholangiocarcinoma	Gallbladder
Right upper abdomen pain	Jaundice	Jaundice
Sharp or dull pain	Abdominal pain	Abdominal pain
Abdominal mass	Weight loss	Weight loss
Jaundice (rare)	Fatigue, fever, night sweats	Fatigue

Histology

Liver

- Hepatocellular no. 1
- Carcinoid
- Hepatoblastoma
- Angiosarcoma
- Leiomyosarcoma

Gallbladder

- Adenocarcinoma no. 1
- Mucinous carcinoma

Lymphatic Drainage and Spread Patterns

- Regional lymph nodes include porta hepatic, celiac, cystic, pericholeductal, and gastric nodes
- HCC can appear spreading or show multiple tumors scattered throughout the liver; may invade the portal vein, hepatic vein, inferior vena cava, or diaphragm
- Nearly one-third of HCC have regional spread at diagnosis, then spread to regional nodes and then to lung, bone, or muscle tissue in abdomen
- Forty percent to 50% of gallbladder carcinomas have distant spread at diagnosis; usually to liver or peritoneum

Workup

- History and physical
- CBC
- Blood chemistry; liver function, coagulation studies
- CA 19-9
- AFP (hepatocellular)
- CEA
- Hepatitis testing
- Ultrasound
- Abdomen, chest, and pelvis CT/MRI
- PET
- Transhepatic or endoscopic cholangiography (if bile duct blockage)

Staging and grading

- Grading is used 1 to 2 low grade 3 to 4 high grade
- TNM staging and Barcelona Clinic Liver Cancer (BCLC) staging
- Child-Pugh classification
- There are several systems for staging recommended; most are surgical relying on the surgeon/pathologist to evaluate invasion

quite extensively. The T categories vary for liver, IHCC, EHC, and gallbladder

Treatment

- Surgery is always in order. Hepatectomy, liver transplant, and radiofrequency ablation for early stage
- Most advocate chemotherapy via chemoembolization, percutaneous ablation, or combination of these
- Ablation with chemicals such as ethanol or acetic acid or by extreme temperatures via radiofrequency, microwave, laser, or cryoablation (this can occur percutaneously or laparoscopically)
- Radiation therapy as definitive if other therapies not feasible; challenge to deliver enough dose without exceeding normal liver tissue tolerance
- IHCC needs complete resection, right or left hepatectomy
- Gallbladder cancers need resections; can be quite radical taking the gallbladder, nodes plus head of pancreas, part of the liver, and bile duct
- Chemoembolization, known as transcatheter arterial chemoembolization (TACE) for unresectable studies, show:

Hepatocellular and IHC

- Surgery is no. 1 choice but most are not candidates

Cholangiocarcinoma and gallbladder

- Surgery is no. 1 choice but most are not candidates (

Figure 8.10)

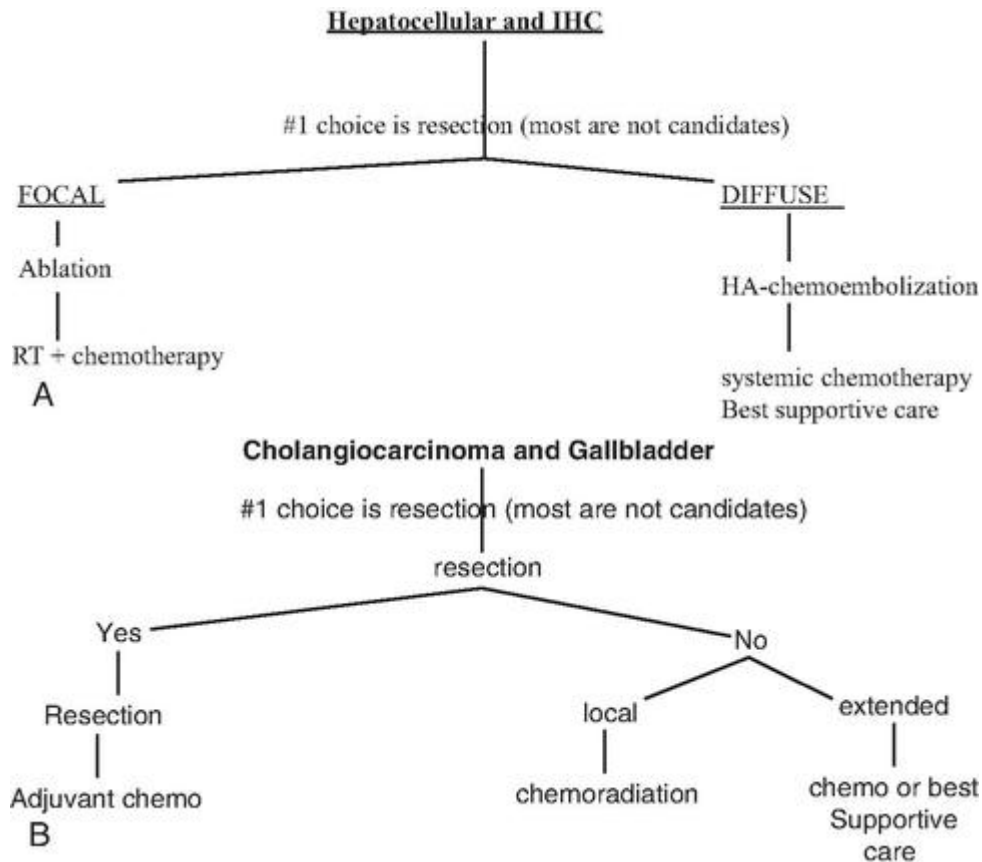


FIG. 8.10 Hepatocellular and IHC management diagram and cholangiocarcinoma and gallbladder management diagram.

A , Management diagram for hepatocellular and intrahepatic cholangiocarcinoma (IHC).

B , Management diagram for cholangiocarcinoma and gallbladder.

Treatment delivery and borders

- Radiation dose to GTV and regional lymphatics 45 to 54 Gy with boost to 55 to 65 Gy
- Need support for nausea, weight loss, malabsorption, pancreatic enzyme insufficiency, lactose intolerance, hyperglycemia, dehydration, electrolyte imbalance, pain, depression, jaundice, anxiety, constipation, anemia
- Pancreas conventionally treated with three field technique (AP/RT/LT) to avoid exceeding kidney tolerance; IMRT techniques

help escalate dose and spare organs at risk

- Gallbladder and liver fields usually limited since normal liver has very low tolerance to radiation, and surgery and chemotherapy take on definitive roles
- Respiratory motion should be managed via breath hold, respiratory gating
- Position patient supine with both arms elevated on simple wing board or complex vac or alpha cradle
- Use of complex immobilization, wedges, and multiple fields with field shaping to protect kidneys and small bowel incur complex daily treatment charges

Pancreas, liver, and gallbladder section review exercises

1. The pancreas is a retroperitoneal organ. What is its anatomic relationship to the:

Stomach _____

Duodenum _____

Liver _____

Spleen _____

2. What is the function of the pancreas?
3. The liver is the largest abdominal organ. What is its anatomical relationship to the:

Stomach _____

Gallbladder _____

Aorta _____

Inferior vena cava _____

Diaphragm _____

4. What is the function of the liver?
5. The gallbladder is a small organ tucked under the right lobe of the _____.
6. What is the function of the gallbladder?
7. The celiac axis is the first branch of the abdominal aorta, which serves to supply arterial blood to the:

1. Spleen
2. Pancreas
3. Stomach

- a. 1, 2
- b. 1, 3
- c. 2, 3
- d. 1, 2, 3

8. Cirrhosis of the liver is often associated with the excessive intake of toxic _____:
- a. Cholesterol
 - b. Heparin
 - c. Renin
 - d. Alcohol
9. The failure of the liver to absorb bilirubin will often lead to a yellowish discoloration of the skin and eyes known as:
- a. Cyanosis
 - b. Xanthosis
 - c. Jaundice
 - d. Chlorosis
10. The highest portion of the normal adult stomach sitting just below the left diaphragm is the:
- a. Pylorus
 - b. Cardiac orifice
 - c. Fundus
 - d. Greater curvature
11. The biliary ducts are principally concerned with the transport of bile and digestive enzymes into the:
- a. Colon
 - b. Stomach
 - c. Small intestine
 - d. Lymphatic system
12. The gallbladder is normally found by its attachment to the ventral surface of the:
- a. Right lobe of the liver
 - b. Left lobe of the liver
 - c. Spleen
 - d. Duodenum
13. The head of the pancreas will normally be located within the:

- a. Lesser curvature of the stomach
- b. Splenic flexure
- c. Sweep of the duodenum
- d. Falciform ligament

14. The release of bile by the gallbladder is triggered by the presence of _____ in the stomach.

- 1. carbohydrates
- 2. clear liquids
- 3. fats

- a. 1
- b. 2
- c. 3
- d. 1, 2, 3

15. The ascending and transverse colon join at an area under the right lobe of the liver called the:

- a. Splenic flexure
- b. Gastric flexure
- c. Hepatic flexure
- d. Duodenal flexure

16. A severe complication associated with excessive irradiation of the liver is:

- a. Thrombocytopenia
- b. Cholelithiasis
- c. Acute hepatitis
- d. Diabetes

17. A common sight for metastatic spread from the liver is the:

- 1. Stomach
- 2. Lung
- 3. Brain

- a. 1, 2
- b. 1, 3

- c. 2, 3
- d. 1, 2, 3

18. The most common type of tumors found in the pancreas are:

- a. Sarcomas
- b. Anaplastic carcinomas
- c. Leiomyomas
- d. Adenocarcinomas

19. Define the following:

Cholelithiasis:

Barrett esophagus:

Crohn disease:

20. List two symptoms of pancreatic cancer.

21. Complete

Table 8.8 :

22. Chemoembolization is:

- a. Systemic administration of chemotherapy with one bolus injection
- b. Systemic administration of chemotherapy using the enteral route
- c. Local administration of chemotherapy using proximal venous access
- d. Local administration of chemotherapy using the transdermal route

23. Hepatocellular carcinoma is increasing in incidence in the United States due to the rising cases of:

- a. Epstein-Barr virus
- b. Hepatitis C
- c. Cholelithiasis
- d. Diabetes

24. A pancreaticoduodenectomy is also known as:

- a. Whipple procedure
- b. Halsted technique
- c. Stanford technique
- d. Endoscopy biopsy

25. The best chance for cure in pancreatic carcinoma is:

- a. Intraoperative radiation
- b. Local radiation
- c. Surgery
- d. Chemoembolization

TABLE 8.8

Digestive Gland Review

Cancer Site	Two Signs/Symptoms	Three Methods of Detection
Liver		
Stomach		
Esophagus		
Colon		

Breast

General Facts and Epidemiology

- Most common malignancy in women in the United States
- One in eight women will be diagnosed with breast cancer
- One percent of diagnosed cases will be men
- Breast tissue made up of fat, glands, and ducts
- Location of growths may be referred according to breast quadrant

- Four quadrants: upper outer quadrant, upper inner quadrant, lower outer quadrant, lower inner quadrant
- Most common location is upper outer quadrant
- Rare location is central
- Minimum size for a palpable lump is 1.0 cm
- Prognosis good overall even with positive lymph nodes

Etiology

- Direct cause unknown but there are some associated risk factors (

[Table 8.9](#))

- Some factors increase risk (high-risk factors)
- Some factors decrease risk (low-risk factors)
- Genetics have a strong influence
- Exposure to estrogen has strong influence
- Previous radiation to breasts
- Alcohol consumption
- Mutations of BRCA1 or BRCA2 gene

TABLE 8.9**Risk Factors Associated With Breast Cancer**

High-Risk Factors	Low-Risk Factors
Female gender	Asian ancestry
Family history	Early pregnancy (by age 18)
History of benign breast disease	Early menopause
Early menarche	Late menarche
Late menopause	Oophorectomy by age 37
Nulliparity	
Children at late age	
Oral contraceptives	

Clinical Presentation**Signs and symptoms**

- Painless lump (hard, nonmobile)
- Nipple discharge (bloody, watery)
- Changes in breast skin color or shape
- Swelling
- Dimpling
- Inverted nipple
- Crusting or scaling of the nipple or areola

Histology**Invasive/Infiltrating**

- Ductal

- Lobular
- Tubular
- Medullary (usually well circumscribed)
- Papillary
- Mucinous
- Inflammatory

Noninvasive

- Lobular or ductal carcinoma in situ (DCIS)
- Paget disease (from underlying in situ or invasive disease)

Lymphatic Drainage and Spread Patterns

- Typically spreads by contiguous pattern through drainage lymph nodes (

[Figure 8.11](#)) including axillary, internal mammary, and supraclavicular

- Distant metastasis through the blood and Batson plexus to skin, bone (especially thoracic spine), liver, lung, and brain
- Axillary lymph nodes will be positive in about 55% to 70% of cases
- Axillary node dissections are common for staging
- Internal mammary nodes positive depending on location of mass (central or inner quadrants)

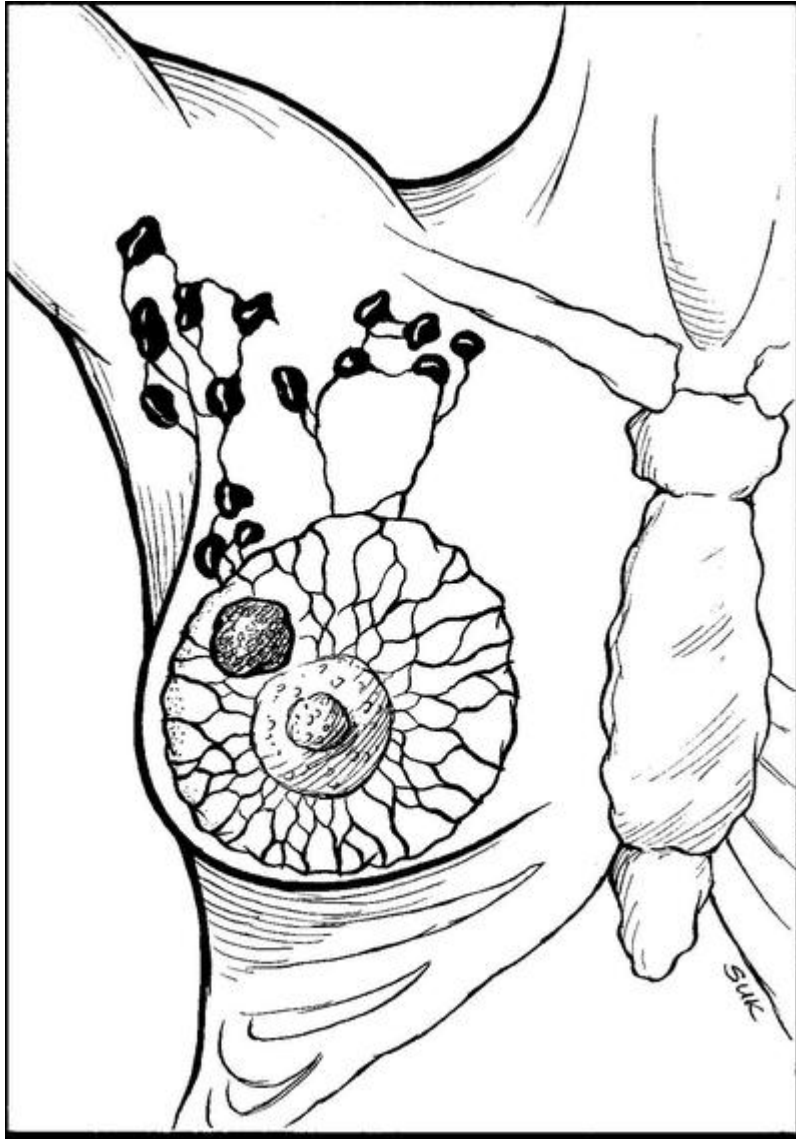


FIG. 8.11 Breast with lymphatics.

Detection and Diagnosis

- Physical examination
- History
- Needle-guided biopsy with mammogram, ultrasound, or CT
- Open biopsy (lumpectomy and node dissection)
- Sentinel node biopsy (removal of node(s) first containing metastasis using radioactive tracer and blue-colored dye)

- Fresh tissue needs evaluation for estrogen and progesterone receptors (ER, PR)
- CT of chest and abdomen
- Bone scan and liver scan for suspected metastasis

Staging

- TNM; clinical staging in office, pathologic staging required

Treatment

- Removal of primary tumor by surgery is preferred with lumpectomy
- Radical mastectomy (breast, pectoralis muscles, and regional lymph nodes—three levels of axillary)
- Partial excision, also known as wide excision (removal of lump and axillary nodes dissected through separate incision)
- Total mastectomy (removes breast and axillary tail, leaving the pectoralis muscles behind)
- Modified radical mastectomy is a total mastectomy with axillary nodes dissected and pectoralis minor
- Consequence of removing too many lymph nodes is chronic lymphedema
- Local recurrence slightly lower for those with radical mastectomies versus total mastectomies
- Partial mastectomy/lumpectomy has psychological advantages
- Surgery may be used for reconstruction (silicone implants, grafts using autologous tissue from abdomen and upper thigh for areola)
- Surgery may be used prophylactically for patients with a high risk for developing cancer in the opposite breast (family history, HER2neu, BRCA1 and 2)
- Radiation used definitively to irradiate the entire breast following lumpectomy or chest wall following mastectomy
- Chest wall radiation therapy for those who had large tumors, positive surgical margins, or at least four positive lymph nodes (en face electron fields or photon tangential fields)

- Local radiation, accelerated breast therapy with brachytherapy used following lumpectomy for low-risk patients (older age, small tumors, negative nodes)
- Chemotherapy has role following surgery (cytotoxic and hormonal therapy)
- Biologic agents have a role
- If ER and/or PR positive, hormonal therapy to maintain remission
- Common cytotoxic combinations are: FEC- 5-FU, epirubicin, cyclophosphamide or CAF—cyclophosphamide, methotrexate, 5-FU, Adriamycin (doxorubicin)
- Adriamycin has increased cardiac toxicity so cardiac gating procedures may be employed for patients receiving radiation to the left breast, especially
- Concomitant cytotoxic chemotherapy and radiation is the standard following surgery for candidates not suited for accelerated brachytherapy

Radiation treatment borders

- Radiation treatment fields for the intact breast should have medial border at midline, lateral border beyond breast tissue, upper border above the superior tail of the breast (about the second intercostal space), lower border about 2 cm inferior to breast fold
- Therapy fields may be initially set clinically
- Lymph nodes included as per disease stage
- At minimum first level axillary nodes are included in tangential fields
- If third-level axillary nodes (apical nodes) found positive or if no axillary dissection, or if tumor was extracapsular, another field may be added and treated AP/PA or posterior only with a posterior axillary boost (PAB)
- Supraclavicular nodes treated if positive with medial border at midline, lateral border about two-thirds of the clavicle and upper border about 2 to 3 cm above the clavicle; lower border carefully matched to tangential fields

- Combination supraclavicular and apical nodes would show an extended field down to the second rib
- Internal mammary field may be treated in a wider tangential field or separate anterior field if tumor was located near midline
- Internal mammary nodes located lateral of sternum about 2.0 cm on each side and from the level of the third to eighth rib; border should be carefully matched to medial tangent and/or supraclavicular field

Treatment delivery

- Total dose to intact breast of about 50 Gy in 5 to 6 weeks using tangents to avoid underlying lung
- Hypofractionated dose of about 40 Gy in 3 weeks
- Wedges or tissue compensators are used for uniform dose distribution within the breast
- Wedges and tissue compensators may be dynamic
- Shrinking fields may be used to decrease skin toxicity and eliminate high-dose areas at the inferior portion of the breast
- Boost the lumpectomy site for an additional 10 to 20 Gy depending on tumor size and margins at surgery time; boost with superficial electron therapy or photons; depending on depth of tumor bed
- Accelerated breast irradiation 1 week using hyperfractionated twice daily; brachytherapy treatment for low recurrence risk cases instead of entire breast radiation
- Chest wall radiation following lumpectomy to about 45 to 60 Gy with photons; bolus scar or entire chest wall
- Chest wall radiation may be delivered with electrons
- Supraclavicular fields treated AP only to depth of 3.0 cm to 45 Gy at 2 Gy per day; Cerrobend or multi-leaf collimator (MLC) beam shaping to protect the head of the humerus and larynx; gantry angle may facilitate sparing of the larynx
- Apical axillary fields (AP/PA or PAB) treated to midline to 45 Gy
- Matching tangential and supraclavicular fields will likely employ half-beam techniques and/or couch angles to prevent overlap at junction

- Internal mammary fields treated with single anterior photon field or en face electrons or a combination; IM nodes at depth of 3.0 cm; careful dosimetric planning to avoid overdose at junction
- Patient position supine with affected arm or both arms up, chin turned away from the affected side
- Large-breasted patients may be positioned prone to pull breast away from chest wall
- Breast boards used to decrease the slope of the chest
- Immobilization for the arms and upper torso
- Lung dose to be minimized, so watch match lines between tangents and supraclavicular fields
- Skin reactions are expected; patient education should include instructions about no razor shaving under the affected arm, protection from the sun, only radiation dermatitis creams should be used, prophylactic application of radiation dermatitis creams under strict instruction (application three times daily, avoid application 1 hour before treatment)
- Use of beam modifiers and multiple fields with use of beam shaping incur complex billing charges

Breast review exercises

1. The PAB field is intended to irradiate:
 - a. Level 1 axillary nodes
 - b. Level 2 axillary nodes
 - c. Level 3 axillary nodes
 - d. Supraclavicular nodes
2. Lymphatic drainage of the breast is primarily to the:
 1. Axillary nodes
 2. Supraclavicular nodes
 3. Internal mammary nodes
 - a. 1, 2

- b. 2, 3
- c. 1, 3
- d. 1, 2, 3

3. Using

[Figure 8.12](#) , draw the location of all lymphatic drainage for the breast.

4. For estrogen receptor–positive cases, an antiestrogen may be used to maintain remission known as:

- a. Taxol
- b. Tamoxifen
- c. Megace
- d. Prednisone

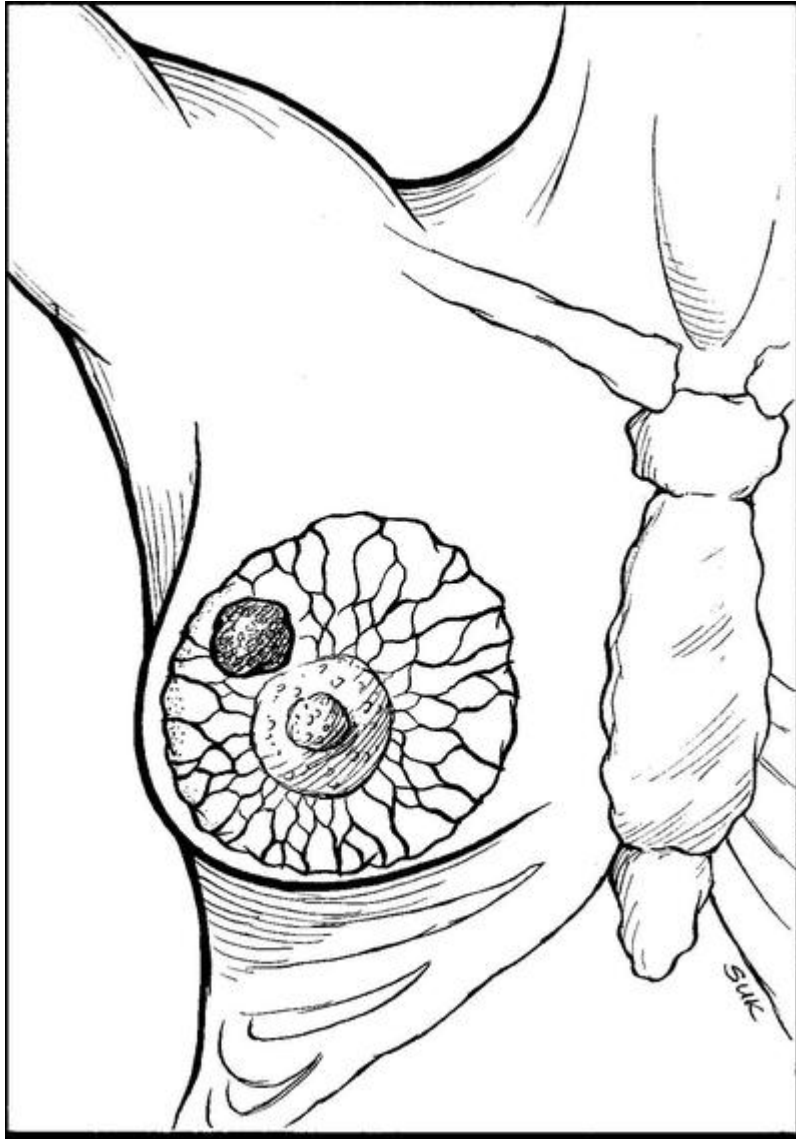


FIG. 8.12 Right breast for drawing.

Think About It

5. Special care must be taken to limit dose to the heart when treating left breast patients who have undergone CAF chemotherapy. Briefly explain.
6. Briefly describe the difference between clinical and pathologic staging for breast cancer.

7. Using the information given, calculate the monitor units required for each treatment field per fraction.

Prescription: 5040 cGy to right breast 180 cGy per fraction

—6-MV photons

4500 cGy to right supraclavicular fossa 180 cGy per

fraction—6-MV photons

1000 cGy boost lumpectomy scar 200 cGy per fraction—

12 MeV en face electrons

6-MV beam output = 1 cGy/MU 12 MeV beam output = 1

cGy/MU

Medial and lateral tangents

Field size = 8×24

SSD = 91 cm

Field size factor = 1.034

TAR @ 9 cm = 0.892

AP supraclavicular field

Field size = 12×10

Field size factor = 1.003

TAR @ 3 cm = 1.002

En face electron boost field

Cone factor = 1.02

Dose to 90% dose line

8. The most common symptom of breast cancer is:

- a. Painless lump
- b. Clear nipple discharge
- c. Dimpling of the skin
- d. Inverted nipple

9. Define the following:

Radical mastectomy:

HER2neu:

BRCA1:

Peau d'orange:

10. When using a breast board for positioning, the optimal incline angle is influenced by:

- a. The angle of the elbow when it is raised
- b. The ability of the patient to raise the arm(s)
- c. The slope of the patient's chest
- d. The gantry angle on the medial tangent

11. When the supraclavicular fossa is treated along with opposing tangents, the supraclavicular field is best treated using:

- a. AP/PA ports
- b. Wedged pair
- c. Rotational beam
- d. Half-field technique

12. The total radiation dose received by the lumpectomy bed in standard whole breast irradiation followed by lumpectomy site boost is:

- a. 40 to 50 Gy
- b. 50 to 60 Gy
- c. 60 to 70 Gy
- d. 70 to 80 Gy

13. The most common histologic type of breast cancer is:

- a. Infiltrating ductal
- b. Lobular in situ
- c. Paget disease
- d. Medullary

14. The acceptable amount of lung tissue included in tangential breast fields is 2.0 cm to decrease the chance of latent:

- a. Pneumonia
- b. Lung fibrosis
- c. Pleural effusion
- d. Atelectasis

15. An en face electron boost to the lumpectomy bed is accidentally treated at 105 cm SSD instead of 100 cm SSD. The error in dose delivered is about:
- a. 5% over dose
 - b. 5% under dose
 - c. 10% over dose
 - d. 10% under dose
16. Ductal carcinoma in situ is classified as:
- a. Stage 0
 - b. Stage I
 - c. Stage II
 - d. Stage III
17. A sentinel lymph node biopsy involves the injection of a blue dye and radioactive:
- a. Iridium 192
 - b. Technetium 99m
 - c. Strontium 89
 - d. Samarium 137
18. The hinge angle between two half-beam tangential ports is 180 degrees. The medial tangent gantry angle is 310 degrees. What is the gantry angle for the lateral tangent?
- a. 230 degrees
 - b. 140 degrees
 - c. 130 degrees
 - d. 50 degrees

Gynecologic tumors

•

[Table 8.10](#) lists gynecologic epidemiology figures in the United States;

Figure 8.13 is a view of the female pelvis;

Figure 8.14 portrays pelvic lymph node drainage.

- Relatively nonspecific early symptoms, resulting in late-stage disease
- International Federation of Gynecologists & Obstetricians (FIGO) staging, as well as AJCC staging

Table 8.10

Malignancy	Estimated New Cases	% of New Cases	Estimated Deaths	% of Deaths Per Malignancy
Overall	114,810		34,020	
Endometrium (uterine corpus and cervix)	80,160	70%	17,340	22%
Ovary	19,710	17%	13,270	67%
Vulva	6470	6%	1670	26%
Other	8470	7%	1740	20%

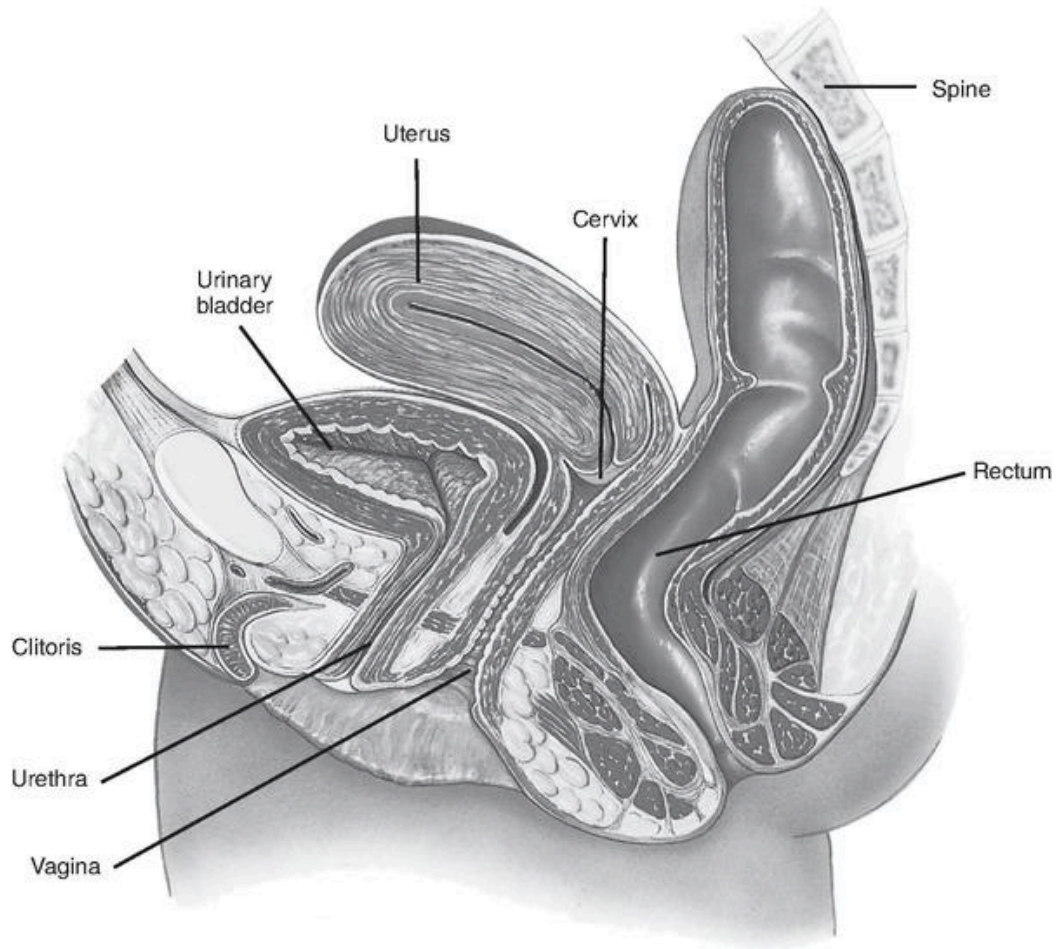


FIG. 8.13 Sagittal view of female pelvis.

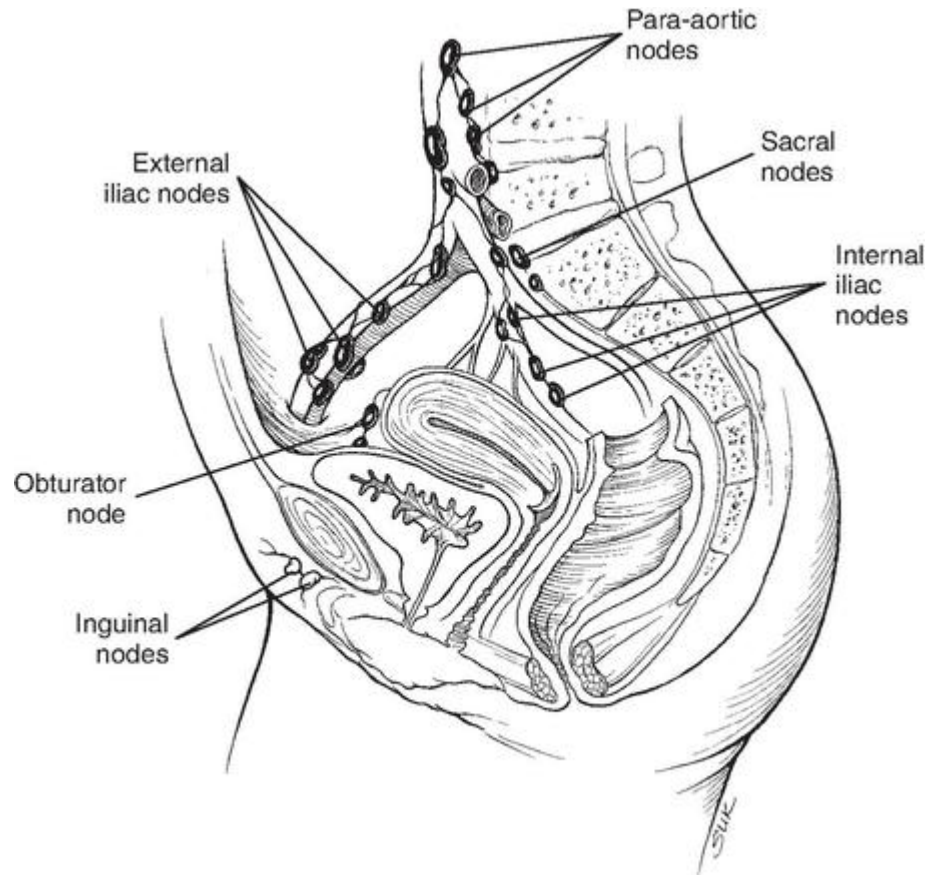


FIG. 8.14 Pelvic lymph nodes.

Vulva

Anatomy

- Outermost portion of gynecologic tract consisting of opening of vagina, labia majora and minora, clitoris
- Perineum—area between the vulvovaginal complex and anal verge

Etiology and Epidemiology

- Accounts for 6% of gynecologic cancer and < 1% of all cancers in women
- Usually occurs in older women; average age at diagnosis is 70
- HPV, genital warts, HIV

- Vulvar intraepithelial neoplasia
- Smoking
- Mutations in

p53 gene

- Melanoma may be associated

Clinical Presentation

- Chronic local itching/irritation
- Subcutaneous lump or mass
- Discoloration or thickening of skin
- Bleeding or discharge not related to normal menstruation

Lymphatic Spread Patterns

- Lymphatic spread predictable (increased in lymph involvement lowers the survival rate).

Superficial inguinal nodes first, followed by

deep femoral nodes, and then

pelvic nodes

Prognosis

- Prognostic factors include the size of the lesion, depth of invasion, and histologic subtype
- 5-year survival rates are 86% for localized, 53% for regional, 19% distant, overall survival is 71%

Detection and Diagnosis

- Biopsy—with histologic examination
- History and physical

- CBC and chemistries
- Urinalysis
- Chest x-ray
- CT, MRI, PET
- Cystoscopy

Histology and Staging

- Squamous cell carcinomas—90%, followed by melanoma, adenocarcinoma, and sarcoma
- Staging—TNM; FIGO

Treatment Considerations

- Surgery
- Simple radical partial vulvectomy treatment of choice for early-stage disease with ipsilateral inguinofemoral LN evaluation
- Radiation
- 3D or IMRT for positive margins or unresectable disease + concurrent chemotherapy
- Cisplatin chemotherapy agent of choice

Treatment

- Field includes primary + inguinal region
- 3D AP/PA fields + anterior electron boost
- Doses of 45 to 50.4 Gy in 25 to 28 fractions (1.8-Gy fractions) for adjuvant therapy
- 59.4 to 64.8 Gy in 33 to 36 total fractions (1.8-Gy fractions) for unresectable disease.
- Patient maybe in “frog-leg” position, empty rectum, supine in vac loc
- Bolus may be placed over vulva and perineum
- Inguinal nodes best treated anteriorly (helps to minimize dose to femoral head and neck)

- Side effects: diarrhea, bladder irritation, fatigue, mucocutaneous reaction

Vagina

Anatomy

- Vagina starts at the cervix and opens at the vulva.
- Vaginal walls are collapsed and open during sex and childbirth.
- Lined by epithelial cells with glands near the opening to keep vaginal lining moist.

Etiology and Epidemiology

- 90% of vaginal cancers are squamous cell carcinomas, primarily in upper part of vagina
- Adenocarcinoma and clear cell adenocarcinoma comprise 10% of cases
- 2% of all gynecologic cancers
- Occurs in older women; average age at diagnosis is 67
- Risk factors include age, Diethylstilbestrol (DES) drug treatment, vaginal adenosis, HPV, history of cervical cancer, smoking/alcohol use, HIV
- Exact etiology unknown

Clinical presentation

- Vaginal bleeding
- Painful intercourse
- Palpable lump
- Painful urination
- Backpain/swelling in legs

Detection and Diagnosis

- History and physical

- Pelvic/cytologic examination (Pap smear)
- HPV testing
- Colposcopy/biopsy
- CBC and chemistries
- Urinalysis
- Chest x-ray
- MRI
- Cystoscopy
- Proctosigmoidoscopy
- PET

Histology and Staging

- Squamous cell (80%–90%); melanoma 5%; clear cell adenocarcinoma (rare)
- Staging: TNM; FIGO
- Overall, 5-year survival rate is 51%

Treatment Considerations

- Radiation therapy and/or surgery is treatment of choice for early-stage disease
- Radiation therapy is standard treatment for stages III & IVA, EBRT ± brachytherapy
- Surgery involves radical vaginectomy
- Cisplatin is chemotherapy agent of choice
- Problems—early acute dermatitis

Treatment

- Brachytherapy—Usually delivered in 5 fractions with a dose of 4.5 to 5.5 Gy/fraction after 45 Gy in 25 fractions of EBRT for total doses of 70 to 80 Gy.
- External therapy—Anterior/posterior fields or IMRT to doses 44 to 50.4 Gy at 1.8 to 2.0 Gy per fraction, with nodal metastases receiving a simultaneous boost to 55 at 2.2 Gy per fraction.

Cervix

Anatomy

- Comprised of the Endocervix—the opening of the cervix that leads into the uterus covered by glandular cells and the Exocervix—the outer part of the cervix composed of squamous cells
- Connects the body of the uterus to the vagina
- Protrudes into the vagina, producing lateral spaces in the vaginal apex called the

fornices

- A canal called the

cervical os extends from the vagina, through the central cervix, and into the uterine cavity, or pelvic portion of the uterus

Etiology and Epidemiology

- Incidence rates of cervical cancer decreased by 65% in women ages 20 to 24 who have received the HPV vaccine (2012–2019)
- Prevalent in younger women between ages of 35 and 44
- Invasive cervical cancer average age 50 to 60
- Low socioeconomic status at greatest risk (less than average participation in cancer screening programs)
- HPV, early sexual activity, multiple partners, smoking, and multiple pelvic infections (genital warts and HIV).
- Multiple pregnancies beginning at a young age
- Family history
- Risk higher in wives of men with penile cancer
- DES
- Screening should begin at age 18 or earlier in sexually active women
- Receive HPV vaccine, limit exposure to HPV, do not smoke

- Use of IUD may lower risk

Clinical Presentation

- Early stage and precancers usually are asymptomatic
- Signs of invasive cervical cancer:
 - Postcoital bleeding
 - Abnormal periods, bleeding after menopause
 - Discomfort with intercourse
 - A malodorous discharge, pelvic pain, and urinary or even rectal symptoms may indicate more advanced stage
- Invasive cancer—friable, ulcerative, or exophytic mass (extension into vaginal canal and involve vagina sidewalls, or invade other organs and tissues such as parametrium, bladder, or rectum)

Lymphatic Spread Patterns

- Orderly spread
- Level 1 (external iliac, internal iliac, obturator, mesorectum) to Level 2 (common iliac, presacral) to Level 3 (para-aortic)
- Lymph node involvement results in 50% reduction in survival rates. (Hemoglobin levels are extremely important due to anemia, a common side effect from treatment.)

Detection and Diagnosis

- H&P, pelvic examination, and Pap smear
- HPV testing
- Biopsy of suspicious lesions—colposcopy, endocervical curettage, cone biopsy
- Post diagnosis testing
- Chest x-ray, CT, MRI
- Cystoscopy and proctoscopy
- PET/CT

Pathology and Staging International FIGO Staging System

- Squamous cell—most common
- Staging Summary:
- Stage 0 carcinoma in situ
- Stage I cells have grown from surface into deeper tissues of cervix, no lymph node or distant involvement, may further express layer invasion
- Stage II cancer has grown beyond cervix and uterus, but no extension into parametria, lymph nodes, or distant sites
- Stage III extends to pelvic wall or lower third of vagina, may have nearby lymph node involvement but no distant sites
- Stage IV bladder or rectum involved or extension beyond true pelvis to areas such as lung or bones
- Squamous cell carcinoma is most prevalent histology

Treatment

- High-risk whole pelvis, four field allows for exclusion of bladder and rectum in patients whose external beam dose is 45 to 50 Gy + concurrent cisplatin
- IMRT to pelvic wall with boost to sites of nodal involvement is 55 to 65 Gy + concurrent cisplatin
- Brachytherapy boost dose approximately > 80 to 90 Gy
- Cervical implant instruments
- Intrauterine tandem (small, hollow, curved cylinder that fits through

cervical os and into the uterus—

Point A)

- * Vaginal colpostats (two golf-club-shaped, hollow tubes placed laterally to the tandem
- into the vaginal

fornices— **Point B)**

- Central doses prescribed to:

-

Point A —prescription point defined as 2 cm superior to the cervical os and 2 cm lateral to the endocervical canal

-

Point B —is 3 cm lateral to point A (2 cm superior to the cervical os and 5 cm lateral to the endocervical canal)

- Tissue tolerance in cervix treatment:

-

Bladder —Point tolerance is < 75 Gy: whole bladder treatment results in acute cystitis at doses as low as 30 Gy, which results in acute bladder irritation with dysuria, frequency, and urgency but usually resolves; chronic cystitis with doses above 50 to 60 Gy.

-

Rectum (immediately posterior to the vagina and cervix)—Point tolerance is also 70 Gy; whole organ tolerance is about 50 Gy; at 30 to 40 Gy, diarrhea, bleeding, urgency, and pain; late effects include stricture, bleeding, and perforation

-

Refer to [Table 8.11](#) for treatment considerations for cervix

Table 8.11**Cervical Treatment Considerations**

Clinical Stage	Fertility-Sparing	Nonfertility Sparing
Low-risk IA1	Cone biopsy	Cone biopsy + simple hysterectomy
IA2 High-risk IA1	Cone biopsy + pelvic LN evaluation Radical trachelectomy + pelvic LN eval	Modified radical hysterectomy and pelvic LN evaluation
	Pelvic LN removal	
IB1	Radical trachelectomy + pelvic LN eval/ possible para-aortic LN removal	Radical hysterectomy + pelvic LN eval/ possible para-aortic LN removal
IB2 IIA1	Possible radical trachelectomy (lack of research)	Radical hysterectomy + pelvic LN eval/ possible para-aortic LN removal
IB3 IIA2		Radical hysterectomy + pelvic LN eval/ possible para-aortic LN removal OR Chemoradiation + brachytherapy

Clinical Stage	Fertility-Sparing	Nonfertility Sparing
IIB III IVA		Chemoradiation + brachytherapy

Endometrium

Anatomy

- Hollow organ comprises the upper portion of the uterus called the body or corpus and the lower end of the uterus (uterine cervix) that joins to the vagina.
- Extending laterally from the superior uterus are the twin fallopian tubes.
- The body of the uterus has two main layers: myometrium, or outer layer of thick muscle, needed for childbirth and the endometrium, the thin inner layer that sheds during menstruation.
- Parametrium—the connective tissue lateral to the uterine cervix.

Signs and Symptoms

- Most present with irregular or post-menopausal bleeding
- Purulent vaginal discharge
- Pelvic pain
- Advanced disease presents with ascites, pelvic mass, or altered bowel habits

Etiology and Epidemiology

- Risk factors include obesity, estrogen use after menopause, long menstrual cycle lifetime, age, tamoxifen use, polycystic ovarian

syndrome

Protective Factors: Birth Control Use, Pregnancy

- Most common cancer of female reproductive organs
- Over 66,000 cases of uterine body and corpus cancers are diagnosed annually
- Affects post-menopausal women most, with average age of diagnosis being 60

Lymphatic Spread Patterns

- Endometrium has few lymphatics
- Lower and middle uterus drain to parametrial, paracervical, hypogastric, and obturator nodes
- Fundus drains to external iliac then para-aortics

Detection and Diagnosis

- Hysteroscopy with dilation and curettage is gold standard endometrial biopsy (usually done in doctor's office) and is reported as having a 94% sensitivity rate
- Transvaginal ultrasound
- H & P
- Chest x-ray
- Blood counts, chemistries, and urinalysis
- Pap smear
- Pelvic CT or MRI when extrauterine disease suspected

Histology and Staging

- Adenocarcinoma—most common
- Endometrioid cancer is the most common type of adenocarcinoma
- Squamous cell carcinoma
- Small cell carcinoma

- Serous carcinoma
- Sarcomas—also advanced
- FIGO and TNM staging summary:
- Stage I limited to endometrium up to myometrium
- Stage II limited to glandular epithelium, no stromal invasion
- Stage III serosa involvement or ascites positive for cancer cells
- Stage IV invasion of bladder or bowel
- Grade summary:
-

Grade 1 tumors have 95% or more of the cancer tissue-forming glands.

•

Grade 2 tumors have between 50% and 94% of the cancer tissue-forming glands.

•

Grade 3 tumors have less than half of the cancer tissue-forming glands. Grade 3 cancers tend to be aggressive (they grow and spread fast) and have a worse outlook than lower-grade cancers.

Treatment Considerations

- Surgery and/or radiation therapy—depending on stage, grade, medical condition of patient
- Preoperative radiation for Stage I is controversial; postoperative RT is standard
- Total hysterectomy (TH) and bilateral salpingo-oophorectomy (BSO) for disease limited to uterus and suitable for primary surgery, adjuvant vaginal brachytherapy for Stage IA and IB
- External beam and/or brachytherapy for non-surgical primary treatment when disease is limited to uterus
- Suspected or gross cervical involvement treated with TH/BSO or EBRT + brachytherapy and possible platinum-based

chemosensitization (Cisplatin)

- Extrauterine diseases treated with systemic therapy $\pm$ EBRT $\pm$ brachytherapy or SBRT $\pm$ TH/BSO

Treatment

- Early-stage 2 disease
- Include external/internal iliac superiorly, upper half of vagina inferiorly and 2 cm lateral to bony pelvis
- Simulate with empty rectum
- EBRT 45 to 50.4 Gy in 1.8 to 2.0 Gy fractions by 3DCRT or IMRT
- Brachytherapy—a vaginal cylinder HDR
- Doses for brachytherapy alone are 7 Gy in 3 fractions at 0.5 cm or 5 Gy in 6 fractions at 0.5 cm
- Doses after pelvic EBRT are 5 Gy in 3 fractions or 4 Gy in 3 fractions
- HDR vaginal cuff boost dose is 6 Gy in 1 to 2 fractions prescribed to surface
- Stage IIIA-IVA receives EBRT $\pm$ vaginal brachytherapy $\pm$ systemic therapy, involved field RT replacing whole abdomen RT Stage IVB receives systemic therapy $\pm$ EBRT $\pm$ vaginal brachytherapy

Ovarian Cancer

Anatomy

- Ovaries are reproductive glands that produce eggs (ova) for reproduction
- One ovary is located on each side of the uterus adjacent to the fallopian tubes

Clinical Presentation

- Palpable pelvic mass
- Ascites, abdominal distention

- Abdominal pain
- Feeling full quickly

Epidemiology Etiology

- Predominant in white women
- Average age at diagnosis is over 60
- Incidence rates slowing declining although accounting for more deaths than any cancer of the female reproductive organs

Risk Factors

- Older age
- Obesity
- Family history some related to genetics (BRCA1, BRCA2)
- Personal history of breast cancer, endometriosis, pelvic inflammatory disease, and tall adult height
- Use of menopausal hormone therapy
- FACTORS to lower risk
- Multiple pregnancies
- Late menarche
- Early menopause
- Hormonal contraceptives
- Lymphatic spread patterns
- Para-aortic, pelvic

Detection and Diagnosis

- Screening tools are inadequate because the disease is only intermittently detectable during physical examinations, radiographic studies, and serologic tests and then it is usually found to be in an advanced stage
- Pelvic examination with transvaginal ultrasound
- Blood test for CA125 tumor marker
- H&P
- Liver and renal function blood work

- Chest x-ray

Histology and Staging

- 90% are epithelial (from ovary surfaces)
- 7% are stromal
- 3% ovarian germ (these include dysgerminomas, which are treated as seminomas—male testicular cancer)

Staging Summary

-

Stage I: Tumor limited to the ovaries (one or both).

-

Stage II: Tumor involves one or both ovaries with pelvic extension and/or implants.

-

Stage III: Tumor involves one or both ovaries with microscopically confirmed peritoneal metastases outside the pelvis.

Treatment Considerations

- Initial—surgical evaluation and debulking hysterectomy and bilateral salpingo-oophorectomy.
- Standard of care postoperative chemotherapy Stage I platinum-based therapy

Stages II to IV After Primary Treatment ± Bevacizumab (Angiogenesis Inhibitor) + Chemotherapy (Olaparib or Niraparib)

Survival Rates

- Overall 5-year survival—50%
- Localized disease 93%, 5 years

Treatment

- Radiation therapy not routinely used in ovarian cancer management
- Palliative, localized radiation may be considered for symptom control of recurrent disease

Side Effects of Pelvic Irradiation

Acute

- Fatigue—First week of treatment
- Exacerbated or complicated by anemia and depression (coming to terms with having being diagnosed with cancer)—treated with rest, reassurance, adequate nutrition, and antidepressants
- Anemia, secondary to blood loss should be corrected (hemoglobin level above 10 to 11 g/dL)
- Diarrhea—second or third week of treatment (to large and small bowel); patient advised—low-fiber diet; sucralfate (Carafate)—small bowel-coating agent; diphenoxylate (Lomotil) and loperamide medication
- Exclusion of small bowel helps by use of belly boards, prone position with full bladder, custom shielding, serial field-size reduction, and IMRT
- Addition of chemo heightens all side effects
- Nausea and upper GI bleeding
- Dermatitis—more common with: low-energy beams, AP/PA fields only; perineal flash; use of bolus; concomitant chemo
- Treatment—Domeboro soaks, Aquaphor ointment, natural care gels (lessens severity and speeds healing); prevention and early treatment of local infection, correction of anemia and nutrition problems also helps skin heal

- Dysuria—third or fourth week of treatment; can be lessened by treatment with full bladder; partial bladder exclusion on lateral fields; maintenance of a partially full bladder during brachytherapy
- Medications—Phenazopyridine (Pyridium), and Urised (anesthetize bladder). To relax bladder relieve urinary frequency—Ditropan, Levsin, and Hytrin. Infections should be treated early and completely.
- Bleeding
 - Anal irritation—Treated with hemorrhoidal preparations, steroids, topical anesthetic agents, and sitz baths
 - Bladder irritation
 - Hemorrhagic tumor

Chronic

- Menopause—HRT
- Vaginal dryness/narrowing/shortening—moisturizing agents
- Chronic cystitis—local medications (Trental)
- Proctosigmoiditis
- Enteritis
- Bowel obstruction—pain medications

Gynecologic review exercises

1. Bladder and rectal doses are very important to the gynecologic radiation therapy planning. The point tolerance for these organs is:
 - a. 2000 cGy
 - b. 3500 cGy
 - c. 5000 cGy
 - d. 7500 cGy
2. Use of this agent is known to increase the risk of endometrial cancer.
 - a. Cisplatin

- b. Methotrexate
 - c. Tamoxifen
 - d. Doxorubicin
3. Which of the following preoperative test might be used in detection of ovarian cancer?
- a. PSA
 - b. BRCAI
 - c. BRCAII
 - d. Ca-125
4. The cervix often protrudes into the vagina, producing lateral spaces in the vaginal apex called:
- a. Cervical os
 - b. Fornices
 - c. Paraaortics
 - d. Ovaries
5. With vaginal and cervical cancers, there is an increased risk of clear cell adenocarcinoma and abnormalities of the stratified epithelium in women whose mothers (during pregnancy) used which of the following drugs:
- a. Diethylstilbestrol (DES)
 - b. Dihydrotestosterone (DEET)
 - c. Dysmenorrheal (DMH)
 - d. Deoxyribonucleic acid (DNA)
6. When treating pelvic tumors with a high radiation dose, a major side effect is diarrhea due to the small bowel in the field. It usually occurs in the second or third week of treatment. Which of the following would be prescribed to alleviate this problem?
- a. Sucralfate (Carafate)
 - b. Diphenoxylate (Lomotil)
 - c. Ibuprofen (Motrin)
 - d. Prochlorperazine (Compazine)

7. Dietary guidelines for patients receiving pelvic irradiation may include all the following, except:
- Whole-grain breads
 - Baked, broiled, or roasted meats
 - Cooked vegetables
 - Peeled apples and bananas
8. The most radiotolerant structure of the gynecologic organs is the:
- Uterine canal
 - Cervix
 - Ovary
 - Bladder
9. Inguinal nodes would most likely be treated when a cancer occurs in which area:
- Cervix
 - Ovary
 - Endometrium
 - Vagina
10. If a patient is having a four-field pelvis treatment, calculate the diameter of the AP/PA and lateral using the following: AP SSD readout is 85, PA SSD readout is 87.5; right lateral 81, left lateral 79.5
- AP/PA diameter = _____
 - Rt/Lt lateral diameter = _____

Male genital

- Prostate
- Testicular
- Penis

Prostate

General Facts and Epidemiology

- Number one in cancer incidence in men in the United States
- Second in mortality in the United States
- African Americans have higher incidence, more advanced disease with worse prognosis
- Overall, very slow-growing malignancy
- Early detection occurs often due to screening improvements
- Average age 60 years

Etiology

- Etiology unknown
- Possible risk factors:
 - Racial origin
 - Environmental factors—Agent Orange
 - Genetics—BRCA1, BRCA2
 - Diet
 - Age

Clinical Presentation

Signs and symptoms

- Early stage-asymptomatic with digital rectal examination (DRE)
- Advanced stage
 - Weak urine stream
 - Blood in urine or semen
 - Weakness in extremities
 - Pain in back, pelvis
 - Urinary incontinence

Histology

- Adenocarcinoma (Acinar) most common
- Transitional cell

- Small cell
- Squamous cell
- Carcinoid
- Sarcoma

Lymphatic Drainage and Spread Patterns

- Direct extension to seminal vesicle(s)
- Lymphatic drainage primarily to obturator and internal iliac nodes
- Secondary lymphatics to the external iliac, pre-sacral, common iliac, and para-aortic nodes
- Hematogenous spread to skeletal anatomy initially to pelvis, spine, ribs, and extremities
- Spread is influenced by grade; low grades stay local for a long time

Detection and Diagnosis

- H&P
- PSA
- Digital rectal exam
- Multiparametric prostate MRI
- Transurethral ultrasound (TRUS)
- TRUS biopsy

Staging/Grading

- AJCC TNM staging
- Gleason grading (

[Table 8.12](#)) assesses differentiation of tissue sample

- Grades 1 to 5 = well differentiated—poorly differentiated
- Two most predominant histologic patterns are identified by the pathologist and then added to give a score 2 to 10

TABLE 8.12**Gleason Scoring**

Gleason Score	Summary	Prognosis
2–4	Well differentiated	Good
5–7	Moderately differentiated	Fair
8–10	Poorly differentiated	Poor

Treatment

- Very low-risk patients—active surveillance (AS)
- Low and favorable intermediate risk—EBRT or brachytherapy, radical prostatectomy ± pelvic lymph node dissection (PLND)
- Unfavorable intermediate-, high-, or very high-risk—EBRT + androgen deprivation therapy (ADT) or external beam radiation therapy + brachytherapy ± ADT, or radical prostatectomy + PLND
- Brachytherapy + EBTR when Gleason score is 9 to 10

Treatment delivery

- IMRT, VMAT, or 3D conformal RT recommended
- Fiducial markers may be placed
- IGRT
- Pelvic immobilization and lower extremity immobilization with vac lock
- Empty rectum, no gas in rectum
- Bladder comfortably full
- Conventional fractionation: 1.8 to 2.0 Gy/fx, total dose 73.8 to 81 Gy
- Moderate hypofractionation: 2.4 to 3.0 Gy/fx, total dose 57 to 72 Gy

- Ultrahypofractionation: 6.1 to 7.25 Gy/tx QOD, total dose 36.25 to 42.7 Gy
- Brachytherapy alone
- HDR 13.5 Gy $\times$ 2 implants or 9.5 Gy BID $\times$ 2 implants
- EBRT and brachytherapy combined
- EBRT 45 to 50.4 Gy $\times$ 25 to 28 fx or 37.5 Gy $\times$ 15 fx plus brachytherapy boost of 15 Gy $\times$ 1 fx or 10.75 Gy $\times$ 2 fx

Testicular

General Facts and Epidemiology

- 95% of malignant tumors in the testes are germ cell tumors
- Most common solid tumor in men ages 15 to 35 years
- Incidence has increased over past 40 years
- More common in Caucasians versus African Americans
- Cure rates are high 70% to 90%

Etiology

- Cryptorchidism (undescended testicle)
- First-born
- Pre/perinatal estrogen exposure
- Down syndrome
- Klinefelter syndrome
- Mumps orchitis

Clinical Presentation

Signs and symptoms

- Painless, testicular mass
- Testicular discomfort or swelling
- Decreased sperm count and sperm mobility

Histology

- 1. Seminoma (50%) (classic, anaplastic, spermatocytic)
- 2. Nonseminoma (50%)
- Embryonal carcinoma
- Choriocarcinoma
- Yolk sac tumors
- Teratomas

Lymphatic Drainage and Spread Patterns

- Local, then spreads to lymph nodes in orderly fashion; external and internal iliac, common iliac, paraaortic, paracaval, renal-hilar commonly involved; inguinal, femoral nodes are rarely affected—previous surgeries may disrupt normal lymph flow patterns so contralateral nodes may be treated
- Distant spread to lungs

Diagnosis and Detection

- H&P
- Testicular ultrasound
- HCG, AFP, LDH serum markers
- Chemistry profile
- CT of abdomen/pelvis

Staging

- Serum markers are strongly considered in staging using TNM (SX-S3)
- T—tumor limited to testes, size <3 cm to >3 cm
- N—nodes <2 cm and ≤ 5 positive nodes to LN >5 cm
- M—absence or presence of distant metastasis

Treatment

- Nonseminoma Germ Cell Tumors

- Radical inguinal orchiectomy and lymph node dissection with adjuvant chemotherapy BEP or EP

Treatment delivery

- AP/PA 3D conformal RT preferred over IMRT to lessen secondary malignancy (

Figure 8.15)

- Supine with arms at sides, elevated or high on chest (elevated makes it easy to use 3-point setup marks)
- Inverted Y or Dogleg/hockey-stick technique
- Scrotal shielding used on contralateral testis
- Field will need beam shaping to protect kidneys, bowel, bladder, and bone marrow reserves in iliac crests
- Patient may experience some nausea so give antiemetic before treatment
- Refer to

Table 8.13 for pure seminoma treatment

- Total doses
- Stage IA,IB—20 Gy in 2-Gy fractions for 10 fx preferred
- Stage IIA—30 Gy in 1.8 to 2.0 Gy/fx
- Stage IIB—36 Gy in 1.8 to 2.0 Gy/fx

PRINCIPLES OF RADIOTHERAPY FOR PURE TESTICULAR SEMINOMA

Treatment Modalities

- Linear accelerators with >6 MV photons should be used when possible.

Target Volumes by Stage (or location)

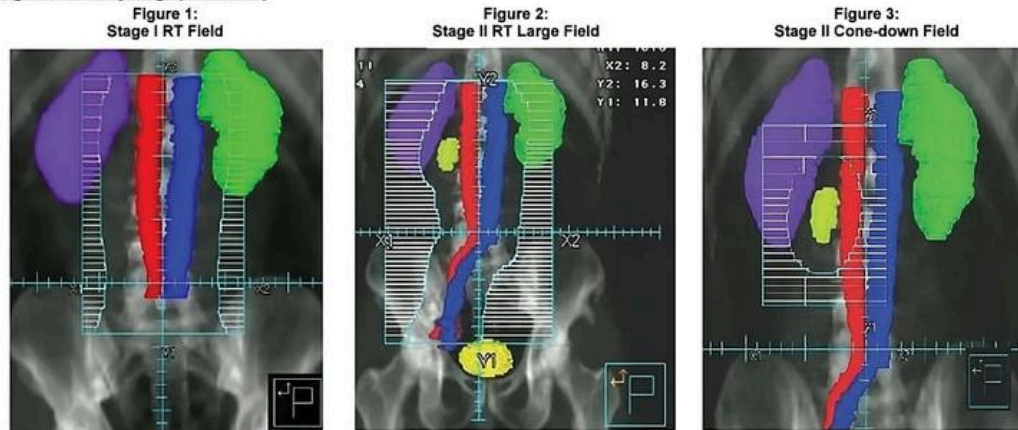


FIG. 8.15 Testicular seminoma RT portals.

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Table 8.13

Pure Seminoma Treatment—Radical Inguinal Orchiectomy With:

Clinical Stage	Primary Treatment
IA, IB	Surveillance for pT1-pT3 tumors or
	Single-agent carboplatin or
	Radiation therapy (20–25.5 Gy)
IIA	RT to include para-aortic and ipsilateral iliac nodes to 30 Gy or
	First-line chemotherapy BEP or EP
IIB	First-line chemotherapy BEP or EP or
	RT to nonbulky field and para-aortic and ipsilateral iliac nodes to 36 Gy
IIC, III	First-line chemotherapy BEP, EP or VIP

Penis

General Facts and Epidemiology

- Rare in the United States 2% of urogenital cancers
- 10% of malignancies in men in noncircumcised populations
- Incidence higher in Asia, Africa, South America
- Most patients diagnosed over age 50

Etiology

- No circumcision at birth
- Poor hygiene, smegma

- HPV

Clinical Presentation

Signs and symptoms

- Mass or persistent sore
- Ulceration, bleeding, discharge
- Inguinal adenopathy
- Pain

Histology

- Squamous cell carcinoma
- Bowen disease—CIS
- Leukoplakia
- Erythroplasia of Queyrat

Lymphatic Drainage and Spread Patterns

- Superficial inguinal, often bilateral
- Deep inguinal
- External and common Iliac
- Para-aortic

Detection and Diagnosis

- Physical examination of penis and inguinal nodes
- Tumor biopsy
- CT of abdomen and pelvis
- PET/CT

Staging

- TNM; depth of invasion important; Mohs technique helpful

Treatment

- Wide local excision
- Partial or total penectomy
- Chemotherapy—TIP (Paclitaxel, Ifosfamide, Cisplatin) or 5-FU
- Laser ablation
- Mohs surgery
- Radiation with external beam or interstitial brachytherapy for those who refuse surgery or are low stage

Radiation treatment borders

- Should include the entire shaft and lower pelvic lymph nodes, inguinal nodes especially

Treatment delivery

- Prone on board or supine with penile box containing wax or water bath (

Figure 8.16) and opposing lateral fields; 2 Gy daily up to 60 to 74 Gy total

- Inguinal nodes with electron therapy; unknown status of pelvic nodes should be treated
- Stage T1-2
- Brachytherapy alone or EBRT to 65 to 70 Gy 1.8 to 2.0 Gy/fx, using bolus to primary lesion
- Consider prophylactic radiation to inguinal nodes for nonsurgical patients
- Stage T3-4 or positive node
- Concurrent chemoradiation to 45 to 50 Gy to whole shaft, pelvic lymph nodes, and bilateral inguinal nodes
- Boost primary lesion and gross lymph nodes to 60 to 70 Gy
- Palliative radiation to 30 Gy in 10 fractions

- Acute effects of radiation—penile swelling, dry/moist desquamation, scrotal edema, diarrhea

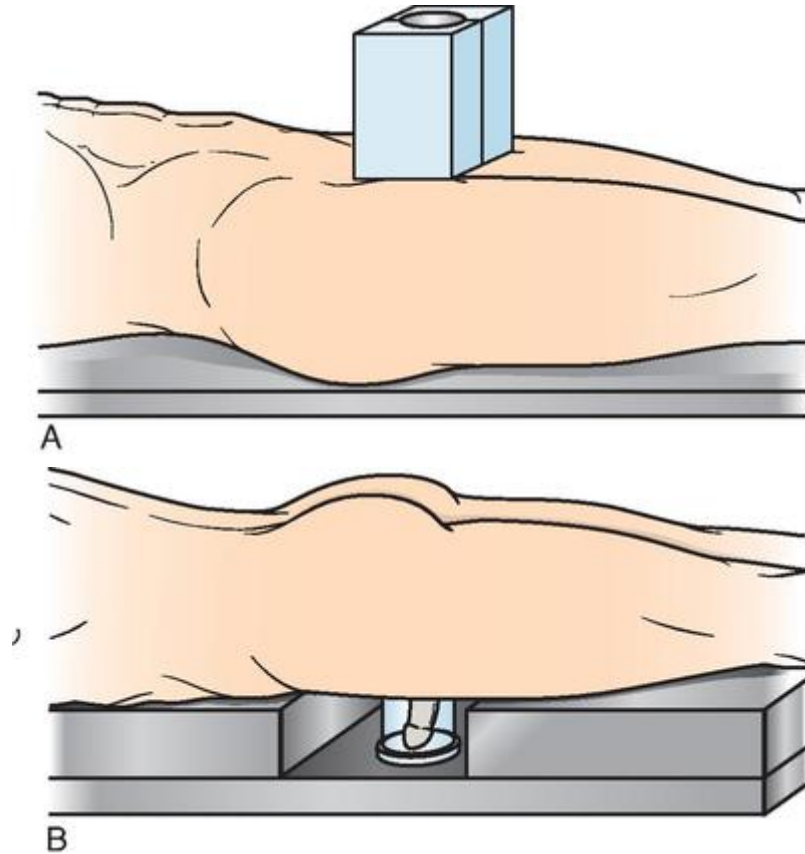


FIG. 8.16 Penile box.

A , Penile box with patient in supine position.

B , Penile box/cylinder with patient in prone position.

Male genital review exercises

1. The most common cancer of germinal origin of the testis is:
 - a. Teratocarcinoma
 - b. Choriocarcinoma
 - c. Seminoma
 - d. Embryonal

2. Testicular cancers are most frequently diagnosed in men aged:
- 60 to 65 years
 - 15 to 35 years
 - 40 to 50 years
 - 70 to 80 years
3. A blood serum marker used in determining extent of testicular cancer is:
- AFP
 - CA 19-9
 - CEA
 - BRCA 1
4. Of the following tumors, which would require the lowest dose to control disease?
- Prostate
 - Testis
 - Penis
 - Breast
5. Of the following tumors, which would require the highest dose to control disease?
- Prostate
 - Testis
 - Penis
 - Breast
6. When irradiating seminoma stages I, IA, IB, the following nodes should be included:
1. Paraaortic
 2. Ipsilateral iliac
 3. Mediastinal
 4. Scalene
- 1, 2

- b. 3, 4
- c. 1, 2, 3
- d. 1, 2, 3, 4

7. The most common histologic type found in prostate cancer is:

- a. Adenocarcinoma
- b. Squamous cell
- c. Transitional cell
- d. Clear cell

8. Hormonal therapy for prostate cancer may include the administration of:

- a. Lupron
- b. Tamoxifen
- c. Megace
- d. Taxol

9. Using

[Figure 8.17](#) , identify the following:

- a. Prostate gland
- b. Seminal vesicles
- c. Rectum

10. Severe wet desquamation should be managed with:

- a. Applications using cold packs
- b. Hot baths with Epsom salts
- c. Applications for severe radiation dermatitis; open wounds
- d. Applications of petroleum jelly

11. A common location for distant metastasis from seminoma is:

- a. Brain
- b. Skin
- c. Liver
- d. Lung

12. Total dose for irradiation of the prostate tumor bed is:

- a. 20 to 30 Gy
- b. 30 to 45 Gy
- c. 50 to 60 Gy
- d. 66 to 75 Gy



FIG. 8.17 CT axial view pelvis.

Urinary

- Kidney
- Bladder

Kidney (Renal Cell)

General Facts and Epidemiology

- Median age of onset 55 to 60 years
- Sixth most common cancer in men and tenth most common in women (United States)
- Men affected twice as much as women

- Highest rates in whites and African Americans; lowest rates in Asian Americans
- Globally incidence rate of renal cell carcinoma (RCC) is highest in North America and Scandinavia and lowest in Asia and South American

Etiology

- Direct cause is unknown, but several risk factors have been identified:
 - Smoking
 - Cadmium, lead, asbestos, and gasoline exposure
 - Thorotrast (alpha emitter) exposure
- Diabetes
- Polycystic kidney disease
- Family history
- Obesity
- Hypertension

Histology

- Most classified as RCC
- Four categories of RCC: clear cell, papillary, chromophobe, or collecting duct
- Urothelial (formerly transitional cell) carcinoma accounts for the majority of renal pelvis and ureter neoplasms with variations such as squamous cell, glandular, micropapillary, clear cell, sarcomatoid
- Nephroblastomas in children

Clinical Presentation

Signs and Symptoms

- Hematuria (gross or microscopic)
- Back pain

- Palpable mass in abdomen
- Weight loss
- Fatigue
- Fever

Lymphatic Drainage and Spread Patterns

- Local invasion through the renal capsule into perinephric fat or adrenal gland or through the renal vein to the inferior vena cava, regional lymphatics include renal hilar, paraaortic, paracaval, celiac axis
- Distant metastasis through easily accessible renal artery and vein to lung, liver, brain or by retrograde venous drainage to the ovary or testis

Detection and Diagnosis

- CT chest and abdomen
- MRI abdomen
- MR angiography
- Cystoscopy
- Blood chemistry
- Urine cytology
- IVP
- Ultrasound
- Nuclear renal scan
- Biopsy (US or CT guided)

Staging and Grading

- TNM staging grade and nodal status are important prognostic factors

Treatment

- Radical, simple or partial nephrectomy, and involved veins and lymph nodes
- Resectable, early stage is curable with surgery only
- Solitary metastatic lesions may be resected as well
- Ablation through radiofrequency heating and cryosurgical freezing for small lesions
- SBRT
- Radiation therapy to tumor bed, residual disease optional for T3 or larger to 50 to 55 Gy
- Radiation used most often palliatively
- Intraoperative RT (IORT) can be used adjuvantly for locally advanced disease
- Adjuvant chemotherapy, immunotherapy and targeted therapy
- Urothelial cancer are sensitive to chemotherapy

Radiation Treatment Borders

- Radiation treatment fields to tumor bed to include bilateral paraaortic and paracaval lymph nodes to 45 to 50 Gy using standard fractionation 1.8 to 2 Gy per fraction; multiple field IMRT helps spare liver, small bowel, stomach, spinal cord, and opposite kidney
- IORT with electrons supplements with dose range 10 to 20 Gy
- Pediatric cases take care to cover the entire vertebral bodies to prevent uneven bone growth along the spine

Treatment Delivery

- Patient supine with arms above head or akimbo for easy triangulation
- Respiratory Immobilization should be considered for SBRT techniques
- Take care of acute nausea of portion of stomach included in ITV

Bladder

General Facts and Epidemiology

- High incidence in industrial cities
- Sixth most common cancer in the United States (2019)
- Men 2.5 times more likely than women
- Median age 68 years
- People of European heritage more affected than African or Hispanic heritage
- Globally, highest incidence in North America, Western Europe, and North Africa with lower rates in Asia
- Likely occurs in the trigone, posterior/lateral walls, or neck of the bladder
- Liver failure and uremia usually cause of death

Etiology

- Dye, rubber, textile, leather, paint working
- Automobile exhaust
- Chlorination
- Chronic bladder infections
- Smoking
- Previous pelvic irradiation
- Pesticide exposure (arsenic)
- Contaminated water supply
- Cyclophosphamide
- Previous pelvic radiation

Clinical Presentation

Signs and Symptoms

- Hematuria (most often gross)
- Urinary tract infection
- Urinary frequency, urgency, dysuria
- Hematospermia
- Vaginal bleeding (for advanced disease)

- Abdominal mass

Histology

- Urothelial (formerly transitional cell) dominant type
- Squamous cell
- Adenocarcinoma
- Neuroendocrine
- Sarcoma
- Lymphoma

Lymphatic Drainage and Spread Patterns

- Direct spread through bladder walls and invade muscle then soft tissues in the pelvis; lymphatics include common, external, internal iliac, and obturator. Distant spread to bone, lungs, liver, and/or peritoneum

Workup

- CT and/or MRI of abdomen, pelvis
- Transurethral biopsy with transurethral resection of bladder tumor (TURBT)
- Urine cytology
- Urinalysis
- IVP
- Ultrasound
- Chest x-ray for metastasis
- Cystoscopy with brushing

Staging

- TNM

Treatment

- Instillation/intravesical chemotherapy or Bacillus Calmette-Guerin for those with no muscle invasion
- TURBT with or without intravesical therapy standard for superficial non-muscle invading tumors
- Muscle invasive tumors might include TURBT followed by concurrent chemoradiation, partial cystectomy, and lymph node dissection or radical cystectomy and lymph node dissection for qualifying surgical candidates
- Nonqualifying surgical candidates with muscle-invasive tumors might have chemoradiation, TURBT followed by RT or TURBT alone
- External beam and brachytherapy
- Radiation for palliation/urinary bleeding
- Cisplatin- and methotrexate-based chemotherapy

Radiation treatment borders

- Preoperative and/or postoperative fields may be simple AP/PA fields or four field box or multiple field IMRT 40 to 50 Gy using standard fractionation 1.8 Gy per fraction
- IMRT helps reduce dose to rectum and bowel
- Upper border at S1 and lower border at obturator foramen if regional nodes included (internal, external iliac, and obturator)
- Lateral border to pelvic rim
- Beam shaping to protect bone marrow reserves in iliac crest
- In bladder-preserving therapy, external beam dose to bladder and regional lymphatics range 60 to 70 Gy using standard fractionation 1.8 to 2 Gy per fraction
- Hyperfractionation is an option using twice daily or three times daily regimens
- When brachytherapy is used catheters are placed into the TURBT site or residual tumor; EBRT may be prebrachytherapy using single dose of 8.5 Gy, three fractions to 10.5 Gy, or 20 fractions to 40 Gy and brachytherapy escalating dose to 70 Gy

Treatment delivery

- Supine with hands folded on abdomen
- Bladder volume should be consistent so instruct patient to empty bladder before CT simulation and treatment; rigorous bladder volume management strategy is needed
- Side effects minimal for preoperative and postoperative cases
- Definitive cases (bladder conserving) may show signs of cystitis, proctitis, diarrhea
- Instruct to drink plenty of fluids, avoid high fiber foods
- Immobilization for the lower extremities with alpha cradle, vac lock, or simple block, and Velcro feet

Urinary section review exercises

1. Common metastatic site(s) for renal cell carcinoma is/are:
 - a. Bone
 - b. Brain
 - c. Lung
 - d. All of the above
2. Cancers manifesting in the renal pelvis are most commonly:
 - a. Urothelial
 - b. Adenocarcinoma
 - c. Clear cell
 - d. Squamous cell
3. Which of the following examinations are best used in the detection of bladder cancers?
 1. TURBT
 2. Urine cytology
 3. Cystoscopy
 4. DRE
 5. PSA
 - a. 1, 2, 3
 - b. 1, 4, 5
 - c. 2, 3, 4, 5
 - d. 3, 4, 5
4. Most bladder tumors arise in the (select three):
 - a. Posterior wall
 - b. Lateral wall
 - c. Trigone
 - d. Neck
 - e. Urethral opening
5. List three etiologic factors for bladder cancer:

6. List three histologic types for bladder cancer:
7. When treating a patient with bladder carcinoma preoperatively, the treatment portals should be large enough to include the:
 - a. Obturator nodes
 - b. Obturator, external, hypogastric, and presacral nodes
 - c. Hypogastric and presacral nodes
 - d. Obturator, paraaortic, and paracaval nodes
8. The ureters attach the _____ surface of the bladder.
 - a. Anterior
 - b. Posterolateral
 - c. Superior
 - d. Inferior
9. Renal cell carcinomas have immediate access to the blood route via the:
 - a. Portal vein
 - b. Superior vena cava
 - c. Inferior vena cava and abdominal aorta
 - d. Mesenteric and femoral artery
10. The right kidney is slightly lower than the left due to the presence of the:
 - a. Diaphragm
 - b. Adrenal gland
 - c. Liver
 - d. Spleen
11. The most common presenting symptom of bladder cancer is:
 - a. Back pain
 - b. Hematuria
 - c. Abdominal pain
 - d. Fever
12. A carcinogen linked to renal cell and bladder carcinomas found in radiation therapy departments is:

- a. Benzene
- b. Asbestos
- c. Cadmium
- d. Leather

13. The ureters enter the kidneys at the:

- a. Renal pelvis
- b. Renal cortex
- c. Adrenal cortex
- d. Medullary zone

14. Urine passes from the bladder to the outside of the body via the:

- a. Ureter
- b. Urethra
- c. Trigone
- d. Calyx

15. Label

[Figure 8.18](#) showing the following structures:

- a. Inferior vena cava
- b. Aorta
- c. Kidney
- d. Ureter
- e. Bladder

16. Using

[Figure 8.19](#) , draw the typical anterior field for preoperative radiation for bladder cancer.

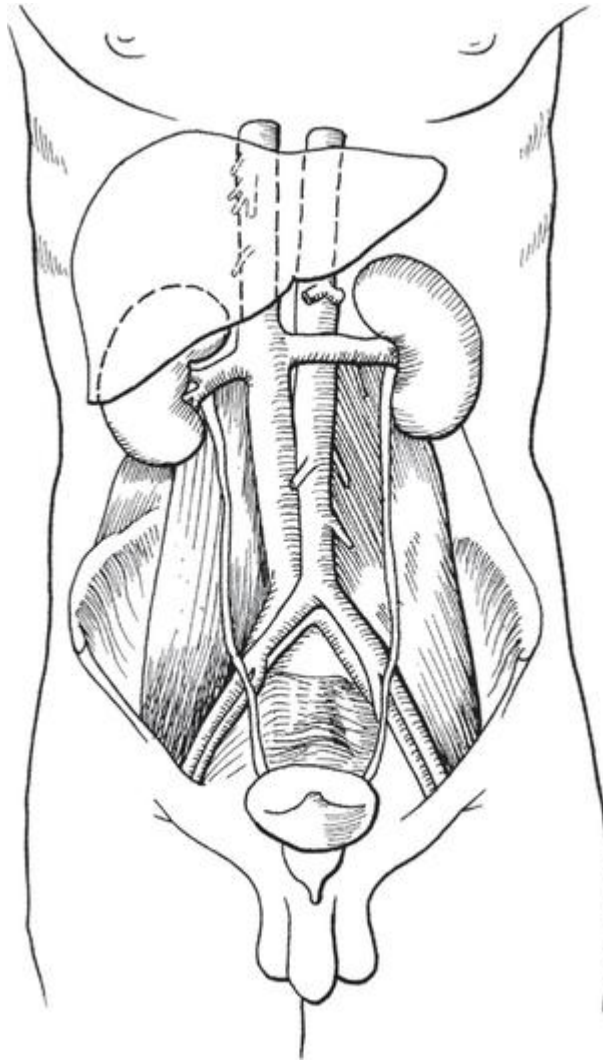


FIG. 8.18 Anterior abdomen and pelvis.

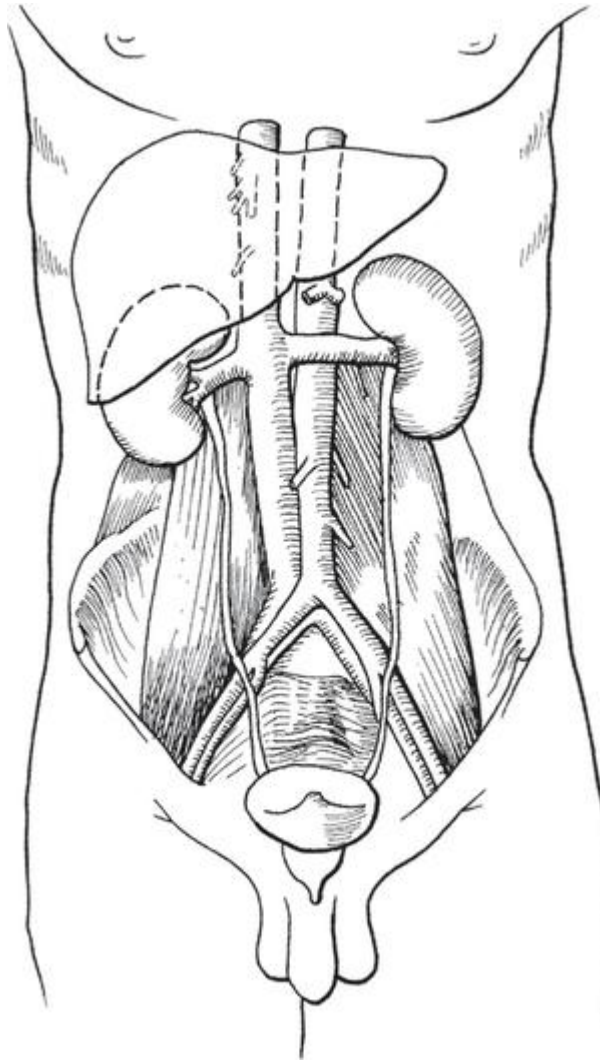


FIG. 8.19 Anterior abdomen and pelvis.

Think About It

17. During treatment planning for bladder carcinoma, the patient should be asked to urinate before simulation begins. If any contrast has to be inserted into the bladder, it should not amount to much more than any residual urine left in the bladder after the patient has voided (an additional 25 mL is acceptable). Why is this important?
18. The TD 5/5 of the kidney ranges from 18 to 23 Gy. When treating the pediatric patient, the opposite kidney should be shielded so that

dose is limited to less than 15 Gy. Why is the tolerance lower in this case?

Central nervous system: brain, spinal cord, pituitary

General Facts and Epidemiology

- CNS malignancies occur at various stages of life.
- Young children have the best prognosis.
- Benign tumors can be life threatening.
- Low-grade, benign tumors may be managed with surgery and radiation.
- High-grade tumors are most threatening but rarely metastasize outside of the central nervous system.
- Majority occurs in the brain.
- Most pituitary tumors are benign.
- Pituitary tumors are the most common new growths near the sella turcica.
- Nonfunctioning pituitary adenomas occur at all ages and at equal frequency among men and women.

Brain and Spinal Cord

Etiology

- Genetics
- History of breast cancer
- Rubber manufacturing and other chemical exposures
- Cystic/polyp conditions of the CNS
- Previous radiation to the head
- Immunosuppression
- History of neurofibromatosis (NF) for primary spinal cord
- Von Hippel-Lindau disease or primary spinal cord

- Epidemiology
- Low grade gliomas commonly present at mean age 37
- High grade gliomas peak incidence in the age range of 65 to 75
- Spinal cord tumors seen in adults and children

Clinical Presentation

Signs and symptoms

- Signs and symptoms depend on the location of the tumor;
- Four functional areas of the cerebrum:
- Frontal—increased cranial pressure (ICP), personality changes, seizures, motor dysfunction, speech impairment, urinary incontinence, cranial nerve VI palsy
- Parietal—increased cranial pressure, vision loss, seizures, weakness, memory loss, loss of touch
- Temporal—speech disorders, seizures, loss of smell, weakness of cranial nerve VI, defective hearing, defective memory
- Occipital—seizures, loss of vision, tingling, weakness, hallucinations
-

Table 8.14 lists the function and location of cranial nerves

- Spinal cord tumors symptoms are a function of local anatomy; within the spinal canal there is a well-defined extradural space containing fat and blood vessels; symptoms reflect involvement of nerves controlling motor and sensory function; some symptoms include the following:
- Decreased temperature
- Pain sensation
- Weakness
- Reflex changes
- Paralysis
- Acute urinary retention
- Incontinence of bowel and bladder

- Impotence
- Radicular pain in the thighs
- 31 pairs of spinal nerves
- Cervical and thoracic spinal nerves pass out of the spinal canal horizontally; lumbar and sacral descend down before they reach the intervertebral foramina (horse-tail)
- Eight cervical nerves
- 12 thoracic
- Five lumbar
- Five sacral
- One coccyx

TABLE 8.14**Cranial Nerves**

Cranial Nerve	Function	Location
Olfactory I	Conveys impulses related to smell	In the olfactory foramina of the ethmoid
Optic II	Vision	From eye to optic canal
Oculomotor III	Controls eye movement; lens and pupil	In the superior orbital fissure
Trochlear IV	Movement of eye and muscle sense	In superior orbital fissure
Trigeminal V	Chewing movements; touch, pain, temperature sense of head and face	In superior orbital fissure
Abducens VI	Movement of the eye	In superior orbital fissure
Facial VII	Facial expressions; taste	In acoustic canal through to facial canal
Vestibulocochlear VIII	Balance and hearing	Internal acoustic canal
Glossopharyngeal IX	Swallowing and secretion of saliva; aid in blood pressure and respiration	Jugular foramen
Vagus X	Sensations and movement of organs	Jugular foramen

Cranial Nerve	Function	Location
Accessory XI	Shoulder movements; turning of the head; movements of the viscera; voice	Jugular foramen
Hypoglossal XII	Speech and swallowing	Hypoglossal canal

Histology sample (the immense range of histologies and grades yield a long list of names)

- Glioma (low grade and high grade)
- Astrocytoma
- Ependymoma (near the cerebellum)
- Meningioma
- Schwannoma
- Medulloblastoma (cerebellum or near the medulla oblongata)
- Neurilemoma
- Craniopharyngioma
- Melanoma (spinal cord)
- Oligodendroglioma
- Hemangioblastoma (spinal cord)
- Pineal gland tumors

Lymphatic Drainage and Spread Patterns

- Astrocytomas, glioblastomas, oligodendroglioma, and meningiomas usually grow locally; some cells may spread to the cerebral

spinal fluid (CSF) but do not implant; signs of increased cranial pressure (ICP) must be addressed immediately

- Medulloblastomas, ependymomas, and pineal gland tumors tend to spread throughout the CSF due mainly to close proximity to the lateral and fourth ventricles
- No lymphatic drainage in the CNS

Detection and Diagnosis

- Physical with neurologic examination
- Spectroscopy-MRI
- CT
- CT-guided needle biopsy
- PET
- Lumbar puncture except for obvious ICP
- Grade, tumor, metastasis (GTM) system since no lymphatic drainage; World Health Organization (WHO) has recommendations for classifying neoplasms by histology and grade

Treatment

- Stereotactic surgery for small tumors like pineal gland growths
- All intracranial tumors should be resected; whenever a complete resection is possible, it should be performed
- Considerations for surgery include neurologic deficits following resection
- Radiation used adjuvant to surgery; conformal techniques desirable to maintain satisfactory sensory and motor function
- Most respond favorably to radiation; resistant tumors may benefit from heavy particle beam therapy
- Heavy particle beam therapy with protons helps spare normal brain tissue and decrease toxicity with great disease control
- Small benign tumors or small recurrent tumors may benefit from single stereotactic radiosurgery using gamma knife or low-energy x-rays
- Small malignant tumors benefit from multifraction stereotactic radiation therapy
- Chemotherapy efficacy is limited due to blood–brain barrier
- Chemotherapy drugs need to be lipid soluble if given intravenously
- Chemotherapy may be administered locally directly into the tumor or into the circulating CSF or intraarterially
- Steroids used to help alleviate and control swelling

Radiation treatment borders

- Primary tumors with low potential for CSF spread are treated with conformal fields; 2- to 3-cm margin around the tumor or tumor bed to begin then shrinking to 0.5-cm margin
- Fields may be static or dynamic
- Low-grade gliomas treated to dose range 45 to 54 Gy using standard fractionation
- High-grade gliomas treated to 60 Gy
- Multiple beam arrangements using IMRT techniques to help spare normal brain tissue, optic chiasm, orbits, and lens
- SRS may be used as boost for high-grade gliomas; single dose range 12-14 Gy
- SRS for primary spinal cord tumors to 10 Gy
- SBRT may also be used for primary spinal cord tumors
- IMRT techniques for GTV+CTV brain tumors and spinal cord tumors
- Some variation in dose schemes based on patient age and tumor histology; post-operative tumor bed dose range 49 to 56 Gy, whereas entire spinal axis received 30 to 36 Gy with standard fractionation 1.5 to 2.0 Gy per fraction
- Primary tumors with high potential for CSF spread require a dose to the entire spinal axis: whole brain helmet technique down to C2 and total spine in single extended field or matched fields
- Entire spinal axis may be treated with proton therapy in pediatric cases especially to avoid exit dose to esophagus, lungs, heart, stomach, small bowel, liver, kidneys, ovaries, testes, and breasts

Treatment delivery

- Total dose for primary tumors ranges from 50 to 70 Gy
- Lower dose for radiation to tumor bed; higher dose for partial resections or no surgery
- Lower dose for those receiving chemoradiation
- Conformal fields may use various portal arrangements; patient may be supine with chin flexed or neutral depending on treatment field

orientation

- Objective is to accurately treat the CTV while consistently sparing normal brain and sensitive tissues such as the lens
- Primary tumors are typically solitary and unilateral; fields will likely be aimed to the affected side only; be mindful of any exit dose to low tolerance tissues; wedged pair is common; multifield IMRT fields also possible
- Reliable immobilization of head imperative since margins are small although movement in the cranium is relatively nonexistent
- When treating entire spinal axis with photons, overlap may be eliminated by using half field technique or table kick and collimator angles
- Skin gaps should be carefully measured daily, and junction changed every 3 to 5 fractions
- Symptoms of disease may cause patients to be dizzy, weak, confused, or nauseous so be prepared to support during transfer from wheelchair/gurney to PSA or while ambulating; advise patients to always come accompanied to therapy
- Side effects from therapy include skin desquamation and hair loss
- Educate patient on scalp care—no harsh shampoo or razor cutting, no chemical processing, protect from the sun
- Fields will require beam shaping with MLC and use of modifiers

Pituitary/Hypophysis

Etiology

- Heredity as part of endocrine syndromes
- Epidemiology
- Pituitary tumor incidence increases with age
- More frequent in females and African-Americans

Clinical Presentation

Signs and symptoms

- Symptoms influenced by the portion of gland affected and which hormones are affected
- The anterior portion of the gland produces at least six hormones: prolactin, adrenocorticotrophic hormone (ACTH), follicle-stimulating hormone, luteinizing hormone, growth hormone (GH), and thyroid-stimulating hormone (TSH)
- The posterior portion stores and releases two hormones: vasopressin/antidiuretic hormone and oxytocin
- Weight changes
- Excess hormonal levels
- Uncontrolled diabetes
- Hyperparathyroidism
- Multigland hyperplasia
- Amenorrhea
- Short stature syndromes
- Seizures
- The presence of a pituitary tumor may also manifest as neuro-ophthalmic disturbances from pressure on nerves and orbit compartment
 1. Headache
 2. Visual disturbances
 3. Cranial nerve III, IV, V, VI palsy
 4. Hydrocephalus
 5. Seizures

Histology

- Traditionally classified pituitary growths by histologic staining and referred to as:
 - Basophil adenoma
 - Eosinophil adenoma
 - Chromophobe adenoma
- Currently classified by hormone function or nonfunctioning such as:
 - GH producing

- ACTH producing
- TSH producing

Lymphatic Drainage and Spread Patterns

- No lymphatic drainage
- Regional spread only to cranial nerves and compression of optic chiasm

Detection and Diagnosis

- History and physical
- Thyroid function
- Lab studies to assess TSG, ACTH, cortisol, prolactin and other hormones
- MRI with gadolinium enhancement
- CT
- PET

Staging

- Classified by location such as: suprasellar, parasellar, or infrasellar
- Wilson's modification on Hardy and Verzina's classification incorporates location, tumor size, grade, imaging, and intraoperative findings of cellular destruction (grade) and extrasellar extension (stage)

Treatment

- Need to treat the hormonal imbalance and reduce the size of the growth
- Dopamine for prolactinomas, GH-secreting tumors
- Other pharmacologic therapies as appropriate for hormone manipulation
- Surgery using a transsphenoidal approach for small tumors can be for biopsy or total resection

- Radiation therapy for postoperative treatment after subtotal removal, recurrent disease, or when surgery not possible
- External beam, standard fractionation therapy with low-energy x-rays
- Stereotactic radiosurgery with single dose x-rays or gamma knife
- Proton beam and other heavy particles good option due to short range and Bragg's peak in this thin area of the body
- Permanent interstitial implant using Y

⁹⁰ ; dose range 500 to 1000 Gy rarely used in the United States

Radiation treatment borders

- No lymphatic drainage and local spread only so small conforming fields needed with tight margins
- Good surface landmarks are just inferior to the glabella at midline; 2.0 cm anterior and 2 cm superior to the external auditory meatus
- Fields are small

Treatment delivery

- Single fraction dose with SRS need to limit dose to optic chiasm to 8 to 10 Gy to minimize damage to optic pathways
- Reported doses of 12 to 35 Gy using SRS; lower doses for nonfunctioning tumors and higher doses for functioning tumors
- Traditional method with external beam fractionation to 40 to 50 Gy using three field technique (vertex + laterals or anterior + laterals) to spare normal brain tissue, or parallel opposed laterals, or rotational arcs
- Patient may be positioned supine with neutral head position for three field or parallel opposed fields techniques; be mindful of protecting the lens
- Patient may be positioned supine with maximum chin flexion for rotational arcs through the coronal plane or three field vertex and laterals

- Patient may be positioned prone with chin hyperextended for three-field technique or rotational arc through the coronal plane
- Reliable immobilization imperative with tight margins
- Arcs may be administered in noncoplanar arrangements requiring couch kicks
- Beam energies may be mixed
- Sophisticated 3D conformal planning and use of wedges for three field technique and arc techniques, mixed energies, couch kicks incur complex billing charges even though beam shaping is nonexistent or minimal
- Side effects are minimal and may include edema, skin reddening, and hair loss
- Advise patient on scalp care—no razor shaving, no harsh shampoo, protect from the sun

Central nervous system review exercises

Multiple Choice

1. The lateral ventricles are located within the:
 - a. Cerebral hemispheres
 - b. Brainstem
 - c. Sella turcica
 - d. Falx cerebri
2. The area of the cerebrum responsible for sensory and association is the:
 - a. Frontal area
 - b. Parietal area
 - c. Temporal area
 - d. Occipital area
3. The sense of smell is conveyed by the:
 - a. Olfactory nerve

- b. Oculomotor nerve
 - c. Abducens nerve
 - d. Facial nerve
4. A glioma spreads by means of:
- a. Local invasion
 - b. Cerebrospinal fluid
 - c. Lymph nodes
 - d. Blood
5. Which of the following brain tumors have the tendency to spread via the CSF?
- a. Glioma
 - b. Astrocytoma
 - c. Medulloblastoma
 - d. Oligodendroglioma
6. Which of the following brain tumors is seen more frequently in the adult?
- a. Medulloblastoma
 - b. Ependymoma
 - c. Pituitary adenoma
 - d. Glioma
7. Which of the following is *not* a symptom of intracranial tumors?
- a. Headache
 - b. ICP
 - c. Seizures
 - d. Nocturia
8. The primary management modality for primary brain tumors is:
- a. Surgery
 - b. Radiation
 - c. Chemotherapy

- d. Hormonal therapy
- 9. Which of the following are symptoms of pituitary adenomas?
 - a. Uncontrolled diabetes
 - b. Visual disturbances
 - c. Sinus pressure
 - d. a and b only
 - e. All of the above
- 10. Using

Figure 8.20 , label the following anatomy:

- a. Pineal gland
- b. Pituitary gland
- c. Pons
- d. Medulla
- e. Third ventricle
- f. Fourth ventricle
- g. Sphenoid sinus
- 11. A primary spinal cord tumor located in the lumbosacral region may be demonstrated by:
 - a. Tingling sensation in the lower abdomen
 - b. Pain radiating along the flank
 - c. Incontinence, impotence
 - d. Radiating pain down the legs
 - e. c and d only
- 12. Facial pain could be associated with a primary CNS tumor near cranial nerve:
 - a. I
 - b. III
 - c. VII
 - d. XI
- 13. Local hair loss and erythema are the expected side effects from cranial radiation. Patients should be advised to:

- a. Use mild shampoo or water only for washing
 - b. Use a razor to shave the head before the hair begins to thin
 - c. Apply keratosis cream to scalp daily
 - d. Apply hot towels daily to re-stimulate hair growth
14. Symptoms of brain tumors commonly include dizziness, diplopia, and seizures. Patients should be advised to:
- a. Come accompanied to each therapy session
 - b. Take an analgesic before therapy
 - c. Take an antidiuretic before therapy
 - d. Apply cold towels to the forehead after each treatment
15. Involvement of cranial nerve _____ may manifest as dysphagia.
- a. IX
 - b. VII
 - c. VI
 - d. V



FIG. 8.20 CT sagittal view brain.

Think About It

16. Several primary tumors metastasize to the brain. However, primary brain tumors do not spread outside of the central nervous system. Briefly explain.
17. Noncoplanar beam arrangements are useful in treating pituitary adenomas. What is the advantage of this treatment strategy over traditional coplanar field arrangements?
18. Radiation therapy treatment fields often conform to primary brain tumors with about a 2-cm margin. Metastatic brain disease calls for whole brain radiation therapy. Explain.

Skin Cancer

General Facts and Epidemiology

- Skin cancers make up one-third of all cancer incidence in men and women in the United States
- There are two main types of primary skin cancers: melanomas and nonmelanomas
- Nonmelanomas are the most common
- Both types are easily visible and extremely curable if detected early
- Many melanomas are not discovered until late so there is greater mortality
- Melanomas are radioresistant
- Nonmelanomas are radiosensitive
- People of Celtic and Irish descent with fair skin are at increased risk

Etiology

- Ultraviolet radiation exposure
- Genetic disorders such as albinism
- Ionizing radiation
- Exposure of skin to chemicals such as arsenic
- Chronic irritation and inflammation

Epidemiology

- Non-melanomas seen in older adults
- Melanomas seen over wide age range young adults to elderly

Clinical Presentation

- Symptoms depend on skin cancer type (

[Table 8.15](#))

TABLE 8.15**Symptoms of Skin Cancer by Histologic Type**

Basal Cell and Squamous Cell	Melanoma
Early signs: small papule with telangiectasia, firm induration of skin, patches of keratosis and scaling	Change in size, thickness, or contour of an existing mole
Late signs: loss of skin markings, change in pigment, hyperkeratosis	Lesions may be tan or black, itching and/or bleeding
Ulcerating lesions show very late	Lentigo maligna: flat, pigmented grow radially, penetrates vertically
As lesion grows, it ulcerates and bleeds and may have a rolled border and look crusty	Superficial spreading: disorderly appearance, extends horizontally and vertically
Nodular: grow vertical, uniform blue-black color, sharp delineation	

Histology

- Melanoma subtypes
- Lentigo maligna
- Superficial spreading
- Nodular
- Palmar/plantar
- Acral lentiginous
- Nonmelanoma subtypes
- Basal cell
- Squamous cell

- Keratoacanthoma—resembles squamous cell
- Bowen disease—single plaque with red, scaly border
- Paget disease—single plaque in nipple, genital area
- Merkel tumor—asymptomatic nodule
- Verrucous carcinoma—wartlike, fungating
- Marjolin ulcer—squamous cell-like with slow growth
- Kaposi sarcoma—AIDS related
- Adnexal (sebaceous gland) carcinoma
- Eccrine (sweat gland) carcinoma

Lymphatic Drainage and Spread Patterns

- Nonmelanomas tend to remain in the dermal layers of the skin
- Melanomas penetrate deep into dermal layers and will metastasize via the blood route easily since blood vessels are in the dermal layers of the skin
- Area lymph nodes considered in management when managing melanomas
- Area lymph nodes are not considered in management of non-melanomas

Detection and Diagnosis

- Physical examination: look for asymmetry, borders, color, diameter, and evolution (ABCDE)
- Excisional biopsy both diagnostic and therapeutic in some cases
- Incisional biopsy if lesion is large, expected benign or in a cosmetically compromising location
- Blood markers: keratin, CEA, S-100 protein
- Mohs surgery especially if melanoma suspected

Staging

- TNM system is used for nonmelanomas. Clark and Breslow staging may be used in melanomas

- Clark method—categorizes lesion according to invasion through the levels of the epidermis and dermis
- Breslow method—categorizes lesion according to vertical thickness between the granular layer of the epidermis and the deepest part of invasion

Treatment

- Surgery for diagnosis and treatment: Mohs technique for recurrent basal cell and squamous cell, questionable borders, or suspicious for melanoma
- Radiation plays definitive role in nonmelanomas, especially if partial excision and/or to preserve cosmesis
- Electron or kilovoltage radiation for nonmelanomas
- Topical chemotherapy for nonmelanomas;
- Cryotherapy—liquid nitrogen for injury to vasculature for nonmelanomas
- Laser therapy—carbon dioxide laser excises with minimal bleeding in nonmelanomas
- Photodynamic therapy—porphyrin administered to patient then exposure to intense light for nonmelanomas
- Systemic chemotherapy and/or immunotherapy for melanomas

Radiation treatment borders

- Radiation treatment fields for nonmelanomas should be focused with 1- to 2-cm margin around lesion
- Fields for adjuvant radiation in melanoma will have margins of 3 to 4 cm and may include regional lymphatics
- Deeply invasive, large nonmelanomas may need regional node dose
- Fields may be en face electrons of energies sufficient to cover the depth of lesion and regional lymph nodes if elected or kV photons for improved cosmetic effects
- Need wider margins for Merkel cell; 4 to 5 cm

Treatment delivery

- Total dose for nonmelanomas ranges from 45 to 70 Gy depending on location; daily fractionation of 2 Gy
- Hypofractionation in single dose of 20 Gy or 32 Gy in 4 fractions
- Patient surface should be perpendicular to the horizontal axis of the electron beam
- Bolus may be used along with electrons to increase surface dose
- Dose for melanomas is lower since radiation is adjuvant to chemotherapy and depends on patient's life expectancy; 30 Gy in 10 fractions, 36 Gy in 6 fractions, or 50 Gy in 25 fractions for solitary metastatic lesions
- Beam shaping achieved with Cerrobend cutouts or thin-lead cutouts placed on patient's skin surface (use wax or equivalent to absorb scatter radiation on the underside of lead cutout)
- Setups are clinical for nonmelanomas; make sure margin is maintained
- Positioning aids and immobilization typically simple: pillows, sponges, tape
- If larger areas need treatment, adjacent, matched electron fields may be used (overdose areas should be identified using computerized, dosimetric treatment planning and skin gaps may be necessary)
- Anticipate wet desquamation at high dose ranges, especially when electrons are used with bolus
- Patients should be educated on skin care; keep area clean and dry
- Inform patient to protect skin from sun, avoid extreme temperatures and ointments containing perfumes and inorganic additives

Skin cancer section review exercises

For Questions 1 to 5, Indicate Whether the Statement Is True or False

1. Nonmelanomas have higher mortality rates than melanomas. _____
2. The most common cancer type overall in the United States is nonmelanoma skin cancer. _____
3. Melanomas are usually tan or black in color. _____
4. In late-stage disease, melanomas tend to ulcerate and have a rolled border on examination. _____
5. Melanomas are not usually treated with radiation therapy alone because they are radioresistant. _____
6. Clark's method for classifying melanoma is based on:
 - a. Width of the growth
 - b. Depth of invasion
 - c. Maximum thickness in millimeters
 - d. Nodal metastasis
7. The following are etiologic factors for skin cancers except:
 - a. Ultraviolet radiation exposure
 - b. Chemical carcinogens
 - c. Epstein-Barr virus
 - d. Genetic albinism
8. Melanocytes are found in the _____ layer of the skin.
 - a. Basal
 - b. Subcutaneous
 - c. Corneum
 - d. Sebaceous

9. Cells most sensitive to radiation are located in which layer of the epidermis?
- a. Stratum basale
 - b. Stratum granulosum
 - c. Stratum lucidum
 - d. Stratum corneum
10. Which of the following activities increases risk of developing skin cancer?
- a. Working in rubber manufacturing
 - b. Sweeping and inhaling Cerrobend dust
 - c. Frequent visits to the tanning salon
 - d. Swimming in high-chlorine pools
11. Nonmelanoma-type skin cancers are not usually seen in children. One possible reason is:
- a. Children have a strong resistance to damaging ultraviolet rays
 - b. Screening for skin cancer is only recommended for adults
 - c. Adult skin cells are more mature and are resilient against injury
 - d. Nonmelanomas are a result of long-term exposure to ultraviolet rays
12. Lentigo maligna is a histologic type of melanoma characterized by:
- a. Growth in a radial pattern with notches and reddish color
 - b. Tan or brown flat stain-like patterns on the palms or soles
 - c. Growth in a radial pattern with tan or black color
 - d. Raised pattern with black, blue-black color

Think About It

13. What role does immunotherapy play in the management of melanoma?
14. List the expected acute side effects of radiation therapy for nonmelanoma skin cancers (include fractionation schemes and

anticipated time of skin reaction).

15. When a lesion on the external surface of the nose is treated with electrons, a lead shield may be placed into the nostril. Briefly explain why.

Leukemia

General Facts

- Heterogenous (not of uniform composition or structure) group of neoplastic diseases of the hemopoietic system
- Divided into two categories
- Chronic—slower growing with uncontrolled expansion of mature cells
- Acute—progresses quickly and characterized by autonomous proliferation of undifferentiated cells in the bone marrow
- Subtypes (four main)

•

Myelogenous leukemia—arises directly or indirectly from hemopoietic stem cells

- AML—Acute myelogenous leukemia
- CML—Chronic myelogenous leukemia

•

Lymphocytic —arise from other cells populating in bone marrow•

- ALL—Acute lymphocytic leukemia
- CLL—Chronic lymphocytic leukemia
- Leukemia develops during the formation of the constituent elements of the blood and lymphocytes
- Hematopoietic process through which mature erythrocytes, neutrophils, eosinophils, basophils, monocytes, and platelets are

formed and lymphopoietic process through which lymphocytes are formed begin at the most primitive level with the pluripotent stem cells

- These cells have a self-renewing capability and generate differentiation cells of multiple lineages
- Myeloid stem cells provide the progenitors for the six types of blood cells, whereas the lymphoid pool provides the progenitors for the classes of lymphocytes
- Cells then become fully mature, functional blood cells and lymphocytes during normal differentiation and maturation
- During leukemic development, the production of the hematopoietic or lymphopoietic progenitors is uncontrolled and greatly accelerated, resulting in incomplete or defective cellular maturation
- Acute leukemia involves the rapid proliferation of primitive, undifferentiated stem cells, whereas cellular differentiation is largely preserved in chronic leukemia
- Symptoms of leukemia result from the leukemic cells' interference with normal processes
- Leukemic cells accumulate in the bone marrow, impairing the body's normal production of adequate supplies of red blood cells, WBCs, and platelets
- Decrease in the number of these necessary blood components results in anemia, thrombocytopenia, and neutropenia, causing symptoms such as fatigue, pallor, bleeding, and infection
- Acute—the accumulating leukemic cells are immature or have undergone a defect in maturation
- ALL—characterized by invasion of the bone marrow by leukemic lymphoblasts
- AML—results from the proliferation of defective or incompletely matured cells derived from the pluripotent hematopoietic stem cell pool
- Chronic—the maturation of the cells is preserved, but unregulated proliferation results in the accumulation of leukemic cells in the bone marrow

- CLL—disorder of morphologically mature, but immunologically less mature, lymphocytes
- CML—involves the replacement of marrow cells with mature myeloid cells that are insensitive to the normal proliferation control mechanisms

Acute Lymphocytic Leukemia

Epidemiology

- Most common pediatric malignancy
- Peak incidence 2 to 5 years of age
- Uncommon after age 15 years of age
- Males predominately
- Hispanic children increased prevalence of ALL compared with African American children and white children
- Disease more common in whites than African Americans
- Higher socioeconomic groups and more developed countries have a higher incidence

Etiology

- Direct cause unknown
- Possible association with physical and chemical agents
- Japanese atomic bomb survivors had tenfold to fifteenfold increase in acute leukemia (ALL over AML)
- Interesting note—no significant increase in leukemia after 1986 Chernobyl, where large amounts of iodine released (but there was significant increase in thyroid cancer)
- Benzene derivatives
- Hydrocarbons
- Alkylating agents—cyclophosphamide increase risk in acute leukemia
- Genetics

- Down syndrome—risk is 10 to 30 times increase change for acute leukemia
- Natural retroviruses and human T-cell, lymphotropic viruses (specific to ALL in adults)

Prognostic Indicators

- 75% of patients with ALL will have complete remission (dependent on a number of factors such as age and WBC at time of diagnosis)
- ALL in age 1 or younger, and older than 10 carry a worse prognosis
- Leukocyte count:
 - Less than 10,000/mm³ is more favorable
 - 20,000 to 49,000/mm³ is worse
 - More than 50,000/mm³ is least favorable
- Other features with low prognostic value (at time of diagnosis) include:
 - CNS or mediastinal mass, massive organomegaly and/or adenopathy, biologic qualities of the leukemic cells such as the immunophenotype, cytogenetics, and DNA content
 - Unfavorable prognostic indicators: poor performance status, impaired organ function, low serum albumin levels

Clinical Presentation

Suppressed natural blood components cause:

- Anemia—from fatigue and pallor

- Thrombocytopenia—manifested by:
 - Oozing gums
 - Epistaxis (nose bleeds)
 - Petechiae—tiny red spots on skin from escape of small amounts of blood
 - Ecchymoses—discoloration of skin from escape of blood into tissues
 - Menorrhagia—excessive menstrual bleeding
 - Excessive bleeding after dental procedures
- Neutropenia causes:
 - Increased respiratory problems
 - Dental issues
 - Sinus problems
 - UTI (urinary tract infection)
 - Liver, splenic, and testicular enlargement
- Mimics rheumatoid arthritis with joint swelling, bone pain, and tenderness (often causes a child to limp or refuse to walk)
- Symptoms rarely occur 6 weeks before diagnosis
- Vomiting, headaches, papilledema (swelling of the optic disc), neck stiffness, and cranial nerve palsy are indications of CNS involvement

Detection and Diagnosis

- CBC count
- Two-thirds of patients have thrombocytopenia and anemia
- Leukocyte counts vary from high to low (abnormal high WBC—poor prognosis)
- Immunophenotyping—morphologic evaluation, special stains, electron microscopic examination, and surface marker studies can yield a diagnosis in 90% of patients
- Bone marrow aspiration biopsy for definite diagnosis (amount of leukemic blast cells is the determinant) or 25% of presence of

- leukoblasts is positive
- Other abnormalities—hyperuricemia, metabolic abnormalities, hyperkalemia, hypomagnesemia, hypercalcemia, and hypocalcemia
- Leukemic infiltrates of liver, periosteum, and bone
- A mediastinal mass (seen on chest x-ray)
- Extramedullary leukemia—most common sites in CNS and testes (sanctuary sites, because they are “hidden” from most chemotherapy agents)

Pathology

- Unregulated by proliferation of lymphoblasts
- Disease cells limit the production of other healthy cells by overcrowding and inhibiting cell growth and differentiation

Staging and Classification

- Morphological appearance
- Immunologic classification
- FAB (French-American-British), L1, L2, and L3 are divisions based on cell size, nuclear shape, number, prominence of nuclei, and amount and appearance of cytoplasm
- Most pediatric ALLs are L1
- L3s carry the worst prognosis
- WHO classification incorporates cytogenetics and immunophenotyping

Treatment Techniques

Used alone or in combination:

Radiation

- To support stem cell transplants total body irradiation (TBI)
example—1200 cGy, 3 consecutive days 200 cGy, twice daily
- Doses may vary from center to center.

- Dose rate set for 100 cGy/min at midplane at the central region, the umbilicus. This low dose is necessary to spare late-responding tissues (all visceral organs, most common is lung).

Figure 8.21 shows an immobilization device for TBI.

- Helmet field (

Figure 8.22) to encompass the meninges dose example—(1800 cGy; 200 cGy/day $\times$ 9 consecutive days). Helmet field covers meninges—encompassing C2 with falloff around the head; special attention to spinal cord in this setup

- Spinal field in combination with helmet—patient prone in head holder to include total spine and brain field (helmet). Field arrangement is very important. Special techniques such as gapping and feathering help avoid hot spots
- Helmet and spine fields are for prophylaxis for those at high risk for relapse



FIG. 8.21 New England Medical Center's custom-made immobilization device for total-body irradiation.

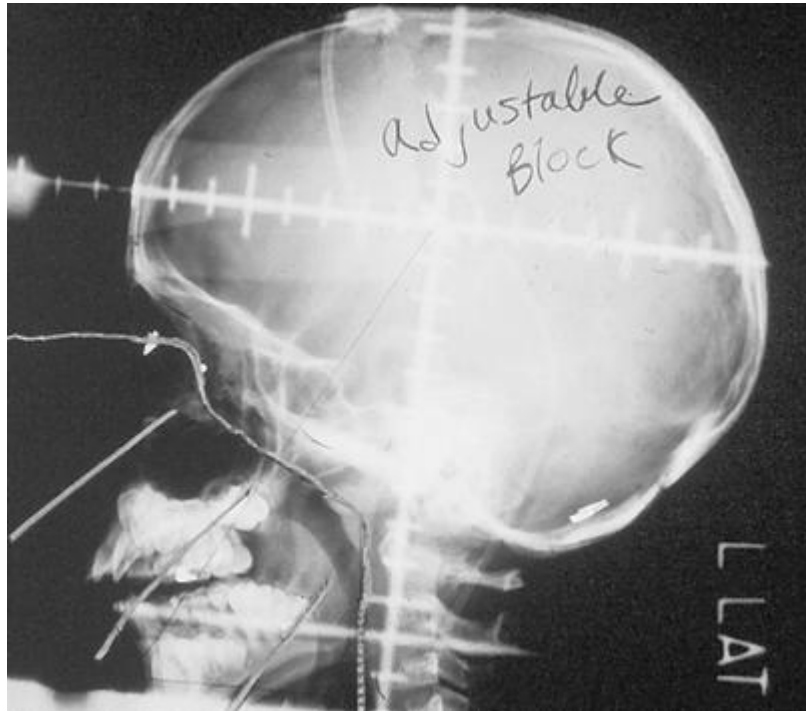


FIG. 8.22 Simulation film for a helmet field that covers the meninges encompassing C2.

Chemotherapy

Remission Induction (given immediately upon diagnosis)

Sample drug combinations:

- Glucocorticoid Vincristine PEGaspargase
- Methotrexate
- Cytarabine
- High-risk patients—also anthracycline, daunorubicin may be added

Consolidation (after remission is achieved)

- IV methotrexate and L-asparaginase

Maintenance or Continuation Therapy

- IV mercaptopurine (6-MP) and systemic methotrexate

Prophylaxis of Overt CNS

- Methotrexate

Bone marrow transplant

- Harvesting of healthy marrow from matched donor
- Diseased marrow has been destroyed or ablated by chemo or TBI
- Harvested marrow injected back into patient
- Transplanted marrow finds its way into bone marrow cavities and begins supplying the patient with normal, healthy hematopoietic cells
- Failures in transplants are recurrent leukemia (primarily in autologous donor) and graft-versus-host disease

Side Effects

Acute

- GI—nausea, vomiting, diarrhea, anorexia, and malaise
- Mucosa of mouth, pharynx, bladder, and rectum
- Normal secretions inhibited impairing their functions
- Integumentary—skin reactions, itching, tingling, bruising, and dry and inelastic skin that cracks easily
- Alopecia
- Blanching or erythema of skin and mucous membranes
- Respiratory—intestinal pneumonitis

Chronic

- Permanent sterility
- Cataracts
- Hepatic fibrosis
- Radionecrosis of genital tissue, muscle, and kidney

CNS Side Effects

- Skin reactions
- Hair loss
- Decrease in blood counts
- Leukoencephalopathy
- Nausea and vomiting
- Somnolence syndrome
- Serious injury to tissue or blood vessels
- Lhermitte sign
- Neuropsychological deficits, intellectual deficits
- Cataracts
- Growth retardation and hypothalamic-pituitary dysfunction
- Hormonal effects
- Myelopathy

Acute Myelogenous Leukemia

Epidemiology

- Median age is 65
- Incidence slightly higher in males and Caucasians
- Represents about 90% of all acute leukemias

Etiology

- Exposure to ionizing radiation
- Increased incidence in military personnel at Nevada bomb test sites
- Patients treated (radiation) for ankylosing spondylitis, menorrhagia, and thymic enlargement
- Thorium dioxide (Thorotrast) an intravenous contrast for angiography test
- Fanconi anemia and Bloom syndrome (genetic disorder with a chromosome breakage)
- Exposure to benzene and alkylating agents

- Tobacco smoke

Clinical Presentation

- Nonspecific flulike symptoms
- Fatigue, pallor, and dyspnea on exertion
- Bone pain
- Anemia
- Petechiae
- Purpura (hemorrhage under skin)
- Epistaxis, gingival bleeding, and GI/genitourinary bleeding (reduced platelet production)
- Neutropenia—susceptibility to infections
- Fever
- Headache
- Tinnitus
- Enlarged spleen

Detection and Diagnosis

- CBC with differential leukocyte and platelet counts and blood smears
- Chromosomal abnormalities
- Circulation of Auer rods in leukemic cells, and increase in leukemic blast cells, and a decrease in normal precursors)
- Biopsy (bone marrow based on percentage of blasts)

Pathology

- Unregulated proliferation of early precursor cells that have lost the ability to differentiate in response to hormonal signals and cellular interactions

Staging and Classification

- Morphological evaluation, FAB systems

- Categorization—different saturation states from M0 to M7

Treatment

- Chemotherapy for induction and consolidation
- CNS prophylaxis achieved with chemo intrathecal
- Radiation therapy has shown no benefit

Side Effects

- Bone marrow depression
- Nausea, vomiting, esophagitis, stomatitis, diarrhea, and ulceration—(GI effects)
- Renal effects
- Rashes and alopecia
- Reproductive—mutagenic and teratogenic

Chronic Lymphocytic Leukemia

Epidemiology

- 30% of all leukemic cases in the United States
- Onset age is 65, most are age 70 (rare under age 40)
- Males over females and less common in Asian population

Etiology

- Heredity (first-degree relatives have a twofold to sevenfold increase in risk)
- Familial clustering—the most notable of all leukemia
- Immunologic factors such as immunodeficiency syndromes and viruses
- Only leukemia

not associated with radiation exposure

Prognostic Indicators

- Stage at time of diagnosis
- Age
- Doubling time of peripheral blood lymphocyte count
- Pattern of bone marrow involvement
- T-cell variety of CLL—the more aggressive

Clinical Presentation

- Characterized by minimal changes in blood count
- Blood tests at routine doctor visit may indicate lymphocyte counts equal to or higher than 10,000/mm

3

- Asymptomatic
- Fatigue, fever, night sweats, weight loss
- Lymphadenopathy and enlarged spleen
- Chromosomal abnormalities

Pathology

- Bone marrow lymphoid tissue
- Increased proliferation of leukemic cells in bone marrow, blood, lymph nodes, and spleen
- Enlargement of lymph nodes and spleen
- Decreased bone marrow function

Staging and Classification

- Modified

Rai system (three major prognostic groups)

- Stage 0—low risk

- Stage I and II—intermediate risk
- Stage III and IV—high risk
- Stages based on adenopathy, splenomegaly, anemia, and lymphocytosis
-

Binet system: three stages based on involvement of five specific anatomic sites: cervical nodes, axillary nodes, inguinal nodes, spleen, and liver

- Cytochemistry used to classify CLL into two subtypes: B cell and T cell

Treatment Techniques

- Optimal treatment is unknown
- Early-stage disease will not benefit from treatment
- Chemotherapy—when progressive anemia and thrombocytopenia—drugs used chlorambucil and alkylating agent and prednisone (chlorambucil prevents the separation of the strands of DNA, which is necessary for cell replication)
- Radiation—used for palliative for localized masses of lymphoid tissue and/or enlarged spleen (AP/PA) total dose of 500 cGy—100 cGy/day $\times$ 5; spleen field design would be clinical encompassing a 1-cm margin; simulation of field by palpation of spleen, fluoroscopy, and now CT with contrast; CNS radiation controversial; TBI if stem cell transplant
- Surgery—splenectomy (an enlarged spleen causes cytopenia, which is the result of accelerated removal or excessive pooling of platelets or RBCs)

Side Effects

- Chlorambucil causes bone marrow depression
- GI—anorexia, nausea, vomiting
- Dermatitis, urticaria

- Reproductive—mutagenesis, teratogenesis, and sterility
- Prednisone causes GI peptic ulcers and pancreatitis
- Metabolic response—centripetal obesity, hyperlipidemia, hyperosmolar nonketotic coma and immunosuppression
- Neurologic side effect is pseudotumor cerebri
- Glaucoma and cataracts
- Hypertension
- Skin striae
- Amenorrhea
- Impaired wound healing

Chronic Myelogenous Leukemia

Epidemiology

- 15% of all adult leukemias
- Peaks at mid-60s
- Slightly more in males

Etiology

- Unknown
- Possible link to radiation and benzene exposure
- Possible link to the Philadelphia chromosome

Prognostic Indicators

- Spleen size, platelet count, hematocrit, gender, and percentage of blood myeloblasts
- Disease typically transforms into acute leukemia after a chronic phase of 3 to 4 years when patient enters a blast crisis
- Survival time approximately 2 years

Clinical Presentation

- Three stages: chronic, accelerated, and acute phase or blast crisis

- Clinical symptoms generally mild—malaise, fatigue, heat intolerance, sweating, and easy bruising
- Symptoms related to splenic enlargement include vague discomfort in the LUQ, early satiety, weight loss, and peripheral leg edema
- 3 to 4 years patient enters blast crisis—fever, bone pain, and pronounced weight loss

Detection and Diagnosis

- Insidious but incidental
- Mild to moderate anemia and leukocytosis
- Myeloblasts, promyelocytes, and nucleated RBCs
- Increased granulocytic and megakaryocytic hyperplasia
- Presence of the Philadelphia chromosome

Pathology

- Abnormal hematopoietic stem cells giving rise to the progeny of the Philadelphia chromosome

Staging and Classification

Three distinct stages:

- Chronic (or stable phase)
- Accelerated phase
- Acute phase (blast crisis)

Treatment Techniques

- Radiation (spleen like CLL, and TBI same as CLL)
- Chemotherapy—Imatinib mesylate (Gleevec), interferon, and hydroxyurea
- Bone marrow transplantation (same as CLL)

Side Effects

- Gleevec—severe skin reactions, fluid retention and edema, GI disturbances, hemorrhage, anemia, neutropenia, thrombocytopenia, liver toxicities, and potential immune suppression
- Interferon—flulike symptoms, fever, chills, malaise, muscle aches, anorexia, and weight loss
- Hydroxyurea—hematopoietic system, bone marrow depression, rapid leucopenia, and erythrocytic abnormalities; GI side effects— anorexia and diarrhea. Facial erythema and maculopapular rash are integumentary reactions; reproductive reaction—teratogenic
- Treatment Delivery Considerations for Leukemia
- Be mindful of communication strategies when treating children; parents often accompany and have concerns
- Build in sufficient time for explanations
- Schedule longer times (treatment may take longer, such as with TBI and/or sedated children)
- Be aware of any special isolation and/or precautions

Leukemia review exercises

Define the Following Terms

1. Thrombocytopenia
2. Leukapheresis
3. Splenomegaly
4. Leukopenia
5. Anorexia
6. Teratogenic
7. Neutropenia
8. Toxicity
9. Benzene
10. Bone marrow depression
11. Auer rods
12. Nadir
13. Pruritus

14. Ecchymoses
15. When leukemic cells accumulate in the bone marrow, there is an impairment of the body's normal production of adequate supplies of:
- a. White blood cells
 - b. Red blood cells
 - c. Platelets
16. Which of the leukemias is found mostly in children?
- a. ALL
 - b. AML
 - c. CLL
 - d. CML
17. Which of the leukemias is not associated with previous radiation exposure?
- a. ALL
 - b. AML
 - c. CLL
 - d. CML
18. The most important diagnostic factor for detecting CML is:
- a. Nucleated RBCs
 - b. Philadelphia chromosome
 - c. Circulation of Auer rods
 - d. Complete CBC

Explain the Following Radiation Techniques and Include Positioning, Sample Immobilization Devices, Total Doses, and Field Arrangements

19. TBI

20. Helmet
21. Total CNS (spinal axis)
22. Patients treated with methotrexate may develop a rapid onset of bone marrow depression, with nadir occurring within a range of:
- a. 3 to 5 days
 - b. 5 to 10 days
 - c. 10 to 14 days
 - d. 15 to 20 days
23. Which of the following would be considered integumentary side effects from chemotherapy drugs seen in leukemia patients?
- 1. Alopecia
 - 2. Dermatitis
 - 3. Hyperpigmentation
- a. 1, 2
 - b. 1, 3
 - c. 2, 3
 - d. 1, 2, 3
24. In a helmet field treatment port, it is very important to cover the meninges and C2. Which of the following is not one of the layers of the meninges?
- a. Dura mater
 - b. Pia mater
 - c. Subarachnoid mater
 - d. Arachnoid mater
25. For a definitive diagnosis for ALL, which of the following is needed?
- a. Biopsy of the spleen
 - b. Bone marrow aspiration biopsy
 - c. CT with contrast
 - d. Definitive white blood count
26. The spleen is located in which quadrant:

- a. LUQ
- b. LLQ
- c. RUQ
- d. RLQ

Lymphoma

General Facts

Lymphoma is cancer of the hematopoietic system. Included are

- Blood
- Lymphatic tissue
- Bone marrow
- Spleen

Three basic types of blood cells

- Erythrocytes (RBC)—smallest of all blood cells; responsible for transporting oxygen and carbon dioxide throughout the body
- Leukocytes (WBC)—formed in red bone marrow; mainly found in the lymphatic tissue of the spleen and include lymphocytes and monocytes; responsible for the body's defense system
- Thrombocytes (platelets)—necessary for blood clotting and they respond with seconds to initiate the coagulation process

The lymphatic system

- Subsystem of the circulatory system
- Closely relates to the cardiovascular system
- Composed of specialized connective tissue containing large quantities of lymphocytes
- Consist of lymphatic vessels, organs, nodes, and lymph (white milky substance)
- Occurs throughout the body

Functions

- Vessels drain tissue spaces of interstitial fluid that escapes from blood capillaries and loose connective tissues, filters it, and returns it to the bloodstream. This is important in maintaining the overall fluid levels in the body (most important function).
- The lymphatic system absorbs fats and transports them to the bloodstream.
- The intricate system plays a major role in the body's defense and immunity. Immunity is the ability to fight off infectious organisms, foreign bodies, and diseases. Specifically, lymphocytes and macrophages recognize and respond to the foreign matter.

Lymphatic System

- Lymphatic vessels contain lymph
- Start in spaces between cells referred to as lymphatic capillaries
- Every region of body that has blood supply has these capillaries, (exception—CNS and bone marrow are avascular)
- Collects cellular debris, sloughed off cells, and foreign substances that occur in the intercellular spaces and transported away for filtration
- Flow is in one direction only
- Lymphatic capillaries join to form larger lymphatic vessels
- Lymphatic vessels resemble veins in structure but have thinner walls and more valves promoting one-way flow
- These larger vessels follow veins and arteries and eventually empty into one of the two ducts in the upper thoracic—the thoracic duct or the right lymphatic duct, which then flow into subclavian veins
- Lymph: Excessive tissue fluid consisting mostly of water and plasma proteins from capillaries; plasma—liquid portion of the blood; 90% water; 10% proteins, nutrients, electrolytes, respiratory gases, etc.
- Differs from blood by the absence of formed elements in it
- Lymphatic Organs

- Spleen—largest mass of lymphatic tissue
 - Posterior to and to the left of the stomach in the abdomen
 - It is 12 cm in length
 - Filters blood
 - Removes old red blood cells
 - Manufactures lymphocytes (B) for immunity surveillance
 - Stores blood
 - Has no afferent lymphatic vessels, so does not filter lymph
 - Often removed during laparotomy for biopsy and staging purposes
 - After removal—bone marrow and liver assume the spleen's function
- Thymus
 - Located along trachea superior to heart and posterior to the sternum in upper thorax
 - Larger in children and more active in pediatric immunity
 - Site where T lymphocytes mature
- Tonsils
 - Lymphatic nodules embedded in the mucous membrane
 - Located at junction of oral cavity and pharynx
 - Protect against foreign body infiltration by producing lymphocytes
 -

Pharyngeal tonsils (adenoids) in nasopharynx

•

Palatine tonsils are in posterior lateral wall of oropharynx

•

Lingual tonsils are at the base of the tongue in oropharynx

- Thoracic duct
 - Left side of body and larger than right lymphatic duct
 - Serves the lower extremities, abdomen, left arm, and left side of head and neck and drains into the left subclavian vein
 - It is 35 to 45 cm in length and begins in front of the second lumbar vertebra (L2) and is called the

cisterna chyli

- Lymph travels through lower extremities to the cisterna chyli, and continues upward to the thoracic duct
- Right lymphatic duct
 - Serves only the right arm and right side of head and neck and drains the right subclavian vein
 - Approximately 1 to 2 cm in length
 -

Box 8.3 illustrates an overview of lymphatic flow.

- Lymph Nodes
 - Located along the path of lymph vessels
 - Vary in size from 2 to 30 mm in length and often occur in groups
 - Contain both afferent (one-way valves entering the lymph node at several points) and efferent vessels, smaller in diameter (valves leaving the node, again facilitating one-way flow)
 - Slowing of lymph out of node facilitates the effective filtering of the lymph through phagocytosis, the endothelial cells of the node engulfs, devitalize, and remove the contaminants
 - If substances are trapped inside the reticular fibers and pathways throughout the node, excessive fluid accumulation occurs producing swelling of node called edema (due to heightened phagocytic activity)

- Swelling goes down as pathogen is devitalized (e.g., if infection-antibiotics may be used)

BOX 8.3

Lymphatic Flow Overview

Tissue fluid leaves the cellular interstitial spaces and becomes lymph. As lymph enters a lymphatic capillary, it merges with other capillaries to form an afferent lymphatic vessel, which enters a lymph node where lymph is filtered. The fluid then leaves the node via an efferent lymphatic vessel, which travels to other nodes then merges with other vessels to form a lymphatic trunk. The lymphatic trunk merges with other trunks and joins a collecting duct (either the right lymphatic or thoracic duct) which empties into a subclavian vein where lymph is returned to the bloodstream.

From Washington CM, Leaver D.

Principles and Practice of Radiation Therapy . 3rd ed.
Mosby/Elsevier; 2010.

Two Main Histological Types

Hodgkin lymphoma (HD)

- Presence of Reed-Sternberg cell
- Spreads contiguous
- Cell contains one to two large nuclei
- Occurs anywhere that lymph travels

Non-hodgkin lymphoma (NHL)

- Spreads randomly

- Lymphoid tissue: primary and peripheral contains B and T precursor cells
- Classified as follicular or diffuse

Epidemiology

Hodgkin

- Less than 1% of newly diagnosed cancer
- Male over female
- Incidence peak occurs before adolescence in underdeveloped countries but in the mid- to late 20s in industrialized countries
- Occur in younger people (<40); median age 38
- Rare in children under 10

Non-hodgkin

- Male over female
- White males have higher incidence
- Median age is 65, peaking 80 to 84
- Third most common childhood malignancy

Etiology

Hodgkin

- Direct cause unknown
- EBV genome in the DNA cell of the Reed-Sternberg cell
- Defective T-cell function

Non-hodgkin

- Direct cause unknown
- Genetic alterations of the B or T lymphocytes
- HIV/AIDS infection
- Ionizing radiation

- Ankylosing spondylitis

Prognostic Indicators

- Staging has the greatest effect on the prognosis
- Risk of relapse after treatment—greater in later stages due to increased bulky disease
- Prognosis slightly worse in males
- Gender may be a deciding factor in treatment
- Youth—favorable prognosis (teens to twenties)
- Extent of disease, presence of “B” symptoms, sites involved, disease in lower abdomen, spleen involved
- Elevation of serum markers (such as erythrocyte sedimentation rate)

Lymphatics

Major lymph nodes (HD/NHL)

- Waldeyer ring (tonsillar lymphatic tissue surrounding the nasopharynx and oropharynx) and cervical, preauricular, and occipital lymph nodes. Tonsils include: (1) nasopharyngeal (2)—tubal (pharyngeal-adenoids), (3)—palatine, (4)—lingual
- Supraclavicular and infraclavicular lymph nodes
- Axillary lymph nodes
- Thorax (hilar and mediastinal nodes)
- Abdominal cavity (paraaortic nodes)
- Pelvic cavity (iliac nodes)
- Inguinal and femoral lymph nodes
- Major lymphatic regions of the body

Clinical Presentation

Hodgkin

- Most disease found above diaphragm at time of diagnosis
- Systemic classic symptoms (B symptoms)

- Unexplained fevers ($>38^{\circ}\text{C}$)
- Drenching night sweats
- 10% weight loss over 6 months or less
- Pruritus (may be included in classic B symptoms)
- Alcohol-induced pain
- Enlarged lymph nodes
- Neck, clavicular, axilla, groin area node enlargement
- Mediastinal mass
- Enlarged spleen or abdomen
- Bony tenderness
- Pleural effusion

Non-hodgkin

- Similar to HD
- Unlike HD, NHL can arise in lymph nodes, GI tract, Waldeyer ring, or CNS (strong association with patients having HIV/AIDS)
- Shortness of breath—may indicate lung involvement
- Abdominal pain or change of bowel habits may indicate pelvic disease
- Headaches, vision changes, seizures

Pathology

Hodgkin

- Lymphocyte-rich Hodgkin lymphoma.
- Nodular sclerosing Hodgkin lymphoma (NSHL)—

Most common subtype in developed countries, accounting for 60% to 80%. Mostly in adolescents and young adults. Mediastinum and supradiaphragmatic most often involved sites. Approximately one-third of patients have “B” symptoms.

- Mixed cellularity Hodgkin lymphoma accounts for 15% to 30% of all Hodgkin lymphoma. It occurs at any age, lacking an early adult

peak of NSHL. Most commonly involved lymph nodes are in the abdomen and spleen.

- Lymphocyte-depleted Hodgkin lymphoma is the least common subtype in the United States. Occurs in older patients and HIV-infected patients; presents with advanced disease in spleen, liver, and bone marrow and with B symptoms. It carries the worst prognosis.

Non-hodgkin

- Two types of lymphoid tissues:
- Primary (central lymph tissue)
- Precursor cells both B and T
- Occurs in bone marrow and thymus
- Periphery (secondary lymph tissue)
- Antigen-specific reactions occur
- Lymph nodes, spleen, and MALT found in the epithelium of nasopharynx and oropharynx (Waldeyer ring), GI tract, distal ileum (Payer patches), colon, and rectum

NHL histologic classification

- Follicular (nodular)—40%
- B-cell origin
- It runs an indolent course with prolonged survival (5–7 years)
- Usually appear below diaphragm and involve mesenteric lymph nodes
- Usually not found in children; do not commonly involve the Waldeyer ring
- Diffuse—60%
- B- or T-cell origin
- It runs a more aggressive course spreading quickly to other nodes and extranodal sites
- Increased involvement in bone marrow and Waldeyer ring

Lymphatic Drainage and Spread Patterns

Hodgkin

- Predictable pattern of spread: referred to as *contiguous*
- Spread is predictable to adjacent lymph node or region (viscera spread)
- Rapidity of the growth is not predictable
- Late stages and spread may include spleen, liver, and/or bone marrow
- Very late stage—lungs, skeletal

Non-hodgkin

- Nonpredictable, noncontiguous
- Spread randomly
- May involve upper digestive tract, CNS, skin, GI tract, Waldeyer ring, or Peyer patches

Workup

Hodgkin

- Complete history and physical
- Lab studies (CBC/platelet)
- Liver/renal function
- Blood chemistry, thyroid function
- Chest, CT, MRI, PET/CT with FDG
- Gallium, bone scan
- Bone marrow biopsy
- “B” symptoms

Non-hodgkin

- Complete history and physical
- Cytologic evaluations

- HIV test
- Blood chemistry
- Urinalysis
- LDH
- Liver function
- Serum alkaline phosphate
- Same x-ray with GI and SB
- Bone marrow biopsy
- CT, MRI, PET

Staging

Hodgkin

- Stages—I thru IV
- Subdivided into A or B groups
- Fever, night sweats, weight loss will be indicated as B symptoms (for example, Stage IIB indicates stage II exhibiting classic symptoms)
- B symptoms indicate worse prognosis
- Ann Arbor Staging Method

Non-hodgkin

- Patients usually have more advanced disease
- Diaphragm has less significant role than in HD
- NHL is usually more bulky disease
- Staging—Ann Arbor is used mostly, but not significant with NHL

Treatment

- Chemotherapy is primary for both HD and NHL.
- Combination chemotherapy is used carefully to limit the risk of known latent effects, such as the development of leukemia (i.e., AML) and infertility.

- HD sample combinations—MOPP (Nitrogen Mustard, Oncovin [vincristine], procarbazine, and prednisone); COPP (cyclophosphamide, Oncovin, procarbazine, prednisone); ABVD (Adriamycin, bleomycin, vinblastine, dacarbazine) and other derivatives of these combinations; etoposide has been increasingly incorporated into treatment regimens to reduce gonadal toxicity.
- NHL sample combinations—CHOP (cyclophosphamide, doxorubicin, vincristine, prednisone); MACOP-B (methotrexate, doxorubicin, cyclophosphamide, vincristine, bleomycin, prednisone).

Radiation Treatment Borders

Hodgkin

- Today, standard treatment for Hodgkin is the combination chemotherapy such as the ABVD regimen alone or in combination with radiation (30 to 36 Gy) to just the involved lymph node region (

Figure 8.23).

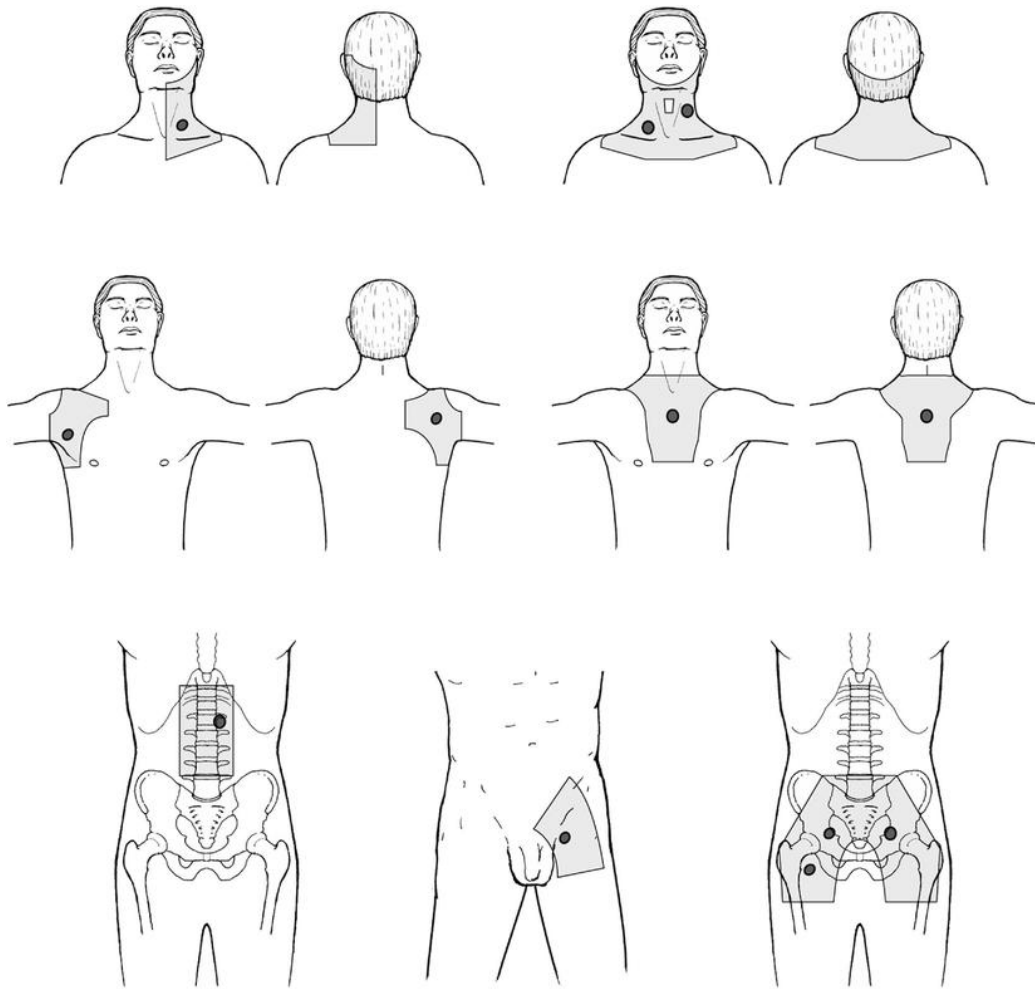


FIG. 8.23 Involved field treatment.

Radiation Treatment

Non-hodgkin

- Non-Hodgkin lymphomas vary in comparison to that of Hodgkin
- Very sensitive to radiation
- Treated with radiation to involved site and chemotherapy for systemic treatment
- 35 to 45 Gy suggested for local control
- Radiation and chemotherapy will vary due to staging of disease
- CNS and gastric lymphomas in NHL are more common in patients with AIDS than general population

- GI tract lymphomas are the most common of the extranodal lymphomas

Treatment Delivery Considerations

Hodgkin

Be aware of possible acute side effects dependent upon field size and area treated:

- Fatigue
- Occipital hair loss (may be permanent)
- Skin erythema
- Sore throat (esophagitis)
- Altered taste (if oral cavity dosed as in Waldeyer's ring)
- Transient dysphagia from radiation-induced esophagitis
- Dry cough
- Nausea
- Occasional vomiting
- Diarrhea

Non-hodgkin

- Be aware of acute side effects (dependent on area treated)

- If mouth and neck treated—
- Dry mouth
- Difficulty swallowing
- Mucositis
- A

Candida infection

- Altered taste
- Sore throat

- Dysphagia
- Redness of skin
- Hair loss
- Dry cough
- If abdomen treated
- Nausea and vomiting
- Fatigue

When delivering therapy

- Pay attention to abutting fields and the importance of blocking critical structures, such as the liver, spine, and kidneys
- Abutting fields will likely call for periodic feathering of field junctions
- Closely monitor blood counts especially when large amounts of bone marrow are irradiated
- Communication is most critical in helping your patient maintain good nutrition and electrolyte balance when large amounts of GI are involved in the radiation field
- Pediatric patients will need special considerations; take time getting acquainted; allow parents to participate, encourage and observe; encourage young patients to be creative about dealing with changes in physical appearance and any interruptions to their normal routine

Lymphoma review exercises

1. List the components and major functions of the lymphatic system.
2. List the three basic types of blood cells and their functions.
3. What are the two types of lymphocytes that participate in adaptive immune responses?
4. What are the smallest vessels of the lymphatic system, which are located in the spaces between cells?
5. Explain the flow of the lymph.

6. Which lymphatic vessels empty into the cisterna chyli, and which duct receives lymph from the cisterna chyli?
7. What happens to foreign substances in lymph that enter a lymph node?
8. Lymph flows through a node in one direction entering _____ lymphatic vessels and flowing out by way of _____ lymphatic vessel.
9. What is the purpose of the spleen?
10. If a spleen is removed, which other organs take over some of the functions of the spleen?
11. How do lymphatic vessels differ in structure from veins?
12. What is the role of the thymus in immunity?
13. The largest single mass of lymphatic tissue in the body is:
 - a. Liver
 - b. Spleen
 - c. Bone marrow
 - d. Thymus
14. Which of the following is not considered a tonsil?
 - a. Pharyngeal
 - b. Palatine
 - c. Lingual
 - d. Vallecula
15. Which of the following organs atrophies after puberty?
 - a. Thymus
 - b. Thyroid
 - c. Spleen
 - d. Liver
16. B cells mature in which of the following?
 - a. Thymus
 - b. Bone marrow
 - c. Spleen
 - d. Liver

17. The lymphatic system consists of:

1. Fluid
2. Vessels
3. Arteries
4. Organs
5. Nodes

- a. 1, 2, 3
- b. 2, 3, 4, 5
- c. 1, 2, 4, 5
- d. 1, 2, 3, 4, 5

18. Lymph nodes are what length?

- a. 4 to 6 cm
- b. 10 to 15 cm
- c. 1 to 25 mm
- d. 2 to 4 in

19. The thymus gland functions in immunity by producing:

- a. Blood
- b. T cells
- c. B cells
- d. C cells

20. Which of the following might describe non-Hodgkin lymphoma?

1. Originates in lymph nodes or in extranodal tissue
2. Most likely to spread randomly
3. Commonly arising in GI tract

- a. 1, 2
- b. 2, 3
- c. 1, 3
- d. 1, 2, 3

21. The thoracic duct is the main collecting duct of the lymphatic system and begins in the:

- a. Suprasternal notch
 - b. Cisterna chyli
 - c. Inguinal areas
 - d. T-12
22. Most Hodgkin disease will have:
- a. Lymphocytic predominance
 - b. Lymphocytic depletion
 - c. Nodular sclerosis
 - d. Mixed cellularity
23. The most common presenting symptom for Hodgkin disease is:
- a. Abdominal mass
 - b. Painless axillary node enlargement
 - c. Painless cervical node enlargement
 - d. Painless inguinal node enlargement
 - e. Mediastinal mass
24. A large binucleate or polynucleate cell present for a diagnosis of Hodgkin is referred to as:
- a. Ann Arbor cell
 - b. Reed-Sternberg cell
 - c. Thomas Hodgkin cell
 - d. Epstein-Barr cell
25. Classification for staging of lymphomas is traditionally:
- a. TNM
 - b. Ann Arbor
 - c. Duke classification
 - d. AJC

Match the letters denoting organ involvement in the staging of lymphomas

26.

S _____ A. marrow
27.

H _____ B. lung
28.

L _____ C. liver
29.

M _____ D. spleen
30.

P _____ E. osseous
31.

O _____ F. skin
32.

D _____ G. pleura

33. T or F Irradiation is the primary treatment modality for the majority of patients with early stages of Hodgkin disease.

34. A 23-year-old male patient has an enlarged cervical lymph node. Diagnostic workup reveals positive mediastinal and axillary nodes as well. Based on this information, the patient would be Stage:

- a. I
- b. I E
- c. II
- d. II E

35. Staging for Hodgkin disease also includes an A-B grouping. Which symptom may be left out of the classical B symptoms?

- a. Profuse night sweats
 - b. Weight loss greater than 10% of body weight
 - c. Unexplained fever above 38°C
 - d. Unexplained pruritus
36. In Hodgkin disease, involvement of several nodal regions of both sides of the diaphragm accompanied by localized involvement of an extralymphatic site is stage:
- a. II
 - b. II E
 - c. III
 - d. III E
37. In the treatment fields of Waldeyer ring for non-Hodgkin lymphoma, the fields' delineation closely resembles that of carcinoma of the:
- a. Supraclavicular fossa nodes
 - b. Orbit
 - c. Pelvis
 - d. Nasopharynx
38. Which of the following are common side effects of radiation therapy to the abdomen?
- 1. Nausea
 - 2. Vomiting
 - 3. Fatigue
- a. 1 only
 - b. 2 only
 - c. 3 only
 - d. 1, 2, and 3
39. A young woman has swelling in her lower neck for suspected HD. A chest x-ray also revealed mediastinal adenopathy. She had not experienced any fever, night sweats, or weight loss. Staging would likely be:

- a. I A
- b. II A
- c. II B
- d. III A

40. The most favorable of the four subtypes of Hodgkin disease is:

- a. Lymphocytic predominance
- b. Nodular sclerosis
- c. Mixed cellularity
- d. Lymphocyte depletion

41. NHL may arise in:

- 1. Lymph nodes
- 2. Gastrointestinal tract
- 3. Waldeyer ring

- a. 1 only
- b. 1, 2
- c. 1, 3
- d. 1, 2, 3

42. In NHL, lymphocytes pathologically arrange themselves in pattern(s) called:

- a. Follicular
- b. Nodular
- c. Both a and b
- d. Neither a nor b

43. Transient dysphagia is an acute side effect after irradiation for Hodgkin. Dysphagia is:

- a. Difficulty breathing
- b. Difficulty swallowing
- c. Discomfort to stomach
- d. Difficulty urinating

44. When extremely large fields are treated adjacent to each other, an appropriate separation must be left between the fields. This is

known as the _____ technique:

- a. Shrinking field
- b. Gap
- c. Algebraic
- d. Half-field

Pediatrics

General Facts and Epidemiology

- Males have higher incidence
- Treatment varies by site but requires multidisciplinary approach because of late effects
- Multidisciplinary approach is appropriate since long-term, disease-free survival is intended; single management modalities would be so intense that the late effects (

[Table 8.16](#)) would outweigh the benefit of cure

- Surgeries are typically conservative to preserve limbs and function
- Cancer is the no. 2 killer of children; accidents are no. 1
- Since children have not had time to accumulate adverse effects of poor diets, chemical exposures and other carcinogenic situations, the study of pediatric cancers has given the opportunity to explore certain genetic/chromosomal abnormalities
- Most children survive their cancer
- Young children will likely require sedation and elaborate immobilization
- Older children through young adults need special age-appropriate considerations
-

[Table 8.17](#) lists some age-appropriate considerations for pediatric patients

TABLE 8.16

Long-Term Side Effects of Radiation and Chemotherapy

Radiation	Chemotherapy
Cataracts, impaired growth, impaired cognition, abnormal dentition, hypoplasia of bone, hypothyroidism, lung fibrosis, pericardial thickening, secondary cancers, hypoplasia of abdominal and pelvic organs	Myocardial damage, lung fibrosis, infertility, sterility, leukemia, hearing impairment, liver and/or kidney dysfunction, impaired cognition, peripheral neuropathy

TABLE 8.17**Age-Appropriate Considerations for Pediatric Patients**

Age Group	Care Considerations
Toddlers	Very attached to their parents but beginning to assert some independence; can communicate in 2- to 3-word sentences; use familiar names; talk in calming tones; allow parents to come along
Preschoolers 3–5 years	Conversational and have increased independence; can cooperate but may be fearful, so ask them to participate; be honest, use terms they understand and analogies; do not punish them for crying or wanting to retreat
School age 6– 12 years	Can think logically about concrete things; be specific and honest; use demonstration to explain procedures
Adolescent 13–18 years	Greater emotional needs; modesty and privacy important; show empathy, keep in mind they fear threats to their physical appearance; establish rapport by having general conversations about what they like or do in their free time

Neuroblastomas

- Originates in the neural crest cells of the sympathetic nervous system
- Most common in infants, most are younger than 5 years old
- Younger than 2 years old tend to have localized disease
- May be linked to abnormal maturation of fetal neural crest cells
- A unique characteristic is that it has been known to spontaneously regress

Clinical Presentation

- Symptoms and signs depend on location (

[Table 8.18](#))

- Can show up anywhere along the sympathetic nerve chain

TABLE 8.18

Neuroblastoma Symptoms

Localized	Disseminated
Chest: cough, dyspnea	Fever, weight loss, malaise, fatigue
Neck: swelling	Bluish skin nodules
Pelvis: bowel or bladder changes	Rapid liver enlargement
Brain: Uncontrolled eye movements, mental retardation	Lytic bone lesions with pain

Lymphatic Drainage and Spread Patterns

- Metastasis may be to the skin, liver, and bone marrow

Workup

- Physical examination
- Chest x-ray
- Urine sampling
- CT abdomen, chest, and pelvis
- MRI
- X-rays of bone
- Bone marrow biopsy

- PET

Staging

- International Neuroblastoma Staging system stages 1 to 4
- International Neuroblastoma Risk Group Staging System (very low, low, intermediate, and high)

Treatment

- Very sensitive to radiation and chemotherapy
- Local disease and low risk is usually managed with surgery alone
- Complete or partial resections are followed by multiagent chemotherapy (examples are cyclophosphamide, doxorubicin, etoposide, cisplatin) for intermediate risk
- Radiation often given in regionally advanced disease; 1000 cGy for palliation, 2000 to 3600 cGy to region of residual disease following surgery
- Radiation TBI can accompany stem cell transplant for high risk
- Survival favorable with intensive management, such as multi-agent chemotherapy and/or bone marrow transplants
- Immunotherapy

Radiation treatment borders

- TBI therapy in the setting of bone marrow transplant preparation
- For hepatomegaly or primary mass palliation, fields are limited to the mass or liver with margin
- For lesions of the adrenal gland or near the abdominal vertebrae, paraaortic lymph nodes to be included
- Vertebral bodies should be treated symmetrically to reduce risk of scoliosis

Treatment delivery

- TBI requires complex dosimetric calculations
- Patient may be positioned standing or semirecumbent with knees bent up toward chest or lying supine at an extended treatment distance
- This age group suitable for supine position at extended distance
- Even dose distribution is of great concern so tissue compensators made with rice bags or gelatin may be placed at thinner areas such as the lower extremities and neck
- Arms bent along chest could compensate for low-density lung tissue from the lateral aspect
- Care to keep doses low to lens using lens shields and lungs, using specially fabricated blocks
- Local, palliative fields are likely arrangements for reduced dose to neighboring tissues and beam shaping

Nephroblastoma (Wilms' Tumor)

- Occurs mostly between 3 and 4 years old
- Genetics is a risk factor
- Multiple genitourinary abnormalities increase risk
- Treatment very successful; overall cure rate is more than 80%
- Arises in embryonal kidney cells
- Can contain renal tubular, glomerular, and connective tissue elements
- Highly anaplastic, clear cell sarcomas and rhabdoid tumors are unfavorable histologies

Clinical Presentation

- Abdominal mass
- Hypertension
- Hematuria (microscopic most frequent)

Lymphatic Drainage and Spread Patterns

- Usually infiltrate the kidney capsule to adjacent structures then through the blood; renal hilar, and paraaortic nodes are commonly positive at diagnosis; distant metastasis to lung, brain, or bone

Workup

- Physical examination
- Abdominal ultrasound
- CBC
- Urinalysis
- IVP
- CT and MRI chest, abdomen, brain
- Liver/kidney function
- Chest x-ray for suspected metastasis in lungs

Staging

- National Wilms' Tumor Study uses stages I to V; stage V indicates bilateral kidney involvement.
- Children's Oncology Group uses stages I to V

Treatment

- Surgery is nearly always the first step with careful exploration of the opposite kidney and lymph nodes
- Chemotherapy and radiation can be used to debulk the tumor before surgery
- Chemotherapy may include actinomycin-D, doxorubicin, and vincristine
- Whole lung radiation for lung metastasis dose of 12 Gy
- Whole brain radiation for brain metastasis dose 20 to 30 Gy
- Radiation for bone metastasis dose 20 to 25 Gy
- Radiation can be used adjuvantly to prevent local recurrence to tumor bed and associated areas of residual disease; dose ranges from 10 to 40 Gy (18–24 Gy for children under 18 months old).

Should be delivered within 14 days of nephrectomy to reduce chance of recurrence

Radiation treatment borders

- Irradiation to the tumor bed defined by presurgery imaging or surgical placement of radiopaque markers.
- The whole abdomen is treated in those with peritoneal seeding or tumor rupture before or during surgery; dose 10 to 12 Gy.
- Paraaortic nodes should be included with the entire width of the spine to avoid scoliosis.
- Boosts may be used for residual disease.

Treatment delivery

- Need beam shaping to protect bowel and normal kidney
- Patient positioned supine using immobilization appropriate for age; arms up for easy triangulation
- Parallel opposed fields to avoid opposite kidney
- Sedated children will be accompanied by parents, nursing, and/or respiratory care staff, respiratory staff; be prepared to educate parents and accompanying staff

Rhabdomyosarcoma

- Arises from embryonal mesenchyme, with potential for differentiating into skeletal muscle
- Most common pediatric soft tissue tumor
- Can arise almost anywhere in the body where striated muscle or mesenchymal tissue is located
- Can invade and spread quickly
- Median age younger than 5 years old
- Histologic subtypes embryonal, alveolar, pleomorphic

Clinical Presentation

- Mass
- Swelling
- Limitation of function
- Obstruction
- Discomfort

Lymphatic Drainage and Spread Patterns

- Spread varies with histologic type but usually local (if manifests in muscle then local spread could be from insertion to insertion) then through blood or regional lymphatics

Detection and Diagnosis

- X-rays
- CT
- MRI
- Myelogram to check for CNS involvement
- CBC
- Liver function
- Bone marrow biopsy
- CSF cytology

Staging

- International Rhabdomyosarcoma Studies system used “grouping” based on extent of disease at time of treatment; stages I to IV; later, a TNM system based on International Union Against Cancer was developed to reflect disease characteristics including grade

Treatment

- Surgery is always in order.
- Complete resection versus gross resection is influenced by the site, cosmetic effect, and function (i.e., orbit RT to tumor and margin and surgery avoided).

- Those staged at II or above may require radiation in the range of 40 to 50 Gy, conventional or hyperfractionation protocols—60 Gy.
- Multiagent chemotherapy (examples are vincristine, actinomycin D, cyclophosphamide, etoposide, ifosfamide, doxorubicin, melphalan).

Radiation treatment borders

- Concentrate on sparing lymphatic vessels (preserve a strip of soft tissue) and ends of bones to retain relative bone growth to extremities, RT to tumor and margin
- Complex planning required to ensure that extensively infiltrating tumors have sufficient margins while growth plates are spared
- Total dose ranges influenced by patient age and size of tumor
- Most desirable to include the entire muscle compartments in extremities with several shrinking fields
- Abdominal tumors also require multiple shrinking fields
- GTV and CTV defined by volume defined before and after surgery by imaging studies

Treatment delivery

- Hyperfractionation protocols; keep an eye on time intervals between doses
- Immobilization critical
- Positioning influenced by location
- For head and neck area, all positive lymph nodes should be irradiated
- CNS tumors only need 2-cm margin
- In pelvis, take care to shield femoral epiphyseal plates and proximal femur
- Extremities—regional lymph nodes only treated if they were found positive
- Low-dose lung radiation for pulmonary metastasis
- Patients receiving high dose need skin care education

Ewing Sarcoma

- Arises in nonosseous portion (medullary canal) of the bone and occasionally in soft tissues
- If it arises in the canal, it may break through the cortex/periosteum, forming a soft tissue mass
- The periosteum is a natural barrier for spread
- Has an onion skin appearance on x-ray
- Age range 5 months to 60 years with peak incidence between 11 and 17
- Most common bone tumor in children younger than 10 years old
- Tumor is rare in children younger than 5 years old
- Primarily occurs in large, long bones and bones in the pelvis

Clinical Presentation

- Bone pain
- Tenderness, swelling
- Neurologic abnormalities if spine/nerves are compressed
- Weight loss, fatigue
- Fever

Lymphatic Drainage and Spread Patterns

- May spread through the blood to the lung, bone, lymph nodes, liver, and CNS; lymphatics rarely involved

Workup

- CT
- MRI
- Plain films
- Chest x-ray
- Bone marrow biopsy
- Lumbar puncture
- CBC

- Kidney and liver function
- LDH serum

Staging

- No accepted system has been adopted; tumors are classified as localized or disseminated

Treatment

- Surgery for biopsy
- Surgery for tumor resection is determined by location, extent, cosmesis, and function
- Ewing very chemosensitive (examples are vincristine, cyclophosphamide, doxorubicin, ifosfamide)
- Chemotherapy is likely the induction then followed by radiation/surgery
- Radiation for local control of primary or sites of metastasis
- If tumor extends or is near the meninges, prophylactic radiation to CNS

Radiation treatment borders

- Keep a margin of soft tissue for lymphatic drainage preservation
- Entire bone with shrinking fields to decrease chances of bone growth retardation
- Need many field reductions; total 55 to 60 Gy
- Controversy on sparing one end of the bone when lesion is centrally located in bone

Treatment delivery

- Position depends on location
- Extremities need to be positioned away from opposite limb and body
- Reliable immobilization is critical

- Keep an eye on multiple cone down doses
- Parallel opposed fields with beam shaping and modifiers such as bolus to increase dose to surgical scar
- Dry and wet desquamation expected at doses at high range
- Educate patient and parents on skin care

Medulloblastoma

- One of the most common pediatric CNS primaries; close to low-grade astrocytomas
- Peak age 5 to 8 years old; another peak 20 to 30 years old
- Male: female ratio is 2:1
- Comes from primitive neuroepithelial cells of the cerebellum
- Usually detected in the fourth ventricle and expands causing obstruction of CSF circulation
- CSF obstruction causes hydrocephalus
- High potential for CNS spread

Clinical Presentation

- Specific symptoms depend on location of tumor
- Hydrocephalus may occur with nausea, vomiting, changes in level of consciousness

Lymphatic Drainage and Spread Patterns

- No lymphatics in the CNS but spread likely throughout the CNS in circulating spinal fluid

Workup

- CT
- MRI
- Neurologic assessment
- Biopsy

- Lumbar puncture (avoid puncture if intracranial pressure increased)

Staging

- TGM for tumor, grade, and metastasis through the CNS
- WHO Classification by groups: Wingless, Sonic Hedgehog, Group 3, and Group 4; groups consider histology, gene mutations, and molecular pathways

Treatment

- Surgical resection, even if not total, could restore CSF flow.
- For children younger than 2, radiation is avoided, and intense chemotherapy is given (examples are cisplatin, vincristine).
- Chemotherapy is last resort or used for those with unfavorable prognostic factors; blood–brain barrier presents an obstacle.
- Have to use lipophilic agents, local therapy (directly into the tumor or intrathecal).
- New drugs have recently been developed with promise of crossing the blood–brain barrier.
- Certain drugs may render the brain and tumor capillaries more porous and penetrable.
- Radiation is an important postsurgical treatment.
- Radiation doses to total 54 Gy to posterior fossa/tumor bed.

Radiation treatment borders

- Whole brain with lower border at C2 for margin on the fourth ventricle; total dose 35 Gy
- Entire spinal compartment from C2 to S2 to cover all circulating spinal fluid; total dose 24 Gy
- Boost posterior fossa with opposed lateral fields with an extra 10 to 20 Gy
- IMRT and proton therapy to escalate dose and avoid organs at risk anterior to the vertebral bodies

Treatment delivery

- Treatment of entire spinal axis requires careful field matching/skin gaping.
- Beam geometry may require collimation and/or couch rotation to prevent overlap.
- Match points should be moved during treatment course; every 3 to 5 days the match point should be moved (feathered) when matched photon fields are used.
- Patients positioned prone with arms at sides in immobilization at least covering head to pelvis.
- Be prepared to counsel patient and family on skin care as hair loss, dry desquamation likely.

Retinoblastoma

- Most common intraocular tumor in children but occurs rarely
- Incidence higher in Africa, India, and among children of American Indian descent in North America
- Small blue cell of neuroectodermal origin
- Occurs in children 6 months to 4 years
- Hereditary pattern has been observed
- 65% are unilateral

Clinical Presentation

- Abnormal retinal light reflex (white rather than red)
- Visual abnormalities

Lymphatic Drainage and Spread Patterns

- Lymphatics not typically involved, local extension into the sclera and into the orbital contents to pre-auricular lymph, sinus, or brain
- Dissemination within the vitreous and retina in the form of small white nodules

- Distant spread to bone, bone marrow and liver

Workup

- No biopsy; risk of severe bleeding is too great
- CT
- US
- MRI
- Bone marrow biopsy
- Lumbar puncture for CSF cytology

Staging

- International Classification for Intraocular Retinoblastoma; Groups A to E

Treatment

- Good response to chemotherapy (direct administration such as intravitreal or systemic with drugs such as vincristine, carboplatin, etoposide)
- Photocoagulation with argon laser for tumors at or posterior to the equator of the eye (obliterates blood supply to the eye)
- Cryotherapy may provide local control
- Transpupillary thermotherapy (heat applied with diode laser)
- Total enucleation leads to almost certain cure while sacrificing the globe
- Radioactive plaques of cobalt or iodine possible; can deliver 40 to 60 Gy in a week
- Cure rates with plaques are greater than 80% with visual preservation
- External beam RT after chemotherapy to dose of 26 Gy

Radiation treatment borders

- Real challenge to treat retina and spare the cornea and lens

- AP and lateral field with hanging lens block; 3D conformal therapy ideal, no lymphatics included
- CT planning defines the CTV to encompass the globe and 0.5 cm of the optic nerve
- Single field proton field anteriorly
- SRT treats GTV with 2- to 3-mm margin

Treatment delivery

- Fields are small, need reliable head immobilization and possible ocular suction to immobilize the eye during SRT
- Watch margin on opposite orbit and lens

Pediatric review exercises

1. When treating the tumor bed for Wilms tumor, care should be taken to include the entire width of the spine to prevent:
 - a. Scoliosis
 - b. Bowel obstruction
 - c. Pericardial thickening
 - d. Lung fibrosis
2. Which of the following is *not* an associated risk factor for pediatric solid tumors?
 - a. Parasites
 - b. Environment
 - c. Ionizing radiation
 - d. Prenatal factors
3. The most common symptom of Wilms' tumor is:
 - a. Hematuria
 - b. Pain
 - c. Abdominal mass
 - d. Nocturia

4. Nephroblastomas metastasize most commonly to the:
- a. Bone
 - b. Lung
 - c. Liver
 - d. Brain
5. Neuroblastomas originate in the:
- a. Neural crest tissue
 - b. Kidney
 - c. Ventricles
 - d. Bone
6. Which of the following primary brain tumors typically spreads to the CSF?
- a. Medulloblastoma
 - b. Craniopharyngioma
 - c. Teratoma
 - d. Astrocytoma
7. The most common symptom of Ewing sarcoma is:
- a. Weight loss
 - b. Neurologic abnormalities
 - c. Pain
 - d. Fever
8. The most frequent orbital malignancy in children is:
- a. Retinoblastoma
 - b. Lymphoma
 - c. Rhabdomyosarcoma
 - d. Osteoblastoma
9. Wilms' tumors originate from what cell type?
- a. Neuroblasts
 - b. Nephroblasts
 - c. Nephroclasts
 - d. None of the above

10. Which type of childhood cancer is mostly associated with *prophylactic* irradiation of the CNS?

- a. Ewing sarcoma
- b. Wilms' tumor
- c. Retinoblastoma
- d. Acute lymphocytic leukemia

11. Stem cell transplantation is successful in treating childhood cancers such as ALL. Transplanted blood cells may come from a compatible donor, the patient, or an identical twin. Match the following:

_____ Allogeneic donor	A. self
_____ Autologous donor	B. compatible match
_____ Syngeneic donor	C. identical twin

12. The most important latent side effects from radiation therapy to the pediatric patient include (select two):

- a. Impaired bone growth
- b. Radiation-induced puberty
- c. Secondary cancers
- d. Epilation

13. An aggressive management for retinoblastoma is an enucleation. An enucleation is:

- a. Surgical replacement of the orbit
- b. Surgical placement of orbital prosthesis
- c. Surgical removal of the orbit

- d. Surgical removal of cataracts
- 14. When caring for preschool-aged children, it is important to:
 - a. Be authoritative and firm
 - b. Make sure that they do not cry
 - c. Keep communications simple and honest
 - d. Allow them to have lots of choices
- 15. When caring for an adolescent, it is important to:
 - a. Be authoritative and firm
 - b. Make sure that they do not cry
 - c. Give them extra time for dressing and undressing
 - d. Acknowledge that modesty and privacy are paramount
- 16. Your 17-year-old Hodgkin disease patient is worried about not having her hair back in time for the prom. An acceptable response may be:
 - a. Do not worry about it, no one will be looking at your head
 - b. Beauty is in the eye of the beholder; forget what others say
 - c. I know someone you can speak with about some creative alternatives
 - d. Your hair should be back within 2 weeks following chemotherapy

Think About It

- 17. The entire spinal axis will be treated using whole brain fields with a field size 15×20 and spine field with field size 8×30 in your pediatric patient using a SAD technique, 6-MV beam. To avoid overlap at the field junction, table kicks will be used during treatment of the lateral brain fields. The SSD for both lateral fields is 93-cm SSD. Calculate the table kick.
- 18. Calculate the monitor units required for the lateral brain fields in the above case using the additional information below.

Prescription: 36 Gy in 24 fractions

Output/reference dose rate = 0.996 cGy/MU
Field shaping using MLC

Field Size	Output Factor for TAR
12 2	1.008
13 2	1.013
15 2	1.021
16 2	1.024
17 2	1.0

TAR table for 6 MV
Field size →

Sarcomas: primary bone and soft tissue

Primary Bone

General Facts

- Primary bone tumors account for less than 0.2% of all malignancies
(

Table 8.19)

- Primary bone cancer is a malignancy of the connective tissue with mesenchymal origin
- Overall 5-year survival is 66%

TABLE 8.19**Primary Bone Histology, General Facts, and Incidence**

Histology	General Facts	Incidence
Osteosarcoma	Most common bone tumor, more predominant in males	Adolescents to young adults 10–30 years of age
Chondrosarcoma	Rare in children	Midlife and older age
Fibrosarcoma/Malignant fibrous histiocyoma	May occur in bone and soft tissue, slight male predominance	Majority diagnosed after age 40
Malignant giant cell tumors	Typically benign, usually arises in distal femur or proximal tibia	Peak incidence at 10–30 years of age
Multiple myeloma	Disease of plasma cells, more common in black populations, male predominance	Occurs in middle-aged to older adults, peak incidence in 6th decade of life
Ewing sarcoma	Mainly diagnosed in Caucasians. Male predominance	Affects anyone ages 5 months to 60 years, peak incidence in children 10–30 years of age
Metastatic bone tumors	Occurs most often in the spine, pelvis,	Accounts for most malignant bone

Histology	General Facts	Incidence
	and ribs followed by skull, humerus, and femur	lesions with majority of cases related to breast, prostate, and lung primaries

American Cancer Society. Key statistics about bone cancer. Accessed June 7, 2023.

<https://www.cancer.org/cancer/types/bone-cancer/about/key-statistics.html> .

Etiology

- Previous radiation
- Genetics
- RB1 and TP53 for osteosarcoma
- ETS & TET for Ewing sarcoma
- Prior exposure to alkylating agents
- Benign conditions—Paget disease

Clinical Presentation

- Pain
- Swelling
- Pathologic fracture
- Decreased range of motion in extremities
- Hypercalcemia (multiple myeloma)

Work up

- Plain radiographs of tumor site

- MRI with contrast
- Chest/abdomen/pelvis CT with contrast
- PET/CT base of skull through mid-femur
- Bone scan if PET/CT inconclusive
- Biopsy to confirm diagnosis

Staging

AJCC TNM staging: Stage grouping I to IV

T: Extent of primary tumor

N: Spread to nearby lymph nodes

M: Distant metastasis

G: Grade of the cancer

Musculoskeletal Tumor Society Staging Grouping I to III

- Uses G, T, and M categories

<https://www.cancer.org/cancer/types/bone-cancer/detection-diagnosis-staging/staging.html>

Treatment

Local therapy:

- Surgery is treatment of choice (limb sparing vs amputation)
- Radiation: Unresectable (sacrum/base of skull), positive surgical margins

Systemic therapy:

- Neoadjuvant therapy may improve limb-sparing
- 3 drug regimens in children (methotrexate, Adriamycin, Cisplatin [MAP])
- Can omit methotrexate in adults

Targeted therapy

- Kinase inhibitors
- Immunotherapy:
 - Pembrolizumab
 - Interferon alfa-2b

Treatment Delivery

Definitive for unresectable lesions

- IMRT/VMAT or protons
- 60 to 70 Gy

Metastatic disease

- 8 Gy $\times$ 1 fraction
- 20 Gy $\times$ 5 fractions
- 30 Gy in 10 fractions

Side Effects of Treatment

- Neurotoxicities from chemotherapy
- Site-specific radiation effects: skin reaction, reduced blood counts, pathologic fracture

Lymphatic Drainage and Spread Patterns

- Lymphatic drainage is usually not involved
- Direct invasion along the bone
- Hematologic spread to the lungs

Soft Tissue Sarcoma

General Facts

- Approximately 1% of malignancies in adults

- 15% in children
- Male predominance
- Extremities (43%), the trunk (10%), visceral (19%), retroperitoneum (15%), or head and neck (9%) are the most common primary sites
- Rhabdomyosarcomas are most common in ages 5 to 20, other STS range from 20 to majority diagnosed over age 60
- Refer to

[Table 8.20](#) for STS Histology and General Facts

TABLE 8.20

Soft Tissue Sarcoma Histology and General Facts

Histology	General Facts
Liposarcoma	Originates in fat tissue, often occurs in thigh, behind knee
Leiomyosarcoma	Originates in smooth muscle tissue, often occurs in abdomen also arms and legs
Fibrosarcoma	Generally occurs in legs, arms, or trunk
Synovial sarcoma	Occurs in articular areas and tendon sheaths
Rhabdomyosarcoma	Most common STS in children, occurs in striated muscle, mainly extremities
Gastrointestinal stromal tumor (GIST)	Occurs in digestive tract
Kaposi sarcoma	Starts in cell lining of lymph or blood vessels, most common in people with AIDS

Etiology

- Male gender
- Genetic mutations/family cancer syndromes (neurofibromatosis, Li-Fraumeni syndrome, retinoblastoma)
- Prior radiation
- Chronic lymphedema
- HIV/AIDS

Clinical Presentation

- Often nonspecific
- Painless mass
- Bloating and pain—abdominal tumors
- Distal edema

Workup

- MRI—extremities, CNS, soft tissues, spine
- CT—lungs, abdomen, pelvis
- Biopsy

Staging

AJCC TNM staging: Stage grouping I-IV

T: Extent of primary tumor

N: Spread to nearby lymph nodes

M: Distant metastasis

G: Grade of the cancer

Treatment

Surgery

- Ideally limb-sparing with negative margins

- Close or microscopically positive margins to preserve critical structures
- Entire anatomical compartment resection not routinely necessary

Radiation

- Preoperative to downstage large, high-grade tumors
- Postoperative when close or positive margins remain
- Interventional oncology—catheter-directed therapies
- Chemotherapy—inconsistent findings
- Neoadjuvant/adjuvant or advanced/metastatic: Doxorubicin, ifosfamide, mesna

Treatment Delivery

Stage I postop RT with close/positive margins

- 50 Gy plus boost to 60 to 66 Gy for close margins
- 66 to 68 Gy for positive microscopic margins
- 70 to 76 Gy for gross residual disease
- IORT boost 10 to 15 Gy

Stage II to III

- Preop chemoradiation: 50 Gy $\pm$ boost for positive margins
- Postop radiation: 50 Gy + boost
- Adjuvant brachytherapy
-

Figure 8.24 demonstrates adjuvant volumetric modulated arc therapy compared to 3D conformal radiation therapy for newly diagnosed soft tissue sarcoma of the extremity.

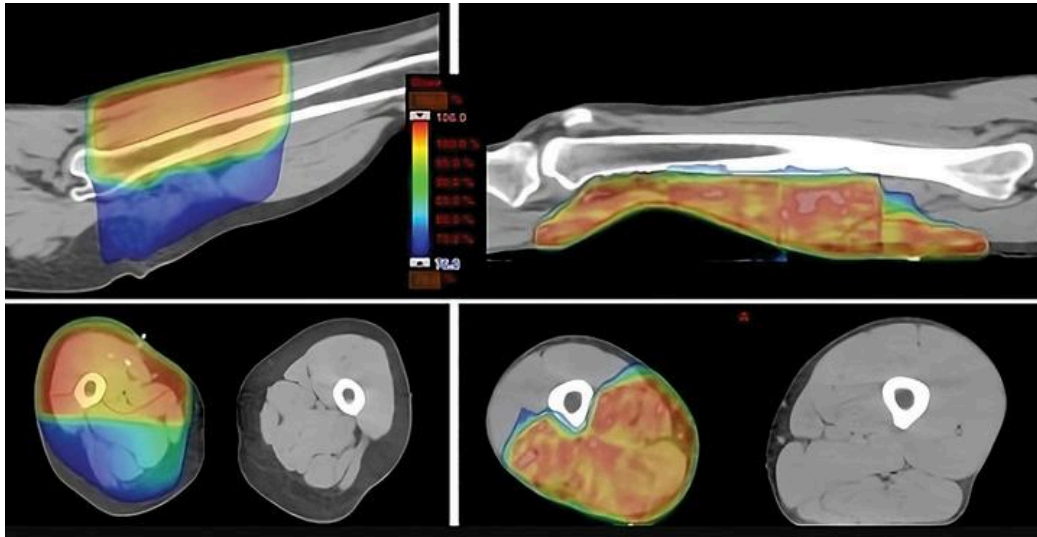


FIG. 8.24 VMAT for soft tissue sarcoma of the extremity. Adjuvant volumetric modulated arc therapy compared to 3D conformal radiation therapy for newly diagnosed soft tissue sarcoma of the extremity.

(Di Brina L, Fogliata A, Navarria P, et al. Adjuvant volumetric modulated arc therapy compared to 3D conformal radiation therapy for newly diagnosed soft tissue sarcoma of the extremities: outcome and toxicity evaluation.

Br J Radiol . 2019;92(1102):20190252.

<https://doi.org/10.1259/bjr.20190252> .)

Lymphatic Drainage and Spread Patterns

- Directly in the longitudinal axis of the primary site compartment
- Usually no lymphatic spread except for synovial sarcoma
- Hematologic spread to lung, abdominal tumors metastasize to liver

Primary Bone and Soft Tissue Sarcoma review exercise

Sarcomas: Primary bone and soft tissue review exercises

Multiple Choice

1. Soft tissue sarcomas usually spread:
 - a. Through several muscle compartments
 - b. Locally, along the longitudinal muscle plane
 - c. Locally, along the vascular supply in the muscle
 - d. Toward the distal joint
2. Sarcomas originate in the _____ tissue layer.
 - a. Endoderm
 - b. Mesoderm
 - c. Ectoderm
 - d. DuoDerm
3. A rhabdomyosarcoma is a malignant tumor arising from:
 - a. Smooth muscle
 - b. Glandular epithelium
 - c. Striated muscle
 - d. Mammary tissue
4. Liposarcomas originate in:
 - a. Muscles
 - b. Articular joints
 - c. Tendons
 - d. Fat
5. Primary osseous tumors metastasize to the lung via:
 - a. Local invasion
 - b. Seeding
 - c. Lymphatics
 - d. Blood

6. What feature would be present on an x-ray image of a lytic primary bone tumor?
- a. Increased density in the region of the tumor
 - b. Decreased density in the region of the tumor
 - c. Expansion of the bony compartment
 - d. Expansion of the adjacent muscle
7. What is the likely explanation for weight loss and fever in the patient suspected to have primary bone cancer?
- a. Presence of the tumor causes infection and loss of appetite
 - b. Presence of the tumor causes physiologic cachexia
 - c. Presence of the tumor causes hypercalcemia
 - d. Presence of the tumor causes hyperthyroidism
8. Radiation to the abdomen for soft tissue sarcomas in the peritoneum is limited by low-tolerance organs such as the kidneys. The TD 5/5 for the whole kidney is:
- a. 45 Gy
 - b. 37 Gy
 - c. 23 Gy
 - d. 10 Gy
9. A solitary multiple myeloma tumor is known as a:
- a. Plasmacytoma
 - b. Histiocytoma
 - c. Osteogenic sarcoma
 - d. Desmoid tumor
10. The primary treatment of choice for local control of soft tissue sarcomas located in the extremities is:
- a. Surgery
 - b. Radiation therapy
 - c. Chemotherapy
 - d. Immunotherapy

Palliative care

General Facts

- Plan of care should be individualized
- Patient's performance status should be considered (Karnofsky, level of function I-IV, ECOG status)
- Extent of disease must be established quickly; palliative care or emergent care is not always given during late-stage disease, exclusively
- Life expectancy will influence plan of care
- Previous treatments will influence plan of care
- Patient convenience and expense must be considered
- Short courses of radiation have demonstrated similar results as longer courses
- Duration of response, acute side effects, chronic complications, re-treatment rates and results must be considered

Brain Metastasis

General Facts and Epidemiology

- Most common anatomic primary sites are breast and lung
- Metastasis from gastrointestinal or gynecologic regions is rare
- Melanoma has highest percentage of brain metastasis than any other primary cancer
- 40% of CNS tumors are metastatic
- Median survival is 3 months
- Favorable factors: Karnofsky greater than 70, absent or controlled primary, age less than 60 years, metastasis limited to brain

Clinical Presentation

- Headache

- Impaired cognition
- Lesions are usually multifocal
- Depending on location of tumor, can also see nausea, vomiting, somnolence, loss of speech, memory impairments, disturbed vision, disturbed hearing, motor impairment, personality changes

Detection and Diagnosis

- CT
- MRI
- Neurologic assessment
- Cognitive and motor assessments

Treatment

- Surgery for single, isolated lesions
- Surgery if metastasis is to the cerebellum, causing severe ataxia
- Large cavitating lesions in the cerebrum are best removed
- Radiation may be combined with surgery and potentially doubles survival; see 70% to 90% symptom relief for those treated with radiation
- 20 Gy in 5 fractions yield similar results as 40 Gy in 20 fractions
- Whole-brain radiation is intended to limit tumor progression and to limit the prolonged use of steroids
- Small, recurrent, single focus lesions may benefit from stereotactic radiosurgery with linac or gamma knife; no larger than 3 to 4 cm in size
- Single dose SRS can be 20 to 30 Gy
- Steroids can relieve symptoms alone within 48 hours
- Steroids improve neurologic function, but do not affect the length of response
- Anticonvulsants may also be beneficial

Radiation treatment borders

- Radiation treatment fields are typically opposed laterals
- Fields should cover the entire cranium
- Inferior border at the supraorbital ridge, through the external auditory meatus, and at the mastoid process
- If lesion is at the inferior portion of the temporal lobe, inferior border may be lowered with care to protect the lens of the eye

Treatment Delivery

- Physically support patients who have impaired ambulation to prevent falls
- Advise patients to refrain from driving and come accompanied to treatments
- Remind patients to use mild soap for hair washing or warm water only, protect head from the sun, take all medications as instructed; no razor shaving of the head
- Be prepared to handle seizures, syncope, dizziness
- Parallel opposed fields will likely call for simple positioning aids such as a neutral head rest and tape, or immobilizing masks are appropriate for patients with cognitive deficits or lowered levels of consciousness
- Minimal field shaping and simple positioning aids
- Use of immobilizing masks and MLC to protect the orbits, lens, and sinuses
- Increased cranial pressure (ICP)

General Facts and Epidemiology

- May be caused by primary tumors or metastatic tumors of the central nervous system
- Identified by expanding lesions in the brain causing pressure in the cranial compartment
- CNS hypoxia is the danger
- Brain shifts may lead to tentorial herniation and brain stem injury

Clinical Presentation

- Headache, nausea, and vomiting
- Blurred vision, diplopia, impaired motor function
- Altered mental function
- Seizures, paralysis
- Difficulty speaking, writing

Detection and Diagnosis

- CT, MRI
- Stereotactic biopsy
- Lumbar puncture should be avoided if disease is intracranial because a sudden shift in brain tissue can be fatal

Treatment

- Steroids initially for reduction of edema
- Anticonvulsants if seizures present
- Radiation for those with confirmed brain metastasis 30 Gy in 10 fractions
- Radiosurgery if solitary lesion
- Surgical resection if primary brain tumor suspected

Radiation treatment borders

- Standard whole brain
- Inferior border at the supraorbital ridge, through the EAM, and just below the mastoid process

Treatment Delivery

- Supine on neutral headrest or chin slightly flexed
- Field is simple with no beam shaping; collimation to avoid lens, sinuses, and oral cavity incurs simple billing charges
- Be prepared to assist patients with motor difficulties
- Be prepared to handle seizure episodes
- Patients should always be accompanied

- Although short course, scalp alopecia and moderate dry desquamation expected
- No harsh shampoo, protect scalp from sunlight, no razor shaving to the scalp, no chemical processing of the hair

Spinal Cord Compression

General Facts and Epidemiology

- Tumors arising in or metastasizing to the bone may cause spinal cord compression
- Most commonly secondary to involvement of spinal column and anterior to spinal cord
- Less frequently posterior to cord and occasionally in epidural space
- Lung, breast, unknown primaries, lymphomas, myeloma, sarcoma, prostate, and kidney primaries are the frequent culprits
- Less than 20% with paraplegia will ambulate again
- Compressions caused by lymphomas or myelomas have better prognosis

Clinical Presentation

- Specific symptoms depend on location
- Long-standing back pain
- Radiating pain from middle back to flank or from lower back to pelvis/lower extremities
- Weakness, sensory deficits, incontinence, urgency
- Paralysis
- Common site is the thoracic region

Detection and Diagnosis

- MRI most informative; shows good contrast between bone and soft tissue

- Conventional x-ray can show blastic or lytic bone lesions causing compression in the spinal cord space
- Neurologic assessment
- Look for elevated alkaline phosphatase

Treatment

- Emergency decompressive, stabilizing surgery especially for fracture dislocation of the spine, acute paraplegia, RT resistant tumors, or no steroid response
- Surgery may include laminectomy and placement of stabilizing rods
- Radiation at 30 Gy in 10 fractions

or an initial 12 to 15 Gy in 3 fractions followed by 18 to 30 Gy in 6 to 15 fractions for a total of 45 Gy show similar results

- Steroids may relieve pain and improve symptoms
- Analgesics/narcotics until pain is under control
- Chemotherapy may help if the primary is chemosensitive

Radiation treatment borders

- Should include the entire vertebral body, spinous processes and cord, with at least one vertebral body above and below the compression
- Location of compression determines the field arrangement; cervical may be delivered posterior only or opposing laterals; thoracic typically posterior only; lumbar may be posterior or AP/PA for deeper section of lumbar spine

Treatment Delivery

- Give adequate support to regions of compression
- Patients may come with spine braces; if braces must be removed, do so with extreme care

- Slightest jerking or twisting may worsen compression and possibly lead to paralysis; avoid using shoulder retractors for cervical spine fields
- Prone position with head in neutral and arms at sides accommodates lateral cervical spine fields, thoracic and lumbar spine
- Avoid having the patient ambulate or transfer themselves from gurney to PSA
- Use assisted sheet lift methods or low-impact sliding board methods
- Give skin care instructions as usual
- Regular pain assessment advised
- Pain should be adequately managed; if not, consult with attending physician or oncology nurse
- Treatment fields rarely need field shaping

Bone Metastasis

General Facts and Epidemiology

- 50% to 80% breast and prostate primary spread to bone
- 40% to 60% lung and Hodgkin lymphoma spread to bone
- 40% to 50% thyroid carcinomas spread to bone
- 30% to 50% renal cell carcinomas spread to bone
- Thoracic and lumbar spine most common location
- Pelvis is the second most common location
- Bone metastasis may also be seen in the skull, ribs, cervical spine, humerus, and femur
- Bone metastasis is the second most common cause of pathologic fracture after osteoporosis
- Life expectancy varies widely

Clinical Presentation

- Pain and impaired mobility
- Fracture
- Lytic or blastic lesions

- Neurologic symptoms from spinal cord compression

Detection and Diagnosis

- MRI
- Conventional x-ray
- Nuclear bone scan
- PET
- Serum calcium levels
- Tumor markers associated with suspected primary, such as PSA (prostate)

Treatment

- Prophylactic internal fixation for impending fracture
- Surgical fixation for lytic lesions in high-stress areas
- Radiation can foster healing and re-ossification in 65% to 85% of patients with lytic lesions
- Radiation brings pain relief to 80% to 90% of patients
- Local radiation with 30 Gy in 10 fractions or single dose of 6 to 8 Gy
- Hemi-body radiation appropriate for widespread metastasis with 6 to 7 Gy total; lungs must be protected and falloff beyond the skin is important to manage
- Radionuclide therapy with rhenium-186, phosphorus-32, strontium-89, or samarium-153
- Analgesics for pain control
- Hormones as appropriate to control primary breast or prostate carcinomas

Radiation treatment borders

- Localized fields to include area of metastasis and generous margins especially in extremities
- Spine fields should include entire vertebral body, transverse and spinous processes; include affected vertebrae and at least one

- vertebral body above and below
- Allow a length of 1.5 cm for each cervical spine, 2.5 cm for each thoracic spine, and 3.0 cm for each lumbar spine to be included in treatment field
- Field widths will likely range from 6 to 8 cm to cover the transverse processes depending on region of spine
- Bone metastasis at L5 or sacrum should be wide enough to include the entire sacrum out to sacroiliac joints
- Spare soft tissues in extremities when possible

Treatment Delivery

- Take care to avoid unnecessary pressure to metastatic sites
- Extremities should be positioned parallel to the horizontal axis of the beam for even dose distribution
- If patient positioned prone for radiation to the spinal column, take advantage of the opportunity to palpate spinous process to verify daily alignment
- Cervical spine should be treated with patient on neutral head rest to avoid stress-increasing pain or the potential for collapse and subsequent cord compression
- As in compressions, cervical spine may be treated using posterior only or opposing laterals to midline; dorsal spine typically treated using posterior only to depth corresponding to region of spine; lumbar may be treated with single posterior or AP/PA fields to midline
- Bone metastasis is painful so make patient comfortable, make sure pain is assessed regularly and properly managed
- Fields usually require very little field shaping, simple positioning aids, no complex immobilization, and incur simple charges
- Recurring metastatic lesions by require more advanced planning and treatment strategies such as IMRT and VMAT

Airway Obstructions

General Facts and Epidemiology

- Lung, trachea, esophagus tumors may compress the trachea, mainstem bronchi, or carina

Clinical Presentation

- Dyspnea
- Hemoptysis
- Stridor
- Cough

- Chest pain
- Anorexia

Detection and Diagnosis

- Conventional x-ray
- CT
- MRI

Treatment

- Expandable metallic stents can help maintain the airway
- Oxygen therapy
- External beam radiation for compression due to extrinsic masses with 2 Gy each fraction to 40 to 50 Gy
- Two 8.5 Gy fractions 1 week apart or a single fraction of 10 Gy, palliates 50% of symptoms; similar results are seen with 10 fractions
- If total atelectasis, begin within 2 weeks of collapse and there is a higher possibility of re-expansion of the lung
- HDR intraluminal radiation with 15 to 20 Gy at 1 cm from the source is as effective as high dose external beam
- Steroids may be used to reduce inflammation

Radiation treatment borders

- Local, conforming fields if immediate symptom relief is desired
- If complete workup shows primary lung or esophageal carcinoma, then fields will include the compressive tumor, margin, and regional lymphatics

Treatment Delivery

- As patients are experiencing dyspnea, use positioning strategies to ease oxygen exchange, such as supine position with upper torso slightly elevated or patient positioned sitting
- Arms above the head expands the chest and may help with more effective oxygen exchange
- If patient on oxygen therapy, follow the prescribed liter flow
- Be prepared to help assist with portable oxygen taking care to support the entire tank when transferring
- Watch out for episodes of syncope and dizziness; assist as needed
- Localized emergent fields will likely have no field shaping and simple positioning aids
- Fields designed to treat primary disease with curative intent will likely begin with simple arrangements and advance to complex arrangements with field shaping and beam modifiers and required complex immobilization devices

Superior Vena Cava (SVC) Syndrome

General Facts and Epidemiology

- Often this emergency is the first diagnosis and does not mean end-stage disease
- Most are from lung cancer but can also be from lymphoma and germ cell tumors, and sometimes benign conditions such as goiter or aortic aneurysm

- Thrombosis of the superior vena cava is common, but death is unusual unless there is a complication, such as brain metastasis or tracheal obstruction
- Must verify histology so we know how to proceed following the relief of symptoms
- Overall survival is poor as most patients have lung cancer; more than 80% with lymphoma can have complete response

Clinical Presentation

- Dyspnea
- Facial edema
- Orthopnea
- Engorged conjunctiva
- Headache, dizziness
- Venous distention
- Cyanosis
- Tachypnea
- Upper extremity edema

Detection and Diagnosis

- CT
- Conventional x-ray
- Sputum cytology
- Bronchoscopy
- CT-guided biopsy

Treatment

- Radiation in large doses initially such as 3 to 4 Gy in 3 fractions, then tapering to standard fractionation as diagnosis is confirmed
- Adding chemotherapy does not improve symptoms but may be appropriate as management for the primary
- Diuretics, steroids, anticoagulants may be helpful
- Expandable stents if previous radiation therapy

- Usually a good, prompt response to radiation is seen within 3 to 4 days

Radiation treatment borders

- Localized fields for the initial high doses for symptom relief
- Once diagnosis is confirmed, fields will include tumor, margin, and regional lymphatics
- Since tumors are often located at the apex of the lung, slight neck extension is required for margin on the lung apex

Treatment Delivery

- Patient should be positioned to ease breathing and oxygen exchange
- Initial emergent fields will be small, simple with no field shaping; patient may lay supine on slight incline with arms at sides and AP/PA arrangement
- Following workup, strategy may include off-cord fields, and reduced fields with total doses approaching 60 Gy; immobilization devices, beam modifiers, and beam shaping with MLC added
- Be prepared to assist with changes in the level of consciousness, syncope, dizziness, and potentially advancing respiratory distress

Liver Metastasis

General Facts and Epidemiology

- Since the liver filters blood from the remainder of the intraabdominal gastrointestinal tract, those originating there have a high tendency to metastasize to liver; such as primaries of the stomach, colon, rectum, esophagus, pancreas
- Other primaries metastasizing to the liver include breast, lung, melanoma, lymphoma, ovarian, bladder
- Common finding in patients with end-stage cancers

- Mean survival is 75 days if untreated; following treatment, then 9 months with substantial response

Clinical Presentation

- Abdominal pain
- Nausea, vomiting, anorexia
- Jaundice
- Ascites
- Fever

Detection and Diagnosis

- Liver function
- Prothrombin time
- Physical examination of abdomen
- CT
- MRI
- Ultrasound
- CT-guided biopsy

Treatment

- Partial hepatectomy if solitary lesion
- Chemotherapy with 5-FU base is shown to get 20% to 30% response
- Intrahepatic arterial chemotherapy infusion
- Radiation doses of 28 to 30 Gy in 14 to 15 fractions to the whole liver known to give significant pain relief, reduce the size, and improve function in 55% to 75% of patients
- Whole liver radiation can lead to radiation-induced liver disease

Radiation treatment borders

- Whole liver should be included if possible

- Partial liver can be dosed using intensity modulation or HDR liver implants or selective hepatic artery with radioisotopes
- Medial border across midline, lower border at the level of L2 with right lateral flash
- Beam shaping to protect the kidneys as much as possible, small bowel and colon
- AP/PA fields appropriate; IMRT assists with limiting dose to kidneys

Treatment Delivery

- Patient should be supine with arms akimbo or above the head for triangulation
- Regularly assess pain and make sure appropriate referrals made for optimal pain management
- If patient is nauseous or vomiting, advise bland diet and plenty of fluids; clear liquids if solid foods are not well tolerated

Gynecologic/Urinary Hemorrhage

General Facts and Epidemiology

- Bleeding may come from late stage, ulcerating tumors in the endometrium, cervix, or bladder; bleeding may also be caused by fistulas
- Pain not necessarily an accompanying symptom

Clinical Presentation

- Excessive bleeding from the vagina or urethra
- Catheterized patients with bladder cancers may show bright red blood in catheter bag

Detection and Diagnosis

- Suspected primary need confirmed pathology

- Cervical or endometrial biopsy
- Cystoscopy with biopsy
- CT of pelvis

Treatment

- Ferric sulfate to the site stops the bleeding while awaiting complete workup and planning therapy
- Radiation to the local site can stop the bleeding by activating coagulating cells
- Initial large doses such as 3 to 4 Gy per fraction for 3 to 5 days may be applied, followed by tapered doses as primary diagnosis and disease staging dictates

Radiation treatment borders

- In either situation, a large pelvic field is used to include the bleeding tumor and generous margin
- To relieve symptoms right away, a standard stop sign-shaped pelvic field from the top of the sacrum to the obturator foramen and wide enough to include the true pelvis; bone marrow in the iliac crests, head of femurs should be shielded
- Borders may change as histology and stage of disease is confirmed

Treatment delivery

- Patient may be positioned supine with arms on abdomen for initial emergent doses; simple immobilization of lower extremities
- Use additional barriers on PSA for bleeding
- Dispose of stained coverings using biohazard bags
- If treatment goal changes to more definitive or curative nature, more may be done to spare small bowel, protect normal colon and bladder
- Initial fields with minimal beam shaping are likely AP/PA and incur intermediate charges

- Follow-up fields may include 4 to 6 fields, using complex beam shaping, intensity modulation, alternative positioning to spare small bowel, complex pelvic immobilization, and will incur complex charges

Palliative care review exercises

1. What area of the brain would you expect to find involved if a patient had vision problems?
 - a. Parietal
 - b. Frontal
 - c. Temporal
 - d. None of the above
2. Distinguish between osteolytic and osteoblastic lesions as they may appear on a conventional x-ray.
3. Compare/contrast palliative doses of radiation for brain metastasis to curative doses for primary brain malignancy.
4. Define the following:
 - Superior vena cava syndrome
 - Laminectomy
 - Partial hepatectomy
5. Steroids are used to:
 - a. Stop hemorrhage
 - b. Decrease nausea
 - c. Restore hydration
 - d. Decrease inflammation
6. A patient with brain metastasis may report:
 - a. A loss of memory
 - b. A change in gait
 - c. Nausea
 - d. Any of the above
7. Compression of the cauda equina will likely manifest as:

- a. Numbness in the arm
 - b. Central back pain
 - c. Incontinence
 - d. Pain in the right flank
8. Which of the following radionuclides may be used in treating metastatic bone disease?
- a. Technetium-99
 - b. Iodine-131
 - c. Strontium-89
 - d. Iodine-125
9. In spinal cord compression and superior vena cava syndrome, high doses of radiation are given in the first few treatments. The following doses are typical:
- a. 300 to 400 cGy per fraction
 - b. 180 to 200 cGy per fraction
 - c. 500 to 700 cGy per fraction
 - d. 700 to 800 cGy per fraction
10. Which one of the following oncologic emergencies is not typically managed by radiation therapy?
- a. Spinal cord compression
 - b. Superior vena cava syndrome
 - c. Painful pathologic fracture
 - d. Radiation pneumonitis
11. Which one of the following sites is the least likely site of bony metastasis?
- a. Humerus
 - b. Femur
 - c. Thoracic spine
 - d. Lumbar spine
12. Metastatic brain disease differs from primary brain malignancy in that:

- a. Metastasis is usually multifocal, and primaries are solitary at the time of diagnosis
 - b. Primary brain tumors are usually multifocal and metastatic lesions are solitary
 - c. Metastatic brain lesions are associated with longer overall survival than primary malignancy
 - d. Metastatic brain disease shows symptoms specific to vision impairments whereas primary malignancy may show various symptoms depending on location
13. When treating a patient who has spinal cord compression in the cervical spine, the best position among the following would be:
- a. Supine with the chin hyperflexed using shoulder retractors
 - b. Supine with the chin hyperextended using shoulder retractors
 - c. Prone with the chin tucked in a total body alpha cradle
 - d. Prone with the chin and forehead in a horizontal plane and arms at sides
14. A typical field size for the treatment of thoracic vertebrae 5 to 10 would be:
- a. 15×20 cm
 - b. 8×36 cm
 - c. 36×8 cm
 - d. 8×15 cm
15. A T-shaped radiation treatment field would likely be seen in the treatment of:
- a. Spinal cord compression in the upper thoracic region
 - b. Spinal cord compression in the lower lumbar or sacral region
 - c. Spinal cord compression in the lower cervical region
 - d. Spinal cord compression in the upper lumbar region
16. Single posterior fields are not usually adequate for lower lumbar or sacral bone metastasis because:
- a. This region of the spine has lordotic curvature
 - b. This region of the spine has kyphotic curvature

- c. This region of the spine has scoliotic curvature
 - d. This region of the spine is not as dense as the rest of the spine
17. A patient with brain metastasis begins to have a tonic-clonic seizure right before his treatment. The therapist should:
- a. Immediately place a hard, sugary candy on his tongue
 - b. Place a tongue depressor between his teeth
 - c. Call for assistance and begin CPR
 - d. Assist the patient to a safe position for the prevention of injury
18. A patient with SVC syndrome appears to have fainted during administration of therapy. The therapist should:
- a. Stop treatment and call a Code Blue
 - b. Stop the treatment, assess vital signs, and call physician or nurse
 - c. Continue treatment as long as the patient does not roll
 - d. Complete treatment and place patient in holding area until conscious
19. A common symptom of liver metastasis is:
- a. Jaundice
 - b. Numbness in the upper extremities
 - c. Venous distention
 - d. Cyanosis
20. Using

[Figure 8.25](#) , draw the typical whole brain radiation treatment field(s).

21. Using

[Figure 8.26](#) , identify whether the treatment portals drawn are likely for:

- a. Primary adenocarcinoma of the middle lobe
- b. Superior vena cava syndrome initial field
- c. Primary mesothelioma of the upper lobe

d. Chronic obstructive pulmonary disease

22. Regional lymphatics are not usually included in radiation fields for palliation because:

- a. Disease spread is assumed to have already taken place
- b. Lymph nodes are less responsive after metastasis
- c. Long-term side effects are too great
- d. The prognosis is better without treating regional lymphatics

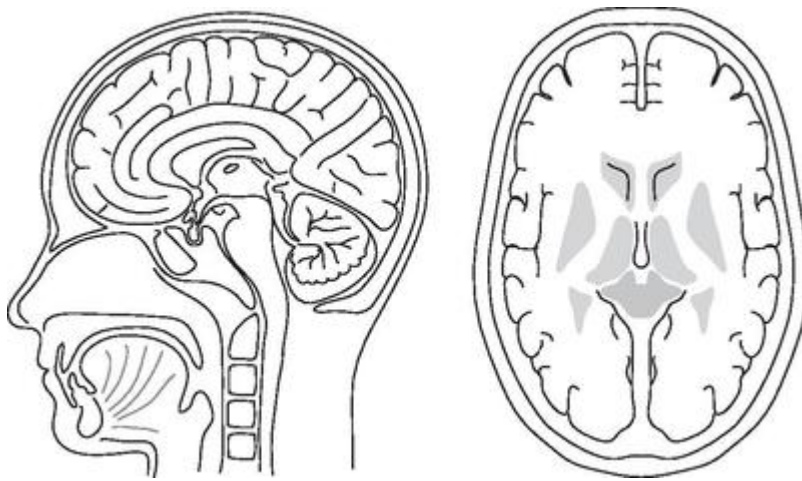


FIG. 8.25 Sagittal and axial sections brain.

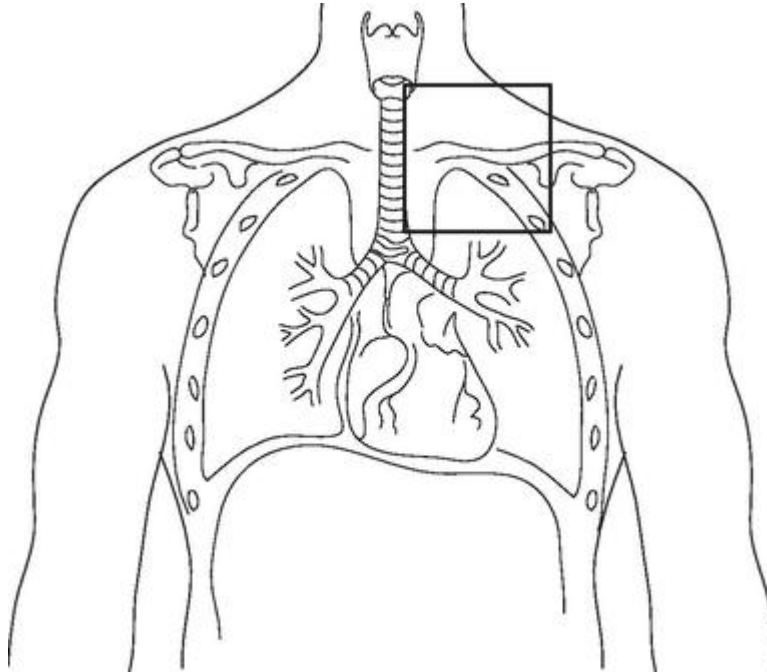


FIG. 8.26 Anterior chest with SVC box field drawn.

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Answer Key

Chapter 1

An Overview of Cancer and Management Modalities

1.

Benign tumors	Malignant tumors
Encapsulated	Unencapsulated
Rarely fatal	Potentially fatal
Little effect on the host	Substantial effect on the host
Differentiated	Differentiated–undifferentiated
Slow growth	Rapid growth
Low mitotic activity	High mitotic activity
Little tissue destruction	Potentially metastatic
Abnormal proliferation of cells	Invasive and destructive to tissue
	Abnormal proliferation of cells

2.

1. Curettage or exfoliation—
scraping of cells

2. Excisional biopsy—

complete removal of suspicious tissue and margin

3. Incisional biopsy—

cutting into and taking a portion of suspicious tissue

4. Fine needle aspiration (FNA)—

use of needle and syringe to draw out fluid from suspicious tissue

5. Core biopsy—

use of large bore needle to withdraw a section of tissue

6. Sputum cytology—

sampling of sputum

7. Washing or irrigation—

introduction of saline into a cavity and analysis of returned solution containing cells

8. Open biopsy—

surgical procedure exposing area of suspicious tissue for the visual investigation of local area

3.

Adenocarcinoma ____

E ____ **A.** malignant tumor occurring in striated muscle

Myeloma ____

D _____ B. malignant tumor occurring in bone
Leukemia _____

F _____ C. malignant tumor originating in the central
nervous system

Osteosarcoma _____

B _____ D. abnormal proliferation occurring in the
bone marrow

Rhabdomyosarcoma _____

A __ E. malignant tumor of glandular epithelium

Glioma _____

C _____ F.abnormal proliferation occurring in the
bone marrow, especially the white blood cells

4.

Phase-specific cytotoxic drugs	Phase nonspecific cytotoxic drugs
Effective on dividing cells	Effective on nondividing cells
One such class would be antimetabolites	One class would be alkylating agents
Examples: 5-FU, cytarabine, floxuridine	Examples: Nitrogen mustard, cisplatin, 6-mercaptopurine, cyclophosphamide
Toxicities include: myelosuppression,	Toxicities include: myelosuppression, kidney toxicity, nausea, anorexia

Refer to chemotherapeutic drug class and side effects table for other possible answers

5.

- Hyperplasia is an increase in the number of cells and is associated with both malignant and benign tumors; typically a

response to an acute injury

- Metaplasia is the replacement of a cell type that usually is not present and is commonly associated with malignant conditions
- Anaplasia is the loss of differentiation and is also associated with both malignant and benign conditions
- All three conditions may correct themselves without intervention

6.

c . Mortality rates are based on the number of persons per 100,000 people in a population.

7.

b . A substance that can potentially initiate cancer is known as a carcinogen.

8.

c . Pain is not a common sign of cancer. Any masses or physiological changes present without pain in the early stages of disease. Refer to the American Cancer Society's 7 warning signs acronym CAUTION.

9.

d . The TNM system evaluates the extent of disease by evaluation of the tumor, any positive nodes, and distant metastases. Grading evaluates the degree of malignancy or the status of the abnormal cells.

10.

c . Malignant conditions that originate in the lymphatic tissues are known as lymphomas.

11.

- a . Concurrent means simultaneously or at the same time. Multiple modalities are often used as management but not necessarily at the same time.

12.

- a . Alkylating agents can be toxic to the skin. Special care is required when drugs in this class need to be handled manually.

13.

- d . Tumors located in the large bowel or rectum may cause a change in bowel habits such as diarrhea, constipation, or change in the caliber of stools.

14.

- c . Adriamycin, also known as doxorubicin, is known to cause cardiac toxicity.

15.

- c . The generic TNM classification system with a designated tumor as level 3 typically classifies the tumor as Stage III. At the same time, lymph nodes are likely positive at this time. Without distant metastases, a large tumor with positive nodes is typically less than Stage IV.

16.

- a . The term carcinoma indicates tissues of epithelial origin.

17.

- c . All screenings listed are helpful in diagnosing malignancy. However, the histopathological study confirms that any abnormal growths are malignant.

18.

b .

Adeno- is the prefix for gland. Carcinoma is the base word for epithelial tissue. So, any malignant tissue of glandular epithelium would be referred to as an adenocarcinoma.

19.

d .

Rhabdo- is the prefix for striated,

myo- is the base term for muscle,

sarcoma the base term for connective tissue. As muscle is a connective tissue, a malignancy of striated muscle would be known as a rhabdomyosarcoma.

20.

b . A laparoscopy is a surgical procedure in which an incision is made in the abdomen to explore the anatomy within.

For Questions 21–26, Circle the Words That Would Correctly Complete the Sentence

21.

prostate ,

breast . Refer to the recent American Cancer Society statistics on cancer incidence in adults.

22.

carcinogenesis . Carcinogenesis describes the process from healthy state to cancerous.

23.

myelosuppression . As cytotoxic drugs affect both normal and abnormal cells, highly proliferating blood cells are most often affected causing a decrease in blood components.

24.

sporadic . Most cancers are caused by repeated mutating events rather than preexisting genetic predisposition.

25.

curettage . Scraping away cells is known as curettage.

26.

grade . Grading a tumor establishes the degree of malignancy by measuring levels of differentiation of cells.

27.

c . Bergonie and Tribondeau established that the most sensitive cells are those that rapidly divide, divide often, and will continue dividing for a long time.

28.

a . DNA synthesis occurs during the “S” phase of cellular division.

29. Mr. Jones’ T2 tumor is likely smaller in size and is less invasive to neighboring tissues than Mr. Smith’s T4 tumor.

30.

b . To palliate means to relieve symptoms.

Questions 31–36 Are True/False Corrective Statements. If the Statement Is True, Place A T on the Line. If the Statement Is False, Place an F on the Line and Correct the Statement So That It Becomes True Without Changing the Intent of the Statement

31.

F . Depending on location, benign tumors may be fatal.

32.

F . Radiation effects are local so only effects would be to the abdominal organs such as nausea, vomiting if irradiating over the stomach, or diarrhea if irradiating the colon.

33.

T

34.

F . Anti-oncogenes are known as tumor-suppressor genes.

35.

F . Older persons have the highest incidence of cancer.

36.

F . Surgery is sometimes used prophylactically; an example would be a prophylactic mastectomy for a patient with a strong family history and no definite diagnosis of cancer at the time of surgery.

37.

e . Cytotoxic drugs may cause many different side effects. Nausea, cardiac toxicity, myelosuppression, and alopecia are possible side effects and vary across drugs.

38.

d . Before the medical oncologist prescribes a certain drug or combination he refers to the cancer type, whether the tumor would

be accessible to a systemic drug, how quickly the drug will be absorbed and if there has been any evidence of resistance to the drug(s) as well as the patient's health status.

39.

c . Surgery is the first documented approach to managing cancerous growths.

40.

c . Malignant tumors tend to divide often and invade neighboring tissues and distant organs by blood invasion or direct extension. Benign lesions may have abnormal growth patterns but tend to stay local and have a unique "encapsulation" feature.

41.

b . Only a small sub-set of cytotoxic drugs can cross the blood-brain barrier. Substitute ureas can cross this barrier.

42.

c . The most common symptom of breast cancer is a painless lump.

43.

d . When looking at the incidence of cancer in a certain population, we may categories frequencies by race, sex, environment, culture, socioeconomic status, religion, and other factors.

44.

b . Lung cancers are easily detected with routine radiography.

45.

d . Beta HCG and AFP are tumor markers frequently associated with tumors of germ cell origin.

46.

- c . Beginning at age 45, men and women should have at minimum a baseline colonoscopy to check for colon polyps or malignancy.

47.

- d . Prophylactic therapy is meant to prevent the future manifestation of disease.

48.

- c . Curative therapy is intended to put the patient in remission.

Questions 49–51 Are Designed to Help You Think About It

- 49. Both clinical and laboratory testing have led to optimal chemotherapy administration delivery methods. Some methods require successive doses with static breaks. Dosages have been refined to allow normal tissue repair. Each successive dose of drug causes a fraction of cell kill, time between doses gives normal tissue time to repair. Normal cells can more readily repair injury than abnormal cells. Cell survival curves are similar in chemotherapy to cell survival curves in radiation therapy.
- 50. Good vasculature is necessary for the distribution of chemotherapy drug to the tumor and throughout the tumor's lattice or cells. The effect of radiation is enhanced with the presence of oxygen. Vasculature assures sufficient delivery of oxygen to the tumor.
- 51. When considering the right management modality for patients, we must consider the main objectives: eradicate disease and maintain a quality life. A quality life could include normal function of organs after therapy. Radiation for the above cancer types would leave the patient with a preserved cervix or uterus (sacrifice of which may lead to emotional trauma for female patients), a preserved voice without the use of a mechanical voice box, and preserved cosmesis without excessive scarring or noticeable skin defects.

52.

- a** . Fractionation or giving small amounts of dose over time allows the normal tissue time to repair from cellular damage.

53.

- c** . Chemotherapy is most often given systemically. Therefore, chemotherapy is appropriate for systemic disease.

54.

- b** . Actinomycin D belongs to the antitumor antibiotic class of chemotherapy drugs.

55.

- a** . Grading establishes the degree of differentiation of cells.

Chapter 2

Radiation Therapy Physics

1.

b . 1 mCi is equivalent to 3.7×10

⁷ dps. Conversion of dps to dpm means multiplying by 60 seconds.
Then converting mCi to Ci requires multiplying by 1000 or 10

3 .

2. Electrons are light, negatively charged particles; they can collide and interact with other particles. Protons are heavy, positively charged particles; only interact with electrons.

3.

b . Types of nuclear decay include alpha, beta negative and positive, electron capture, internal conversion, fission and fusion aftermaths.

4.

d . During ionization characteristic x-rays may be produced. If the electron comes close to the nucleus, bremsstrahlung radiation may result. Auger electrons may be emitted as a result of another electron filling an empty space left by the ejected electron.

5.

a . In the basic x-ray tube, the anode receives the streaming electrons and is known as the positive side of the tube.

6.

c . Use the activity formula $A = A_0 e^{-\lambda t}$.

$A_0 e^{-\lambda t}$

$A_0 e^{-\lambda t}$

7.

d . Use the formula Average life = $1.44 (T_{1/2})$.

8.

c . As the maximum energy increases, more of the converted energy becomes photons.

9.

b . The decay constant expresses how many atoms are lost over time.

10.

a . In elastic collisions the incoming electrons give up all of their energy. On the other hand, inelastic collisions may allow bounce back where the incoming electron shares its energy.

11.

d . The electromagnetic spectrum shows wavelengths shortening as energy increases.

12.

a . The outgoing photoelectron has an energy that is the difference between the incoming electron and the binding energy of the electron collided.

13.

a . The electromagnetic spectrum shows that the frequency increases as the energy of radiation increases.

14.

b. As radioactive cobalt transforms, gamma rays and beta negative particles are emitted.

15.

protons . Radionuclides with the same number of protons but different number of neutrons are known as

isotopes .

16.

b . Bohr's model shows the massive part of the atom being the nucleus, where protons and neutrons reside.

17.

d . Loss of an electron leaves an imbalance to the atom. Positive charge would then be greater than negative charges.

18.

a. alpha decay b. beta positive

19.

a . Electrons have a negative charge, protons positive charge. When equal, they neutralize the atom.

20.

d . During pair production, two particles of equal energies $-.511 \text{ MeV}$ are emitted. The incoming photon must have at least that combined energy.

21.

a . Activity is expressed in units of Curie or Becquerel. The Becquerel is the SI unit.

22.

b . Photoelectric effect occurs when a photon interacts with a tightly bound electron. Its energy must be equal to or greater than the binding energy.

23.

a . Characteristic radiation is emitted when electrons switch places in the shells of the atom.

24.

c . The farther away from the nucleus, the lower the binding energy.

25.

a . Isomers are the same element but in an excited state.

26.

b . Electromagnetic radiations have the potential to travel at the same speed, they have virtually no mass and carry no charge.

27.

c . Isobars have the same mass.

28.

d . The number of electrons per gram has been computed using helium as a reference. For helium 3×10

²³ is the number of electrons per gram. Tissue in the question has not been specified as soft tissue or bone, both having a different atomic weight than helium.

29.

b . 24 days have elapsed. This would be a three half-life period for this isotope. Three half-lives would leave about 12.5% of the initial activity. 80 mCi (12.5%) = 10 mCi. The activity formula could also be used.

30.

d . The half-life of cobalt is 5.26 years. 10 years is approximately two half-lives, leaving about 25% of the original atoms.

31.

d . The Angstrom is the unit of measure for the wavelength.

32.

c . C in Einstein's equation is the speed or velocity of light. Option D has incorrect time units.

33.

c . Photoelectric effect often occurs with an electron tightly bound and in the inner shells of the atom.

34.

c . All radiations in the electromagnetic spectrum have the same speed/velocity regardless of wavelength or frequency.

35.

a . Bragg peak shows maximum ionization at the end of the range for heavy, high LET particles.

36.

b . Isotopes have the same number of protons and different neutrons. The number of protons and electrons is equal in a neutral atom.

37.

c . The average life is given by the formula: $T_a = 1.44 (T_{1/2})$. So, the half-life is less than the average life. The average life comes close to what may be thought of as the life span for a radioactive nuclide.

38.

b . The symbol in the activity formula is the decay constant and expresses the constant fraction of atoms decaying in a certain amount of time.

39.

b . Secular equilibrium occurs when the parent nuclide has a longer half-life than a daughter product.

40.

a . Ultrasound is not electromagnetic radiation.

41.

d . The electron's mass is low compared to its kinetic energy so it must be traveling at about light speed. The alpha particle has the greatest total energy.

42.

d . Protons, neutrons, and nucleons have a mass about 1800 times that of an electron.

43.

c . When an atom is ionized, an electron is ejected from the atom.

44.

c . Unstable radioactive nuclides have excess energy in their nuclei.
The nucleus achieves stability by redistributing energy between the nucleons.

45.

b . The total attenuation coefficient represents the sum of all possible interactions.

46.

b . Energy loss is proportional to the square of particle charge and inversely proportional to the square of its velocity.

47.

c . This maximum energy loss is known as Bragg peak.

48.

c . Electrons have low mass and therefore deposit energy as they move quickly through the medium.

49.

c . The energy transferred is not enough to eject the electron. The incoming electron does not have an energy higher than the binding energy of the orbiting electron.

50.

b . The strong electromagnetic field of the nucleus decelerates the electron as it approaches. In the deceleration, some of the energy is lost in the form of an x-ray photon called bremsstrahlung.

51.

d . The electromagnetic spectrum shows x-rays having energy of at least 124 eV.

52.

a . Alpha particles have a positive charge.

53.

a . Radiation is energy in motion.

54.

d . The formulas show the element iodine, which has the same chemical properties. The mass number is different, and the z number is the same at 53 protons so the number of neutrons is different.

55.

b . Inverse square law says the intensity of radiation is inversely proportional to distance by a square of distance change.

Chapter 3

Radiation Biology

1.

c . TD 5/5 indicates 5% chance of injury within 5 years following exposure.

2.

a . LD 50/30 is the lethal dose to 50% of the population in 30 days following exposure.

3.

c . The TD 5/5 for the whole kidney is about 23 Gy. Lower volumes of the kidney would increase the tolerance dose up to 50 Gy.

4.

c . TD 5/5 for the whole brain is 45 Gy. Lower the volume of brain would increase the tolerance up to 60 Gy.

5.

a . Oxygen enhances the sensitivity to radiation by increasing the possibility of free radical production.

6.

b . The “S” phase is most resistant to radiation. The “S” phase is the stage of DNA synthesis.

7.

- d .** The prodromal syndrome occurs immediately after a large acute radiation exposure. Nausea, vomiting, diarrhea, and anorexia are the symptoms of the prodromal stage of radiation sickness.

8.

e

- . Cells that are highly mitotic, undifferentiated, and have a long dividing life are most responsive to radiation according to Bergonie and Tribondeau.

Complete the Table to Show Cellular Sensitivity to Radiation

9.

Mitotic rate	Differentiation	Sensitivity	Examples
High	Undifferentiated	High	Blood cells, germ cells
Moderate	Moderate differentiation	Intermediate	Intestinal cells, skin
Low	Moderate differentiation	Low	Liver, mature bone
Low to none	Well differentiated	Low	Nerves, adult brain

10.

- b .** Protracted or fractionated doses allow for the repair of normal tissue.

11.

- b .** The cumulative effect of radiation dose is the decreased ability for tissue to recover. This is desirable in cancerous tissue and is demonstrated by increased severity of normal tissue injury as doses accumulate. Although normal tissue can recover more readily than cancerous tissue, more dose means longer delay in recovery.

12.

- b .** Threshold dose-response curves indicate that there is no overt response by exposed tissue below certain doses.

13.

- b .** Hematopoietic syndrome is caused by reduced blood cells. Leukocytes are most sensitive of blood cells and are the first to show decrease leaving victims feeling fatigued and vulnerable to deadly infections.

14.

- a .** LET or linear energy transfer is the energy deposited in an absorber as radiation passes through.

15.

- b .** Compared to the others, the epithelial cells in the alimentary tract have a longer mitotic future and divide more often than mature central nervous and connective tissues found in muscle and cardiovascular systems.

16.

- b .** The four Rs include reoxygenation, repopulation, redistribution, and repair.

17.

- c .** At this dose range, a decrease in peripheral blood cells and depression of the bone marrow is likely to occur.

18.

- d .** The development of radiation-induced lung cancer would occur 10–20 years following exposure. A stochastic effect is one that occurs

much later after initial exposure.

19.

a . The D

o value on the cell survival curve most accurately represents the sensitivity of certain cells to radiation. The smaller the D

o , the more radiosensitive.

20.

b . The single whole-body dose of 5000 cGy or greater, would likely cause the exposed to suffer from the CNS syndrome.

21.

a . Single whole-body dose of about 10 Gy, or 1000 cGy would cause bone marrow suppression. Blood transfusion may rescue, but without this intervention death would likely occur within 10 days.

22.

d . Normal tissue may recover from radiation exposure by regeneration of cells or repair of cellular damage.

23.

c . Beyond the tolerance of the spinal cord, there would likely be swelling and cell death.

Circle the Correct Word Questions 24–28

24.

lower . TD 5/5 is the dose for 5% incidence of injury in 5 years. TD 50/5 is the dose for 50% incidence of injury in 5 years. The larger

dose would cause more of the exposed population to experience the selected effect.

25.

lower . Tolerance for immature cells that are highly mitotic is lower than for mature cells with little mitotic activity.

26.

lower . Giving radiation in single doses lowers the tolerance of tissue because there is no time for cellular repair and repopulation.

27.

fistula . Fistula is a possible endpoint for the colon exposed to fractionated doses of radiation up to 55 Gy.

28.

lower . Germ cells in the ovary are highly mitotic making these cells more sensitive to radiation and manifesting a response sooner than lung tissue having lower mitotic activity and sensitivity to radiation.

29.

c . The lens of the eye shows an adverse late effect at doses as low as 500 cGy.

30.

a . The lens is more sensitive to radiation than the skin. Early effects will be seen at lower doses.

31.

d . Radiation protection standards are in place to prevent radiation-induced responses, both acute and latent.

32.

d . The onset dose for wet desquamation using standard fractionation is 40 Gy.

33.

a . Somatic effects are limited to the individual exposed and may be acute or latent.

Think About It Questions 34–38

34. Head and neck cancers originating in the mucosa have high mitotic activity and short intervals between mitotic events.

Hyperfractionation attempts to delay mitotic activity and synchronize cells to most sensitive phases of division to increase cell kill. The spleen stores blood cells that are very radiosensitive. Hypofractionation provides the opportunity to cause cell death in any malignant cells infiltrating the organ and at the same time providing time for the sensitive normal cells to repair.

35. The physician and physicist/dosimetrist should be informed immediately. This is an ideal situation for use of the BED formula to determine what dose and fractionation scheme would lead to the same biological effect as the intended fractionation scheme.

36. This is not a feasible plan. Radioprotectors should be given prior to radiation within an hour or two.

37. This is not a feasible plan. Multiple fractions need to have an interval of 6 hours to allow for normal cellular repair. The interval should consider the understood growth and dividing behavior of the cells to be irradiated.

38. The 3-week break gives the normal and abnormal cells adequate time to repopulate. An adjustment to his total dose and fraction size may need to be made using the BED formula due to his prolonged absence. The original 6 weeks may need to be altered.

39.

d . There are four signs of injury, including redness, swelling, heat, and pain.

40.

b . The more tissue irradiated, the lower the tolerance.

41.

b . Lethal damage leads to cell death and cannot be repaired.

42.

d . Cellular division begins in the M phase, then goes through G1, S, G2, and M again.

43.

a . The cell survival curve for human cells usually has a shoulder region and a straight-line portion.

44.

c . Higher LET radiations have mass and charge and therefore cause greater radiobiological effects.

45.

d . A linear curve will show the changes in factors proportional.

46.

d . The principal target in the human cell is DNA.

47.

b . The greatest amount of the cell is about 85% water.

48.

c . The extrapolation number is denoted by the “n” or the measure of the shoulder on a cell survival curve.

49.

b . Increasing the protraction, or period over which radiation is given, decreases the effects on the cell.

Chapter 4

Radiation Protection and Safety

1.

d . According to the current dose limits, the hand of the pregnant therapist has the highest annual dose limit.

2.

b . Cumulative exposure is given by $10 \text{ mSv} \times \text{age in years}$.

3.

b . One disadvantage to film badge monitoring is that there's time required for badge to be sent to an agency for reading.

4.

b . For the entire gestation period, exposure should not exceed 0.5 rem or 5 mSv.

5.

c . The cutie pie is not normally used to monitor personnel. Rather this ionization chamber is appropriately used for area surveys.

6.

b . The Roentgen measures exposure or ionization events in the air.

7.

d . Excessive heat, submersion in fluids, or damage to the light-tight wrapper can cause damage to the film or unnecessary fogging,

affecting accurate reading of the badge.

8.

a . The quality factor, also known as radiation weighting factor, parallels the linear energy transfer of the radiation type. Radiations with high LET have higher quality factors or radiation weighting factors.

9.

c . Wrappings and storage containers for radioactive materials should bear the sign Caution Radioactive material.

10.

NRC . Nuclear Regulatory Commission (NRC). The NRC recommends radiation dose limits.

11.

150 mSv or 15 rem . According to most recent NRC recommendations as of this writing.

12.

500 mSv . According to most recent NRC recommendations as of this writing.

13.

use factor . The use factor is the fraction of time the beam is aimed at a particular wall or ceiling.

14.

200 mrem/year . Radon contributes about 200 mrem/year to internal radiation exposure.

Think About It Questions 15–20

15a. Answer: 30 mR

Step 1: 6 minutes = 0.1 hours

Step 2: 0.1 hours (300 mR/hr) = 30 mR

15b. Answer: 67.5 mR

Step 1: Apply the inverse square law

Step 2: 30 mR (3/2)

$$^2 = 67.5 \text{ mR}$$

16. Answer: 5.7 TVLs

Step 1: 8 hr/day $\times$ 5 days/wk = 40 hr/wk = 2400 min/wk

Step 2: Dose at office; Inverse square law = 0.5 rem/min
(40/20)

$$^2 = 2 \text{ rem/min or } 2000 \text{ mrem/min}$$

Step 3: 2000 mrem/min $\times$ 2400 min/wk = 4,800,000
mrem/wk

Step 4: 10 mrem/4,800,000 mrem = 0.0002% or 0.000002;

Step 5: 0.1

$$^x = 0.000002$$

Step 6: Log (0.1

$$^x) = \text{Log } (0.000002)$$

Step 7: $-1x = -5.6989$

$$x = 5.6989$$

17a. Answer: 31,500 cGy/wk or 315 Gy/wk

Step 1: Apply workload formula

Step 2: $35 \text{ patients/day} \times 5 \text{ days/wk} \times 4 \text{ fields/patient} \times 45 \text{ cGy/field} = 31,500 \text{ cGy/wk}$ or 315 Gy/wk

17b. Answer: 0.0000126

Step 1: Apply the barrier transmission factor formula

Step 2: $1 \text{ Gy} = 1 \text{ Sv}$ (gamma and x-rays), $1 \text{ mGy} = 1 \text{ mSv}$

Step 3: $B = 1 \text{ mGy/wk}$ (1 meter)

$$1 / 315,000 \text{ mGy} (0.25) (1) = 0.0000126$$

18. Answer: 6.25%

Step 1: Ask how many half value layers of material is 4.4

Step 2: $4.4 / 1.1 = 4 \text{ HVLs}$

Step 3: $4 \text{ HVLs} = 0.5$

$$0.5^4 = 0.0625 \text{ or } 6.25\%$$

19. Crystals in the emulsion on the film badge are transformed, film is processed, and density is read by a densitometer to determine dose. Lithium fluoride crystals trap electrons when exposed in the TLD. When the TLD is heated, trapped electrons are released in the form of light. Light photons are proportional to absorbed dose.

20. Ion chambers measure ionization of air, or migration of charges between charged plates by the liberation of electrons. The Fricke dosimeter relies on a chemical reaction. Ferrous sulfate, Fe^{2+}

Fe^{2+} is oxidized when exposed to radiation and becomes Fe^{3+}

ions.

21.

c . Dose equivalence is measured in the traditional unit-rem or system international unit-Sievert.

True/False Corrective Questions 22–24

22.

F Exposure rate from a patient following insertion should be measured with an ion chamber.

23.

T Two HVLs reduce transmission to 25%. 0.05

$^2 = 0.25$.

24.

T Barrier protection is reduced when there is a beam stopper on the unit as found in Cobalt rotational units.

25.

d . The Food and Drug Administration regulates the use of radiation producing machines.

26.

d . Although there is a latent period for the development of cataracts, the latent period is far shorter than the typical period of 5–20 years for stochastic effects.

27.

b . The GM counter measures the presence of radiation and would be useful in locating a misplaced radioactive source.

28.

b . Radon contributes about $2/3$ of total background radiation exposure.

29.

d . Gray is the system international unit for absorbed dose.

Write Letter C, T, I Questions 30–35

30.

C . Cosmic radiation is a result of interactions in upper atmosphere.

31.

T . Terrestrial is defined as pertaining to the earth.

32.

C . Higher altitudes bring exposure to interactions in the upper atmosphere closer.

33.

I . Potassium, carbon, hydrogen, and strontium are some contributors to internal radiation.

34.

I . There is no shielding for internal sources of radiation.

35.

T . Some geographic locations have greater concentrations of natural radioactive materials in the soil and rock.

36.

b . The main types of background radiation are cosmic, terrestrial, and internal.

37.

d . Terrestrial radiation comes from the soil and rock and can vary based on geographic location.

38.

b . TLD has properties most like living tissue and measures absorbed dose.

39.

d . Transfer, burning, or burial are all appropriate for the disposing of depleted radioactive sources.

40.

a . Hot labs containing solid radioactive sources should have a sign that reads Caution Radioactive Material.

41.

a . The workload is an expression of beam-on time.

42.

a . Concrete is less dense than lead or iron and therefore would have a lower attenuation coefficient requiring more material for adequate limitation of exposure.

43.

d . During HDR procedures, radioactive sources are outside of protective containers. To maintain compliance with the ALARA principle, HDR procedures should be conducted in shielded areas such as the simulator or linear accelerator vault.

44.

c . Hydrogen-3 is a gas always present in our bodies. Hydrogen-3 carries charge and releases energy in the form of low radiation.

45.

c . Radioactive sources should be transported in shielding containers also known as “pigs.”

46.

d . Personnel caring for a patient while radioactive sources are implanted should plan to work as efficiently and quickly as possible to limit exposure to any low dose secondary radiation. Standard precautions are always in order.

47.

a . $0.5 \text{ Sv} = 0.5 \text{ Gy}$

Step 1: Use the dose equivalent formula

Step 2: $\text{Sv} = \text{Gray} \times \text{Quality factor}$

Step 3: Quality factor for gamma radiation is 1

Step 4: $0.5 \text{ Sv} = x (1)$

48.

d .

Use the formula $\text{HVL} = 0.693/\mu$

Step 1: $32 \text{ mm} = 0.693/\mu$

Step 2: $32 (\mu) = 0.693$

Step 3: $\mu = 0.0216$

49.

d . 1 HVL reduces transmission to 50%

Use the formula 0.5

$x = 0.02$

Step 1: $\log 0.5$

$$x = \log 0.02$$

$$\text{Step 2: } -0.301x = -1.699$$

$$\text{Step 3: } x = 5.64 \text{ HVLs}$$

Think About It Questions 50–51

50a. Answer: 0.063 mm

–1

$$\text{Step 1: } 11 \text{ mm} = 0.693/\mu$$

$$\text{Step 2: } \mu = 0.063 \text{ mm}$$

–1

50b.

Answer: 55.6 mm lead

Step 1: Use the formulas $I/I_0 = \text{transmission}$ and $I = I_0 e$

$$-\mu(x)$$

Step 2: I/I_0

$$0.03$$

Step 3: $0.03 = e$

$$-0.063(x)$$

$$\ln 0.03 = \ln e$$

$$-0.063(x)$$

$$-3.506 = -0.063(x)$$

$$x = 55.6 \text{ mm lead}$$

51a.

Answer: 7.8 cm

Step 1: Use the formula $HVL = 0.693/\mu$

Step 2: $0.693/HVL = 0.089 = 7.8 \text{ cm}$

51b.

Answer: 43.9 cm

Step 1: Use the formulas $I/I_0 = \text{transmission}$ and $I = I_0 e$

$-\mu(x)$

Step 2: I/I_0

$I_0 = 0.02$

Step 3: $0.02 = e$

$-0.089(x)$

$\ln 0.02 = \ln e$

$-0.089(x)$

$-3.91 = -0.089(x)$

$x = 43.9 \text{ cm}$

Chapter 5

Radiation Therapy Equipment and Quality Assurance

1.
 - b** . The linear accelerator target needs to have a high melting point and high atomic number to accommodate the high-energy electron stream directed toward it.
2.
 - c** . Electrons are burned off the electron gun by thermionic emission.
3.
 - a** . Linear accelerators use transmission targets positioned perpendicular to the stream of electrons, allowing transmission of converted energy on the opposite side of the target. Diagnostic x-ray tubes use reflection targets allowing converted energy to be reflected at an angle away from the target.
4.
 - c** . The cyclotron accelerates heavy particles like deuterons, neutrons, and protons.
5.
 - d** . The flattening filter evenly distributes the energy of the photon beam. Without the flattening filter, the photon beam has concentrated energy toward the central axis.
6. The ion chamber monitors dose rate and field symmetry.

7. The magnetron and klystron produce microwaves for acceleration of electrons in the linear accelerator. The klystron amplifies microwaves in the higher power accelerators.

Think About Questions 8–9

8. Using bolus materials on/in an irregular anatomical surface losing the skin sparing effect of high-energy photon and electron beams. Standard wedges and custom compensators are positioned within the beam at established distances from the patient's skin surface, therefore preserving the skin-sparing feature of the therapy beam while correcting for irregular surface contour.

9. Radium is expensive to harvest from the earth and has a carcinogenic daughter product—radon gas.

10.

- d** . Strontium-89 is available as an unsealed source and is injectable for diffuse metastatic disease.

11.

- c** . Phosphorus-32 emits beta radiation strictly. Cesium, cobalt, and iodine emit gamma radiation.

12.

- a** . The field light represents the area of radiation.

13.

- b** . The scattering foil is inserted in the path of electrons when the accelerator is operating in electron mode. The foil scatters electrons across a broad area.

14.

a . The klystron or magnetron is a source of microwaves in the linear accelerator.

15.

c . The cyclotron can produce heavy particles like protons, neutrons, and deuterons.

16.

b . Positioning devices help to achieve the desired patient position for accurate treatment delivery.

17.

a . Superficial therapy machines operated in the range of 50–150 kV.

18.

a . Long cylinders loaded with isotopes may be positioned in the vagina to deliver dose to the vaginal cavity. Applicators such as Heyman's capsules or tandem and ovoids would deliver dose to endometrium and pelvis side wall. Therapy to the vulva could be delivered using teletherapy beams.

19.

b . Acceleration of electrons occurs along a linear path in the linear accelerator.

Matching Questions 20–23

20.

f

21.

b

22.

e

23.

d

24.

b . Heyman's capsule looks like a small tampon and is inserted into the uterine cavity for delivery dose to the endometrium.

25.

b . Fletcher's suite consists of tandem and ovoids loaded with low output sources into the female pelvis. This is an example of intracavitary brachytherapy. Dose is delivered over a few days.

26.

d . The BAT system is a bedside ultrasound unit used for daily target localization.

27.

a and c . The light field indicates the field size and is relied upon as an indicator of where the radiation field is projected.

28.

b and c . The performance of the linear accelerator relies on current, which is not static and may fluctuate periodically. As equipment wears, the auxiliary and primary power sources can wear down and fluctuate in output therefore affecting the output of the accelerator.

29.

c . The optical distance indicator (ODI) gives the distance from the source to the patient's skin.

30.

b . Lasers should agree with the ODI within 2 mm at isocenter.

31.

a . Constancy of output should be verified daily for both photon and electron beams on the linear accelerator.

32.

b . Output values taken during commissioning and acceptance testing should be within 3% of benchmark values supplied by the manufacturer and/or identical systems.

33.

a and b . Symmetry and flatness may be checked using film or beam profilers. Densitometers need to be used to evaluate the film exposed if this method is chosen.

34.

b . Field flatness for the photon beam in the linac is recommended to be within 2% across 80% of the beam.

35.

b . Indicated scan and couch position in the vertical aspect, especially, are recommended to be within 2 mm of actual.

36.

d . Total overhaul, that is, a review of all technical aspects, should be performed each year.

37.

a . All sources should be checked for leaks at minimum at the time of receipt, then periodically depending on the half-life of the source.

38.

c . The exact position of sources should be checked using radiographic imaging.

39.

c and d . Sources should be calibrated before use and then these measurements must be documented and traceable to an accredited calibration laboratory.

40.

d . In the brachytherapy room, a survey meter must be available before and after the procedure, a temporary storage container for any unused sources, and a cutter and long-handled tongs in case sources need to be handled manually.

41.

a . light and radiation field coincidence should be within 2 mm or within 1% on a side.

42.

b . Lasers should be within 2 mm of isocenter on simulators.

43. K

44. C

45. L, M

46. A

47. B

48. D

- 49. E
- 50. F
- 51. G
- 52. H
- 53. H, F, G
- 54. L
- 55. B
- 56. C, M
- 57.

c . Split-field testing for longitudinal displacement can be achieved by exposing film allowing one half of the field to be set at a set collimator angle and then rotating 180 degrees and exposing the other half of the field.

58.

b . A spirit level can be used to check the accuracy of gantry digital read-outs. It's acceptable to check readouts at 45-degree increments.

59.

a . Light field and radiation coincidence can be checked using radiographic film with metallic markers at the field borders to verify against radiation exposed area on the film.

60.

d . Recommendation is that the door interlock be checked daily.

61.

a . The back-up timer, radiation off switch, door interlock, and emergency off switch all put the operator in control of dose delivery. Override switches help avoid unnecessary exposure and

indicate the potential exceeding of previously set parameters.
Collision rings help prevent patient injury or damage to equipment.

62.

- b .** During megavoltage therapy, patients should be monitored using closed circuit intercommunication systems.

63.

- b .** Acceptance testing is performed to assure that the manufacturer's specifications on machine performed is actual.

64.

- b .** Dose rate constancy should be verified daily and also monthly. The other quality checks are recommended to be performed monthly.

65.

- 1 degree .** AAPM recommends that gantry and collimator indicators are accurate within 1 degree.

66.

- +3% .** Field flatness across the central 80% of the beam should not vary outside of 3%.

67.

- c .** Flatness of the beam is influenced by correct position of the flattening filter or target and fluctuations in current. Mirror angulation influences light field and radiation agreement.

68.

- b .** Limit switches protect mechanical gears and bearings in the gantry and collimators. If the gantry rotates beyond the end point, the limit switch for the gantry is not fully functional.

69.

- d .** The mechanical distance indicator or pointer is used to verify the accuracy of the ODI and to verify the correct alignment and agreement of lasers.

70.

- b .** The mirror and bulb assembly must be in perfect geometrical relationship to accurately represent the radiation beam. Any adjustments or repairs to the system require quality checking of congruence.

71.

- b .** Gold has a half-life of 2.7 days, cesium 30 years, iridium 74 days, and radon 3.8 days.

72.

- c .** Low energy x-ray machines would use filters to harden the beam, filtering out low energy radiation. Increasing the filtration would sift out more soft radiation thereby increasing the overall quality and penetrating power of the beam.

True/False Questions 73–75

73.

- F.** The effective energy of the photon beam is not influenced by how long the beam is on or by the current (number of electrons coming across the tube). Effective energy is influenced by increasing the potential across the tube (voltage and supplemental energy boosts from alternating frequency waves).

74.

F. The effective energy of the photon beam is not influenced by how long the beam is on or by the current (number of electrons coming across the tube). Effective energy is influenced by increasing the potential across the tube (voltage and supplemental energy boosts from alternating frequency waves).

75.

T. The effective energy of the photon beam is not influenced by how long the beam is on or by the current (number of electrons coming across the tube). Effective energy is influenced by increasing the potential across the tube (voltage and supplemental energy boosts from alternating frequency waves).

76.

a . OBI is an acronym for on board imaging devices. OBI devices can take on many forms from simple detectors and video cameras to complexed cone beam CT attachments.

77.

a . The cyclotron uses two D-shaped cavities across which heavy particles are accelerated.

78.

d . The Klystron is in the drive stand or in the modulator cabinet.

Chapter 6

Radiation Therapy Treatment Planning

1.

b . Several terms are used for the removable grids that show the crosshairs on a port film. They include BB tray, fiducial tray, graticule, and reticule.

2.

focal spot, point . SAD is measured from the source to a reference point in space around which the gantry and PSA rotate.

3.

c . The most commonly used database used for treatment planning is CT.

4.

d . MRI, PET, CT, and US can be fused and used for therapy treatment planning. PET and CT fusion studies are used often.

5.

T . xyz coordinates work well for target localization. The patient can be moved and tracked in any direction to a specific distance.

6. Thinner CT slices increase DRR resolution because of additional detail to reconstruct from.

7.

1. Photos
2. Detailed description of set up
3. Good marks on the patient
4. Well-made immobilization devices
5. Appropriate, well-fitting positioning aids

8.

a . The CT simulator top should be flat so that the patient's anatomy responds the same when on the flat PSA in the treatment room.

9.

b . Ballpoint pen is not an appropriate tool to use for patient skin markings.

10.

F . Unlike conventional radiation therapy, each IMRT port or gantry stop contains a number of beamlets. In most cases, the beamlets are so numerous that filming each one would not be feasible. Instead, QA is chosen to compare output and fluence from a phantom onto which the plan is run to the output and fluence provided by the treatment planning computer. Usually, orthogonal films are taken to verify isocenter placement.

11.

knee support/sponge . A support that slightly elevates the knees takes pressure off the lower back and decreases the lordotic curve in the lumbar spine.

12.

d . Allowing the breast to find its natural position offers excellent reproducibility and treatment planning conformality.

13.

d . Percent depth dose is used for nonisocentric or SSD treatment techniques and represents the fraction of dose at depth.

14.

b . When beam-shaping devices are used, the effective square should be used to find the percent depth dose, TMR, or TAR.

15.

F . Mayneord's formula is used to change a standard %DD at a standard SSD to a %DD that can be used at a nonstandard SSD. The formula is based on the inverse square principle.

16.

Answers:Pros— More clearance between the gantry and patient

Larger field size can be achieved

Less collimator scatter to the patient

Cons—Patient must be moved between each gantry position

Rotational therapy, IMRT, and conformal therapy would not be feasible

17. Answers:

Patient does not have to be moved between gantry angles

Set up errors are minimized

18.

d . Multileaf collimators made intensity modulated radiation therapy a possibility.

19.

b . Sterling's formula is used to determine the equivalent square.

20.

a, b, c . Extended SSD technique requires the use of Mayneord's factor (factor goes in the denominator or may convert the old %DD for the new field size) and inverse square.

21. The therapist places radiopaque wires on the patient's skin.

22.

b . Multiple fields increase the integral dose. An increase in dose is not an advantage to the patient.

23.

Lung tumor __6__
Nasopharynx __6__
Prostate _____18____
Cervix _____18____
Pancreas _____18____
Breast _____6____
Upper arm sarcoma _6__

Thinner anatomical areas or where low-density tissues such as lung tissue are optimally treated with lower energy beams. Whereas thicker areas with deeply positioned targets require the use of a higher energy beam.

24.

dosimetrically . Field sizes around a target area should be large enough to give $\pm 5\%$ of the prescribed dose to the target.

25.

b . Expediting treatment time should not be a primary consideration for determining gantry positions.

26.

c and d . Dmax is the point of peak dose in tissue. Peak dose occurs where electronic equilibrium occurs.

27.

PTV
GTV
CTV

28.

false . Wedges filter out weak photons from polyenergetic beams. The average energy of a polyenergetic beam increases (hardens) after passing through a wedge.

29.

1. Brings Dmax closer to the surface
2. Fills in deficits so that the dose distribution is more homogenous

30.

d . TD 5/5 is the dose that will likely cause complications in 5% of the population exposed after 5 years.

Think About Questions 31–39

31.

b and c . Refer to

Figure 6.12 . Using the SSD technique, less dose is absorbed as the depth increases. Therefore, any tissues before the target will receive more dose and tissues beyond the target will receive less dose. Refer to an isodose chart.

32.

a and d . Refer to

Figure 6.12 . If the beam energy was increased, the same phenomenon would be true. However, comparing low energy to high energy, the high-energy beam spares more tissues near the surface and deposits more at depth.

33.

b . A high-energy x-ray beam such as the energies used in therapy will have maximum dose deposit below the surface. The higher the energy, the deeper the point of electronic equilibrium.

34.

6; 18; 18 . Higher energy beams have greater penetration and deposit more dose at depth.

35.

Direct proportion: 200: 0.65 as x: 0.85, x = 262 cGy

OR

Applied dose = TD/%DD; 200/0.65 = 307.6 cGy then....

Applied dose x %DD = TD; 307.6 cGy x 0.85 = 262 cGy

36. Use the formula:

Dmax dose = TD/%DD

150 cGy/0.60 = 250 cGy

37.

2 . An electron beam loses about 2 MeV of energy per centimeter of tissue.

38.

c . An advantage of electron arc therapy is that Dmax is moved further away from the surface.

39.

1. Safe containment of the isotope
2. Filters out alpha, beta, and lower energy gamma radiation

40.

interstitial . Seeds are placed within the prostate tissue.

41.

intraluminal . Source is placed within the lumen created by a balloon.

42.

interstitial . Ribbons are threaded and secured into the tissues of the tongue.

43.

d . When more than two planes are used, the planes create a three-dimensional shape conducive to a volume as opposed to an area as a 1- or 2-plane implant provides.

44. Activity (decay constant)/distance

2

45.

—

D __

Patterson —

Parker/Manchester

—

B __

Quimby

—

A __

Memorial

—

C __

Paris

46.

b . Reference points used in gynecologic brachytherapy are points A and B. Though points B, rectum and bladder doses are evaluated, point A determines the implant duration. Point A is located 2 cm superior and 2 cm lateral of the cervical os.

47.

helium ;

positive

48.

negatron

49.

beta

50. A magnet could be used. Gamma particles would not react, but the charged alpha and beta particles would. The alpha particle has a positive charge but is heavier than the beta particle. The beta particle would be most reactive to the magnet.

51. Possible answers:

1. Cobalt
2. Cesium
3. Palladium
4. Gold
5. Iridium
6. Iodine
7. Phosphorus
8. Ytterbium
9. Strontium
10. Samarium

52.

c . Ultrasound is most often used for prostate implant treatment planning because of the ease of visualizing the prostate slice by slice during the procedure.

53.

20

54.

0.5 ;

2.0

55.

b . A change in the field size will change the output. The change should be documented and submitted for recalculation of MU.

56.

a . Too many fractions to the preliminary field have changed the absorbed dose to all other tissues besides the GTV. Actual dose to other tissues needs to be considered before proceeding to the next phase of the patient's treatment plan.

57.

- c** . Patient measurements must be considered before any dose is administered. Monitor units cannot be calculated without knowing the location of isocenter at minimum.

58.

- c** . Likely during the 3-week break, the patient has lost marks. Changes in weight and anatomical dimensions may have also changed. The 3-week break has allowed some tissue healing and possibly regrowth of cancerous cells. BED calculations should be performed so that adjustments to fractions or total dose can be performed.

59.

- a and b** . The wedge angle is determined by the tilt of the 50% isodose line in low-energy beams such as Cobalt. The dose line at a depth of 10 cm is used to name the wedge angle for higher energy beams used most commonly in therapy today.

60.

- d** . The thoracic spine is positioned near the posterior aspect of the body. In patients of normal body habitus, the depth for the upper thoracic vertebral bodies is about 5–6 cm deep. A single posterior low-energy beam is sufficient.

61.

- a** . Whole breast irradiation is best delivered using tangential fields. The N1 staging classification likely indicates positive disease in the axillary region which is easily covered using tangential fields. A boost to the tumor bed may be elected to decrease the likelihood of recurrent disease.

62.

c . A right temporal tumor is a challenge to treat due to the proximity to the lens. A right-sided wedged pair will spare normal brain. Using the vertex field instead of an anterior field will eliminate concern for exceeding tolerance of the lens.

63.

b . Wedges are used to compensate for missing tissue and/or to shift dose lines. The aspect of the pelvis through which beams would enter for treatment of the rectum is irregular in contour (rounded) and will likely require the use of wedges positioned appropriately for compensation for missing tissue—heels up toward the posterior aspect.

64.

Yes . The plan directive is met. The DVH demonstrates 20% of the left lung receives 35 Gy. Just 15% of the left lung receives 40 Gy.

65.

d . Treating the neck often requires lateral beams. Shoulder retractors push the shoulders down out of the potential path of those lateral ports to the neck.

66.

d . Optimal hinge angle may be found by using the formula:
Hinge = $180 - 2 (\text{wedge})$.

67.

b . The separation angle between two beams is known as the hinge angle.

68.

- b .** A good starting point for figuring appropriate wedge size is to first consider the hinge angle between beams and then apply the formula: $\text{Hinge} = 180 - 2 (\text{wedge})$.

69.

- b .** Using Sterling's formula, the equivalent square for a 15×6 cm area is 8.6 cm.

70.

- a .** Two adjacent spine fields would have dimensions showing the longest sides as lengths. The two fields would be matched along these lengths. Apply the skin gap formula to compute the skin surface space between the two fields that would allow field overlap at the specified depth: $\frac{1}{2} \text{Length \#1} (d/\text{SSD}) + \frac{1}{2} \text{Length \#2} (d/\text{SSD})$.

71.

- b .** The plan data sheet indicates the use of asymmetric jaws. The field width would be the sum of X1 and X2 jaws and the field length would be the sum of the Y1 and Y2 jaws.

72.

- a .** The gantry angle for the LPO treatment field is shown as 100.0 degrees.

73.

- a .** Using the x, y, z coordinate system referenced on an axial view, the data sheet indicates a shift to the patient's right of 1.0 cm. See data labeled Isocenter X on the sheet. On axial image, the patient's right is on the negative side of the x plane.

74.

d . Using the x, y, z coordinate system referenced on a sagittal view, the data sheet indicates a shift posterior to the original isocenter. See data labeled Isocenter Z on the sheet. On sagittal image, the patient's posterior surface is on the negative side of the z plane.

75.

c . Using the rules of thumb $E/2 = \text{range}$, $E/3 = \text{depth of 80\% dose line}$, $E/4 = \text{depth of the 90\% dose line}$. We can calculate that the 20 MeV beam would show the 90% dose line at a depth of 5 cm.

76.

c . An anterior SSD of 86 cm indicates isocenter depth of 14 cm. A posterior SSD of 92 cm indicates isocenter depth of 8 cm. The sum of the depths is the patient's total separation. $14 + 8 = 22 \text{ cm}$.

77.

c . Field size and distance from the source are directly related. A direct proportion can be used to solve. 16 cm at 100 cm from the source is to unknown field size at 130 cm from the source. $16/x = 100/130$, then $16 \text{ cm} (130 \text{ cm}) = 100 (x)$, then $x = 20.8 \text{ cm}$.

78.

c . Use the MU formula; $\text{MU} = \text{Prescribed dose}/\text{reference dose rate (PDD)}$. $200 \text{ cGy}/1.00 \text{ cGy/MU} (0.50) = 200 \text{ cGy}/0.50 = 400 \text{ MU}$.

79.

d . Use the formula for calculating dose to points of interest in isocentric technique. Point A is the spinal cord. Dose to point A = Dose to point B/TMR point B (source to point B distance/source to point A distance)

$^2 \times \text{TMR for point A}$. Dose to point A = $10 \text{ Gy}/0.770 (100/94)$

$^2 \times 0.946$. Dose to point A = 13.8 Gy.

80.

d . An accurate DVH needs all slices and contours of the complete target and organs at risk.

81.

c . Use the MU formula for isocentric technique. Prescription Dose/ $Sc \times Sp \times TMR$. Sc relates to the collimator setting. Sp relates to the treated field size. TMR relates to the treated field size. Each field prescription for equal weighting is 125 cGy. MU per field = $125 \text{ cGy} / 1.014 \times 0.993 \times 0.761$. MU = 163.

82.

b . Mayneord's F correction is a special application of the inverse square law that accounts for a change in PDD after the SSD is increased beyond calibration distance.

83.

e . Use the applied dose (D_{max} dose) formula. Dose to D_{max} = Given dose at depth/PDD. $3 \text{ Gy} / 0.75 = 4 \text{ Gy}$.

84.

e. CT is superior to MRI for imaging calcifications.

85.

c . Gated radiation therapy improves target dose coverage.

86.

c . The pancreas is surrounded by and is positioned inferior to the liver.

87.

d . As the isocenter needs to move superiorly in the patient, the table must move out and away from the gantry.

88.

e . PTV D95 to 60 Gy refers to a minimal dose of 60 Gy to 95% of the planned target volume.

89.

b . Exceeding the tolerance dose of organs and tissues may lead to the ability of the organ to function. Among the listed, the kidneys have the lowest tolerance dose of 18–23 Gy. Explore tolerance doses for all organs listed with volumes considered.

90. B

C

E

A

D

91.

a . 20% of the esophagus received 30 Gy according to the DVH.

92.

a . The prostate gland is inferior to the bladder and anterior to the rectum.

93.

- a. aorta
- b. kidney
- c. liver
- d. bowel
- e. spinal canal

94.

- a. bladder
- b. prostate
- c. seminal vesicles
- d. rectum
- e. femoral head

95.

c . Use Mayneord's correction. Mayneord's $F = (100 + 1.5/100 + 5)$

$$^2 \times (80 + 5/80 + 1.5)$$

$$^2 = 1.01. \text{ Then } 1.01 \text{ (old PDD). } 1.01 \text{ (61\%)} = 62\%.$$

96.

a . Using rules of thumb and 80% rule. Electron energy/ 2.8 = depth of the 80% isodose line. $6 \text{ MeV}/2.8 = 2.1 \text{ cm}.$

97.

c . 4D CT planning is helpful when movement in the GTV is likely.

98.

d . Image fusion can occur between diagnostic images and CT simulation images OR different diagnostic images OR same diagnostic images on different dates.

99.

e . The objective function of IMRT optimization is to determine the quality of the treatment plan by conforming dose to the defined target at various segments while sparing organs at risk.

100.

e . IMRT has the benefit of more conformity over 3D conventional treatment planning.

Chapter 7

Oncology Patient Care

1.

d . For infections to spread, a germ must be present, the germ must have a place to live and multiply, and a susceptible host must be present with a way for the germ to enter the host. Removing any one of these components breaks the chain of infection.

2.

d . The normal platelet count in an adult ranges from 140,000–400,000/mL.

3.

c . Direct contact involves touch, sexual contact, and kissing.

4.

b . Anaphylactic shock occurs when a patient has an allergic response to the iodinated contrast. The contrast triggers a quick and massive release of histamines leading to systemic vasodilation.

5.

c . Due to constriction of the airway, wheezing and labored, noisy breathing occurs.

6.

c . Side effects of radiation therapy depend on the area treated and will occur only in the area being treated.

7.

- d .** Radiation recall is defined as the recalling by the skin of previous radiation exposure in response to the administration of certain response-inducing drugs.

8.

- b .** Superior vena cava syndrome is caused by the blockage or narrowing of the superior vena cava, often by a tumor in the apex of the lung, decreasing blood flow back to the heart.

9.

- c .** Narcotic medications given around the clock have the tendency to cause constipation. Administering mild laxatives helps to maintain normal bowel motility.

10.

- b .** Pressure on the spinal cord can cause compression of nerves that pass through the spaces between the back bone or the bundle of nerves that extend downward from the spinal cord. Compressions secondary to cancers in the lumbar spine may cause tingling in the lower extremities, trouble walking, and incontinence.

11.

- a .** Neutropenia is a blood disorder which is characterized by an abnormally low number of neutrophils. Neutrophils serve as the primary defense against infection.

12.

- a .** Surgical asepsis dictates the environment is free from all biological contaminants.

13.

a . Patient safety is first and foremost, after assisting the patient then call for help.

14.

b . Parenteral routes for medication involve injection into a vein, muscle, artery, abdominal cavity, heart, or fatty tissue. If biological pathogens enter then infection may occur.

15.

c . Respiration in the adult ranges from 10 to 20 breaths per minute.

16.

a . Anaphylactic or allergic reaction is a severe reaction to asparaginase.

17.

c . Asepsis is the absence of disease producing micro-organisms called pathogens.

18.

b . Hand washing is instrumental and easiest to achieve in breaking the chain of infection thereby preventing the spread of infection.

19.

d . The Patient's Bill of Rights says that patients have the right to refuse treatment, know the qualifications of personnel, and trust that records will be secure.

20.

a . Medical terminology—

Dys - means lack of or difficulty;

-*pnea* refers to breathing.

21.

b . The definition of epilation is removal of or loss of hair.

22.

c . Medical terminology—

Anti- means against;

-*emesis* refers to vomiting.

23.

d . Tachycardia means rapid pulse. The normal heart rate is 60–80 beats/minute.

24.

b . A diuretic helps eliminate excess fluid. Urination is the means by which excess fluid is eliminated.

25.

b . Our professional code of ethics commits us to caring for individuals unrestricted of personal attributes, race, or religion. However, other clinicians who may be asked to perform a procedure that is against their personal beliefs (such as abortion) may refer a patient requesting this certain procedure to another qualified professional.

26.

a . Professional ethics are a set of principles that have been agreed upon and meant to reflect consensus regarding conduct among a body of professionals in certain work-related situations.

27.

b . The ethical principle of confidentiality commits us to holding all patient information in confidence.

28.

c . Operating and performing duties outside of your scope of practice puts you and your employer at risk of liability if any harm comes to the patient as a result.

29.

c . HIV and HBV are bloodborne; therefore, needle stick injuries pose the greatest risk for communication of disease.

30.

d . Sources of infection are many. Living hosts with pathogens easily transmissible by the airborne, contact or droplet modes may lead to communication of disease.

31.

b . Universal precautions were instituted to minimize the transmission of bloodborne disease. It includes the use of protective equipment, aseptic procedures, as well as various types of isolation.

32.

b . The scope of practice for radiation therapists describes, in detail, the job responsibilities of the therapist.

Chapter 8

Clinical Applications in Radiation Therapy

Head and Neck

1.
 - a. Oral cavity—swelling or an ulcer that fails to heal
 - b. Oropharynx—painful swallowing and referred otalgia
 - c. Hypopharynx—dysphagia, painful neck nodes
 - d. Nasopharynx—bloody discharge, difficulty hearing
 - e. Larynx—hoarseness and stridor
 - f. Maxillary sinus—long-standing sinusitis, nasal obstruction, bloody discharge

2.

See [Figure 8.2](#)

and label all structures indicted

3.

F Superior orbital margin (SOM)

N Inferior orbital margin (IOM)

P External occipital protuberance (EOP)

R Mastoid process

I Zygomatic arch

J Glabella

C Nasion

O Inner canthus (IC)

A Outer canthus (OC)

Q Tragus

K Commissure of the mouth

B C1

E C2

M C3

H C4

L C6

D C7

G Sternocleidomastoid muscle

4. Fill in the function of each of the cranial nerves:

Olfactory	I	Smell
Optic	II	Sight
Oculomotor	III	Eye movement (up and down)
Trochlear	IV	Eye movement (rotation)
Trigeminal	V	Sensory (facial) and motor (jaw)
Abducens	VI	Eye movement (laterally)
Facial (masticator)	VII	Expressions, muscle contractions, and mouthing
Acoustic	VIII	Hearing
Glossopharyngeal	IX	Tongue and throat movement
Vagus	X	Talking and sounds
Spinal accessory	XI	Movement of shoulder and head
Hypoglossal	XII	Movement of tongue and chewing

5.

b. One-third of the body's lymph nodes are located in the neck divided by convention into six regions labeled by Roman numerals.

6.

c . Nine cartilages make up the three regions of the larynx-supraglottis, glottis, and subglottis.

7.

d . The sternocleidomastoid muscle divides the neck into anterior and posterior triangular regions.

8.

c . The jugulodigastric nodes, located in the upper region of cervical node triangle, are commonly enlarged in the presence of cancers in the neck.

9.

- a .** The hyoid bone is an attachment site for muscles needed for swallowing.
- 10.
 - b .** The internal jugular vein is the largest vascular structure in the neck.
- 11.
 - b .** The upper cervical jugulodigastric node may also be referred to as the subdigastric node.
- 12.
 - b .** The hypopharynx includes the posterior and lateral pharyngeal walls below the base of the tongue, the pyriform sinuses, and the post-cricoid region.
- 13.
 - d .** The soft palate is part of the oropharynx, not the oral cavity. The oral cavity ends posteriorly at the hard palate.
- 14.
 - b .** The tonsils are the most common location for cancer in the oropharynx.
- 15.
 - d .** The upper aerodigestive tract can be easily examined by palpation, direct inspection, and biopsy.
- 16.
 - b .** Rouvière's node is in close proximity to the carotid artery and inaccessible for surgery and should be included in the treatment volume for the nasopharynx.

Define the Following Symptoms Often Indicated in Specific Areas of Head and Neck Cancers. List of the Specific Areas Where They Often Occur

17. Otalgia—referred pain to ear due to tumor in the oropharynx region
18. Dysphagia—difficulty swallowing
19. Stridor—harsh, raspy breath
20. Diplopia—double vision
21. Erythroplasia—red, velvety patches on the mucous membrane of the mouth
22. Leukoplakia—small, white, raised patches on the mucous membrane
23. Keratosis—a lesion on the epidermis marked by the presence of circumcised overgrowth of the horny layer
24. Dysplasia—abnormal tissue development
25. Odynophagia—painful swallowing
- 26.
- b .** The majority of head and neck cancers are squamous cell carcinomas.
- 27.
- b .** Smoking and alcohol use are common etiological factors for the development of head/neck cancers.
- 28.
- d .** When managing head and neck cancers, the main goals are to eradicate disease, maintain function, and preserve cosmesis.
- 29.

a . Plummer-Vinson syndrome is an etiological factor for cancers of the oral cavity.

30.

c . If the supraclavicular area is treated for the management of head/neck cancer, the typical total dose is 5000 cGy.

31.

b . The vallecula is located at the base of the tongue.

32.

a . Special care should be taken to make sure that the spinal cord is kept under tolerance while treating the hypopharynx and cervical lymphatics, including Rouvière's node.

33.

b . The highest rate of positive lymph nodes occurs in cancers of the hypopharynx.

34.

d . Cranial nerve involvement occurs in 15% to 25% of cases of nasopharyngeal cancer.

35.

b . A bite block or tongue blade may serve to separate or displace the palate from the oral cavity.

36.

b . The eye, especially the lens, is at the most risk of exceeding tolerance when treating the maxillary antrum.

37.

c . The lung is the most common site of distant metastasis from primary head/neck cancers.

38.

b . Most cancers of the head/neck are squamous cell carcinomas.

39.

a . It is not unusual to see a wedged pair, superior-inferior oblique portal orientation, in the treatment of the parotid gland.

40.

b . The maxillary sinus has the highest frequency of malignancy among all sinuses.

Lung

1. Define the following:

Odynophagia —painful swallowing

Feedback: The proximity of the bronchus to the esophagus and the potential for mediastinal lymphadenopathy may cause a patient with diagnosed lung cancer to experience pain when swallowing food

Hemoptysis —coughing up blood

Feedback: Bronchial tumors may begin to break up with persistent coughing and produce bloody sputum

Dyspnea —difficulty breathing

Feedback: Patients with lung tumors and/or positive mediastinal disease may experience difficulty breathing

Atelectasis —collapse of the lung

Feedback: The location or persistence of a lung tumor or chronic obstructive conditions of the lung may lead to collapse of the lung

2. List all mediastinal lymph nodes.

Para-tracheal, para-esophageal, hilar, subcarinal, peri-aortic, interlobar, lobar, segmental, subsegmental

Feedback: Involvement of mediastinal lymph nodes is common in primary lung cancers

3. Using the cross sectional images shown in

Figure 8.4 :

- a. Outline the gross tumor volume

On image A, mass is located in the left upper lobe, apex region

On image B, axial cross-section, mass is located in the left lung near the posterior

On image C, axial image circular nodules in the left mediastinum are enlarged lymph nodes

- b. Outline the critical structures and list tolerance doses for each
On all images, normal left lung, opposite lung, heart, and spinal cord should be outlined.

TD 5/5 1/3 of lung 45 Gy; 3/3 of lung 17.5 Gy

1/3 of heart 60 Gy; 3/3 of heart 40 Gy

5 cm of cord 50 Gy; 20 cm of cord 47 Gy

- c. Diagram possible directions for off-cord and boost treatment fields

Off-cord fields would include gross tumor and mediastinal nodes in right anterior and left posterior oblique fields avoiding the spinal cord. Boost fields may be a 90-degree pair including a posterior and left lateral OR a single posterior boost field could deliver a high dose to the

primary tumor while sparing all normal lung tissue.

4. List four etiologic factors for lung cancer.

Smoking, asbestos, atmospheric pollution, arsenic, nickel exposure, previous thorax radiation, exposure to ether, chronic obstructive pulmonary disease

Feedback: The strongest risk factor for the development of lung cancer continues to be cigarette smoking.

5. Note common anatomical locations and physical characteristics for the manifestations of the following lung tumors:

Adenocarcinoma:

Tend to be located near the periphery of the lung.

Squamous cell carcinoma:

Tend to be proximal and involve the hilum. Will likely grow into the bronchial lumen and cause associated pneumonitis.

Pancoast tumor:

Located in the apex of the lung.

Mesothelioma:

Manifests in the lung pleura.

Large cell carcinoma:

Shows up similar to adenocarcinoma.

- 6.

- a .** Adenocarcinomas of the lung are commonly seen in patients with no history of smoking.

7.

- a. Clubbing of the fingers is a symptom of COPD or other diseases of the heart or lungs where there is a decreased blood oxygen level.

8.

- a. Oat cell carcinoma, also called small cell carcinoma, is a very aggressive malignancy and is assumed to have begun metastatic spread at the time of diagnosis.

9.

- c. Posteriorly located lung tumor may be easily treated during the boost portion of radiation therapy by using a single posterior field or posterior oblique fields.

10. Using the anatomical diagram as

Figure 8.5 draw the likely emergency treatment field for the patient diagnosed with Superior Vena Cava syndrome caused by right Pancoast tumor.

The appropriate treatment field for the emergency field should be a simple field covering the tumor and moderate margin of about 3 cm on all sides. No lymphatics are included in the initial emergency fields for SVC syndrome.

11.

- c. Dose for prophylactic radiation to the brain is typically 36–40 Gy.

12.

- b. The CT scan is helpful in establishing the presence and location of a mass and involvement of neighboring tissues but would not supply the clinician with a definite histological type.

13.

b . The right lobe has three lobes while the left lobe has two.

14.

c . Due to cardiac and respiratory motion, lung tumors move as the heartbeats and also on inspiration and expiration. To decrease the risk of target miss, cardiac or respiratory gating procedures may be utilized.

15.

b . Mesothelioma has the closest association with asbestos exposure.

Alimentary

1.

posterior . Review anatomy, esophagus is situated posterior to the trachea, closest to the spine.

2.

splenic flexure . Anatomy review, junction of transverse and descending colon is in the left upper quadrant of the abdomen anterior to the spleen.

3.

a . Diverticula are a result of debris causing out pouching and weakening of the intestinal wall.

4.

duodenum . Anatomy review, the duodenum is the first section of the small bowel.

5.

small bowel . Anatomy review, the small bowel makes up 90% of the alimentary tract.

6. Using

Figure 8.8 , draw typical AP/PA fields for upper 1/3 esophagus squamous cell carcinoma.

7.

Table 8.5

Treatment site	Anatomy included in the treatment fields	Critical tissues in the area	Optimal position/immobilization
Rectum	From L5 to margin on tumor; out beyond the pelvic inlet; common iliac, internal and external iliac nodes	Small bowel Bladder Bone marrow	Prone with or without the belly board Immobilize lower extremities and pelvis
Anus	From 31 to margin on tumor; wide enough to include inguinal lymph nodes, internal and external iliac nodes	Small bowel Rectum Bladder Bone marrow	Supine for inguinal boost if necessary frog-legged decreases inguinal folds; Prone if no inguinal node boost Prone or lithotomy for electron boost if necessary

8.

c . Histological types for small bowel cancer include adenocarcinoma, sarcomas, lymphomas, and carcinoid.

9.

b . Adenocarcinomas comprise about 95% of stomach cancers.

10.

c . Surgery has the most promise for cure for stomach cancers.

11.

c . Most stomach cancer cases are diagnosed late. At the time of presentation, the most common report is a persistent, vague discomfort around the stomach.

12. Cachexia—

weight loss caused by physiological malabsorption of nutrients

Hematemesis—

vomiting blood

Dysphagia—

difficulty swallowing

True/False

13.

T

14.

T

15.

F . The procedure described is called an exploratory laparotomy. An abdominal perineal resection (APR) resects the rectum and anus and installs an anterior colostomy.

16.

d . Colon cancers metastasize to the liver, lung, and out into the peritoneal cavity.

17.

d . Studies have shown that gastric cancers are associated with low-fiber diets and frequent consumption of salted and smoked foods.

18.

b . Primary lymphatic drainage for the anus is to the internal iliac and inguinal lymph nodes. The inguinal nodes should be included in treatment fields.

19.

d . In areas where the skin is broken down, it is best to decrease friction and cause more tissue injury. Patting dry instead of wiping is best.

20.

c . Having a history of colon polyps increases the risk of developing a malignant colon tumor.

21.

d . Lower esophagus tumor fields will likely include a section of the stomach. Irradiation to the sensitive lining of the stomach will cause acute nausea.

22.

b . Radiation for upper esophagus tumors will cause esophagitis realized by the patient as a difficulty swallowing.

23.

c . The layers of the intestinal wall from the inside out are the mucosa, submucosa, muscularis, then serosa.

24.

b . Positioning the patient in the prone position will push some small bowel up and out of the pelvis.

25.

a . The Modified Astler-Coller stage A describes a carcinoma in situ with no nodes and distant metastasis. This correlates with Stage 0 using the TNM system.

Digestive Organs: Pancreas, Liver, and Gallbladder

1.

Stomach__

inferior and

posterior _____

Duodenum__

tucked in, to the left _____

Liver__

inferior _____

Spleen__

head is medial, tail is in splenic hilum _____

2.

Secretion of digestive enzymes and sodium bicarbonate to help neutralize acid in the stomach and duodenum. Islets of Langerhans secrete glucagon to regulate sugar levels, insulin for the metabolism of carbohydrates, proteins, and fats, and somatostatin, which controls the metabolic process.

3.

Stomach__

to the right _____

Gallbladder_

superior _____

Aorta_

anterior _____

Inferior vena cava_____

anterior _____

Diaphragm__

inferior_ _____

4.

Storage and filtration of blood, secretion of bile, conversion of sugars to glycogen, synthesis and breakdown of fats, and temporary storage of fatty acids; helps regulate blood volume, fibrinogen, and prothrombin.

5.

liver

6.

Stores bile

7.

d . The celiac axis from the aorta supplies blood to the spleen, pancreas, stomach, and liver.

8.

d . High consumption of alcohol causes cirrhosis of the liver.

9.

c . Jaundice is characterized by yellowish discoloration of the skin and eyes.

10.

c . Anatomy review; the fundus is the highest portion of the stomach.

11.

c . The biliary ducts carry bile and other digestive juices into the duodenum (beginning of the small intestine).

12.

a . The gallbladder is in the right abdomen and found tucked under the larger right lobe of the liver.

13.

c . The head of the pancreas is nestled in the curve of the duodenum.
14.

c . The presence of fats in the stomach triggers the release of bile.
15.

c . The hepatic flexure of the colon is just under the right lobe of the liver.
16.

c . Excessive radiation of the liver can lead to a severe complication known as acute hepatitis.
17.

c . Primary liver cancers spread to the lung and brain.
18.

d . Pancreatic tumors are most often adenocarcinomas.
19.

Cholelithiasis—

stones in the gallbladder

Barrett's esophagus—

a condition where columnar epithelium extends more than 3 cm into the distal esophagus instead of normal squamous epithelium

Crohn's disease—

a form of inflammatory bowel disease often at the terminal end of the ileum

20.

Abdominal pain

Dark urine

Jaundice

Clay-colored stools

Newly diagnosed diabetes

21. Complete the

Table 8.8 :

Cancer site	Two signs/symptoms	Three methods of detection
Liver	Right abdomen pain Abdominal mass Weight loss Fatigue	Liver function Coagulation studies CA 19-9, CEA markers Ultrasound CT
Stomach	Vague epigastric discomfort Nausea, vomiting Hematemesis	Endoscopy Barium swallow CT Stool examination
Esophagus	Dysphagia Hematemesis Weight loss Fatigue	Endoscopy CT Barium swallow Ultrasound Esophagoscopy
Colon	Pencil stools Rectal bleeding Constipation Diarrhea	CEA Digital rectal exam Colonoscopy Barium enema CT

22.

c . Chemoembolization is the local administration of chemotherapy using proximal venous or arterial access.

23.

b . Hepatocellular carcinoma has a strong association with hepatitis C infection.

24.

a . The Whipple procedure removes a section of the pancreas and small intestine and re-establishes the communication between remaining pancreas, small intestine, and biliary tree.

25.

c . Pancreatic carcinomas have proven to be very aggressive and have shown limited response to radiation and chemotherapy. The best chance for cure is surgical removal of the tumor with clear margins.

Breast

1.

c . The apical nodes, also known as level 3 axillary nodes, are the deepest and are most adequately treated using a posterior field (PAB) or midline opposing fields.

2.

d . Lymphatic drainage for the breast includes all three levels of axillary nodes, supraclavicular nodes, and internal mammary nodes.

3. Using

Figure 8.12 , draw the location of all lymphatic drainage for the breast.

4.

- b . Tamoxifen is an antiestrogen administered to counteract the nurturing effects of estrogen on breast cancers.**

Think About It

5.

A unique toxicity associated with Adriamycin is cardiac toxicity. Radiation dose should be limited so as not to compound the potential latent injury to the heart.

6.

Clinical staging includes physical examination taking survey of the skin of the breast, and the status of palpable lymph nodes. Imaging studies may also be used for clinical staging. Pathological staging would include everything necessary for clinical staging but adds surgical exploration and resection with pathological evaluation of tissue sample.

7. Using the information given, calculate the monitor units required for each treatment field per fraction prescription:

- 5040 cGy to right breast 180 cGy per fraction-6 MV photons
 - 4500 cGy to right supraclavicular fossa 180 cGy per fraction-6 MV photons
 - 1000 cGy boost lumpectomy scar 200 cGy per fraction-12 MeV en face electrons
- 6 MV beam output = 1 cGy/MU 12 MeV beam output = 1 cGy/MU
medial and lateral tangents Field size = 8×24
SSD = 91 cm
Field size factor = 1.034
TAR @ 9 cm = 0.892 AP supraclavicular field
Field size = 12×10
Field size factor = 1.003

TAR @ 3 cm = 1.002
 En face electron boost field
 Cone factor = 1.02
 Dose to 90% dose line
 Answer

Medial tangent	98 MU
Lateral tangent	98 MU
AP supraclavicular	179 MU
Electron boost	218 MU

8.

a . A painless lump is the most common sign of breast cancer.

9. Define the following:

Radical mastectomy—

resection of the breast, pectoralis muscles, and regional lymph nodes

HER2neu—

an oncogene expression seen in certain breast cancer patients; an epidermal growth factor

BRCA1—

a tumor suppressor gene whose failed type is associated with elevated risk for breast cancers

Peau d'orange—

an orange coloring of the skin of the breast indicating infiltration of cancerous cells into the dermal layers of the breast; skin feels thick and leathery

10.

- c .** The breast board should be inclined to decrease the slope of the patient's chest to optimize the sparing of lung tissue while covering breast tissue.

11.

- d .** The supraclavicular field is best treated using half-field technique to prevent overlap into the upper aspect of the tangential fields.

12.

- c .** The entire breast following lumpectomy is typically 50 Gy. Then the lumpectomy scar is boosted 10–20 Gy.

13.

- a .** Most diagnosed cases of breast cancer are infiltrating ductal carcinoma.

14.

- b .** Volume of lung included in the tangential breast fields should be kept at minimum to prevent lung fibrosis. Although some signs of lung pneumonitis may be observed in the small amount of lung irradiated following breast irradiation.

15.

- d .** The change in distance would render an output correction factor of 0.907. Indicating an approximate 10% change. Since distance is increased, dose would be decreased.

Use inverse square law to find the correction factor
(100/105)

$$^2 = 0.907$$

16.

- a .** In situ cancer is confined to the lumen of the ducts. This type of tumor has limited capacity for spread and is classified as Stage 0.

17.

- b .** Technetium 99 and blue dye are injected into the breast tumor area and observed as they flow to lymphatic drainage sites. The node(s) collecting the most Technetium are identified as “hot” by a gamma camera and resected during a sentinel node biopsy.

18.

- c .** 310 degrees is 40 degrees positive from 270-degree position on the gantry. The opposite angle would be 40 degrees positive from 90-degree position on the gantry. OR 310 degrees is also 50 degrees negative from the 0-degree position. The opposite angle would be 50 degrees negative from the 180-degree position.

Gynecologic

1.

- d.** The tolerance dose for a 5% complication rate within 5 years of treatment for the bladder and rectum are 6500 and 6000, respectively. Exceeding the tolerance dose can lead to significant acute and late toxicities like cystitis and proctitis. Keeping the dose too low will risk the effectiveness of the treatment.

2.

- c.** Tamoxifen stimulates estrogen receptors in the endometrium causing proliferation, leading to hyperplasia. Long-term use increases the risk, particularly in postmenopausal women.

3.

- c .** Cancer Antigen 125 is a protein that is often elevated in the blood of women with ovarian cancer. For women at high risk, it may be used as part of a screening protocol.

4.

- b.** The fornixes are lateral spaces in the vaginal apex. Fornixes are recessed areas created where the cervix protrudes into the upper part of the vagina. They help support the cervix and maintain its position within the vaginal canal.

5.

- a.** Women whose mothers used DES before their birth show an increased risk of clear cell adenocarcinoma of the cervix and vagina. DES is a synthetic estrogen that was used to prevent miscarriage. It was discovered that DES prevents normal stratification of vaginal epithelium and resorption of vaginal glands, resulting in vaginal adenosis. This is an abnormal condition that can be a precursor to cancer.

6.

- b.** Lomotil can be prescribed to manage diarrhea. Ibuprofen is an antiinflammatory and pain reducer, sucralfate is used to treat duodenal ulcers, and Compazine is used to treat nausea.

7.

- a.** Patients receiving radiation to the pelvis should follow a low-residue diet that would not include whole grain breads. Residue refers to the undigested parts of food, primarily fiber, that make up stool. A low-residue diet limits high-fiber foods to minimize the frequency and volume of bowel movements.

8.

- a. The most radio tolerant structure among the gynecological organs listed is the uterine canal. The uterine canal is lined with endometrial cells, which have a higher capacity to repair and regenerate after radiation than more sensitive cells of the ovary and cervix. The ovaries contain a limited number of cells and are highly sensitive to radiation. The cervix and bladder have a higher density of rapidly dividing cells that make them more sensitive to radiation.

9.

- d. Inguinal nodes are primary lymphatic drainage for the vagina and should be included in the treatment field. Involvement of inguinal nodes at diagnosis is associated with a poorer prognosis.

10. If a patient is having a four-field pelvis treatment, calculate the diameter of the AP to PA and lateral using the following:

AP SSD readout is 85, PA SSD readout is 87.5, right lateral 81; left lateral 79.5

a. AP/PA diameter = 27.5

b. Rt/Lt lateral = 39.5

**AP 100 – 85 = 15 PA 100 – 87.5 = 12.5 15 + 12.5 = 27.5
cm**

**RL 100 – 81 = 19 LL 100 – 79.5 = 20.5 19 + 20.5 = 39.5
cm**

Male Genital

1.

- c. Seminoma is the most common germ cell cancer of the testis. Seminoma is the most common due to the frequency of cell division making them susceptible to mutations. They grow and

spread slower than nonseminomatous germ cell tumors allowing for early detection and treatment, contributing to higher prevalence.

2.

- b .** Testicular cancers show up in young men between the ages of 15 and 35. Peak incidence in this age group is because this is when the testicles are most active in terms of sperm production and hormonal activity, which may be a contributing factor. The high levels of testosterone may also affect the incidence.

3.

- a .** Tumor markers for testicular cancer would include alpha-feto-protein (AFP) and beta human chorionic gonadotropin (BHCG). Seminomas do not produce AFP, so if AFP is present, it suggests the presence of nonseminomatous component. These markers help differentiate between different types of testicular tumors.

4.

- b .** Standard external beam radiation doses to the prostate are 70–81 Gy. For breast cancer, depending on fractionation, doses approximate 50 Gy. Penile cancer is generally treated to a dose of 50–60 Gy externally, and doses of radiation to control testicular cancer are approximately 30 Gy due to the sensitivity and immaturity of the cells.

5.

- a .** Standard external beam radiation doses to the prostate are 70–81 Gy. For breast cancer, depending on fractionation, doses approximate 50 Gy. Penile cancer is generally treated to a dose of 50–60 Gy externally, and doses of radiation to control testicular cancer are approximately 30 Gy due to the sensitivity and immaturity of the cells.

6.

- a . Paraaortic lymph nodes are in the posterior abdomen around the aorta. They are treated to prevent recurrence and control disease. Same-side (ipsilateral) pelvic nodes may be included for IA and IB tumors to treat microscopic disease for higher risk of spread.

7.

- a . Over 95% of prostate cancers are adenocarcinoma, which originates from glandular cells that line the prostate and produce prostatic fluid. They are the most abundant type of tissue.

8.

- a . Lupron, a luteinizing hormone inhibitor, is appropriate in the management of prostate cancer since prostate cancers are nurtured by the presence of male hormones.

9. Using

[Figure 8.17](#) , identify the following:

Prostate gland
Seminal vesicles
Rectum

10.

- c . Severe wet desquamation should be managed with special dressings to promote healing. Applications for severe radiation dermatitis; open wounds—keep the area clean, avoid scrubbing, and irritants. Use nonstick absorbent dressings to cover the area. Hydrogel can maintain moisture and promote healing.

11.

- d . Seminomas metastasize to the mediastinum and lung. Seminomas typically spread first through the paraaortic lymph nodes near the kidneys. There, the cells enter the bloodstream and travel to the lungs because they receive a large amount of blood supply.

12.

d . Following total prostatectomy, radiation dose to the tumor bed would be in the range of 66–75 Gy.

Urinary

1.

d . Renal cell carcinomas metastasize to the lung, liver, bone, and brain.

2.

a . Cancers found in the pelvis of the kidney are commonly transitional cell histology.

3.

a . For the detection and confirmation of bladder malignancy, urine cytology, cystoscopy, and/or transurethral resection of the bladder are valuable.

4.

a, b, and c . Bladder tumors are often found in the posterior-lateral walls and trigone area.

5.

Dye working
Chronic bladder infections
Smoking
Exposure to cadmium
Previous pelvic irradiation

6.

Transitional cell
Squamous cell
Adenocarcinoma
Sarcoma
Lymphoma

7.

b . If radiation is given preoperatively, a pelvis field including the obturator and external and internal iliac (hypogastric and presacral) nodes is accepted.

8.

b . Anatomy review; the ureters attach to the bladder's posterior lateral surface.

9.

c . Anatomy review; the kidneys received blood supply from the IVC and abdominal aorta via the renal vein and arteries.

10.

c . Anatomy review; the large liver on the right makes the right kidney slightly lower than the left.

11.

b . Common symptom of bladder cancer is blood in the urine (hematuria).

12.

c . Cadmium is a metal found in some kinds of Cerrobend used for custom blocks. Cadmium is a known carcinogen linked to kidney and bladder cancer. Cadmium-free Cerrobend is now available.

13.

a . Anatomy review; the ureters are located at the renal pelvis.

14.

b . Anatomy review; urine passes to the outside of the body via the urethra.

15. Label

Figure 8.18 showing the following structures

Inferior vena cava

Aorta

Kidney

Ureter

Bladder

16. Using

Figure 8.18 draw the typical anterior treatment field for pre-operative radiation for bladder cancer.

Think About It

17.

When the patient is treated, the bladder should be empty so that localization and targeting are consistent. After the patient voids, the bladder is expected to begin filling during setup and treatment.

18.

The pediatric patient has greater sensitivity due to dividing immature cells. TD 5/5s we study most often are based mainly on tissue sensitivities in adults (unless otherwise stated) using standard fractionation. Variables such as patient's age, revised fractionation schedules, irradiated tissue volume, and type of

radiation used change the tolerance of tissues. In addition, the pediatric patient is hoped to have a longer life expectancy and therefore the focus must remain on keeping the possibility of long-term effects at the bare minimum.

Central Nervous System

1.
 - a . The lateral ventricles are located within the cerebral hemispheres.
2.
 - b . Sensory and association are controlled in the parietal area.
3.
 - a . The sense of smell is conveyed by the olfactory nerve-cranial nerve I.
4.
 - a . Primary brain tumors spread by local invasion; gliomas tend to remain localized.
5.
 - c . Medulloblastoma, ependymomas, and pineal gland tumors have high potential to spread throughout the CSF.
6.
 - d . The majority of primary brain tumors in adults are gliomas.
- 7.

d . Symptoms of intracranial tumors would not include nocturia (frequent urination during the night).

8.

a . Whenever possible, total resection is the primary mode of management for primary brain tumors.

9.

e . Pituitary adenomas may show symptoms associated with hormonal imbalance as in diabetes or visual disturbance or sinus pressure due to anatomical location and extension of tumor.

10. Label on

Figure 8.20 CT sagittal view brain

Pineal gland
Pituitary gland
Pons
Medulla
Third ventricle
Fourth ventricle
Sphenoid sinus

11.

e . A tumor compressing the lumbosacral region of the spine could cause incontinence, impotence, and pain down the legs.

12.

c . Cranial nerve VII controls movement and sensory of the face.

13.

a . Injury to the scalp from radiation exposure should be managed by little friction, avoidance of chemicals and perfumes found in

shampoos and commercial ointments, and avoidance of extreme temperatures.

14.

- a . Patients with CNS malignancies should always be accompanied and assisted to minimize risk of falling and injury.

15.

- a . Cranial nerve IX controls swallowing and secretion of saliva.

Think About It Questions 16–18

16. One theory is that since the central nervous system is central station for all bodily functions it is self-contained for protection from systemic, pathogenic disability. It therefore sets strict limits regarding what comes in and goes out. Permeation is uniquely controlled in either direction. Non-CNS primaries more readily make their way to the CNS (especially the brain) via the blood route than CNS tumor through common vasculature.

17. Noncoplanar beam arrangements allow for smaller doses from each field with more conforming dose distribution than with traditional fields traversing a single plane and exposing normal tissues to higher total dose.

18. Metastatic brain disease is usually multi-focal. Even if not demonstrated as multi-focal at the time of detection, it is accepted that there is likely microscopic disease throughout the brain. Primary tumors are usually solitary and tend to grow radially from the primary location.

Skin Cancer

1.

- F . Melanomas are the deadliest type of skin cancers.

2.

T

3.

T

4.

F . Ulcerating and rolled borders are more characteristic of late-stage basal cell or squamous cell skin cancers.

5.

T

6.

b . Clark's method is based on the depth of invasion through skin layers.

7.

c. Epstein-Barr virus is not a known risk factor for skin cancer.

8.

a. Melanocytes are found in the stratum basale of the epidermis.

9.

a . The stratum basale is the most sensitive to radiation due to high mitotic activity.

10.

c . Intense UVA light radiation from tanning beds is damaging to the skin and is just as carcinogenic as ultraviolet rays from the sun.

11.

d . Nonmelanomas occur following repeated, long-term UV exposure. Children have not had long-term exposure.

12.

c . Lentigo maligna is similar to superficial spreading in that it grows radially to begin with then vertical growth begins. They are usually tan or black and superficial spreading have a variety of reddish tones.

Think About It Questions 13–15

13. Immunotherapy is used since melanomas have been noted to regress. Regression is understood to be the body's immune response to disease. Immunotherapy attempts to take advantage of this response and gives the immune system a boost to help fight disease.

14. Using typical fractionation of 40–50 Gy total dose in 2 Gy fractions:
Erythema at 20 Gy
Dry desquamation at 30 Gy
Wet desquamation at 40 Gy

15. The lead shield protects the underlying mucosa from residual radiation. Wax behind the shield will further protect the mucosa closest to the septum from secondary radiation from electron/lead interaction.

Leukemia

Define the following terms:

1. Thrombocytopenia—

decrease in thrombocytes, also known as platelets.

2. Leukapheresis—

the sifting out of white cells; selective removal of leukocytes from withdrawn blood that can then be re-transfused.

3. Splenomegaly—

enlargement of the spleen.

4. Leukopenia—

decrease in white blood cells.

5. Anorexia—

weight loss usually associated with a conscious decision to decrease food intake.

6. Teratogenic—

causing physical defects in the developing embryo; teratogenous—developed from fetal remains.

7. Neutropenia—

decrease in the number of neutrophils in the blood; neutrophils are granular leukocytes.

8. Toxicity—

being poisonous; degree of being poisonous or harmful.

9. Benzene—

a chemical solvent from coal tar; can be used as an insecticide.

10. Bone marrow depression—

decrease in function of blood forming tissues.

11. Auer rods—

rod-shaped structures, present in the cytoplasm of myeloblasts, myelocytes, and monoblasts, found in leukemia.

12. Nadir—

The word nadir means the lowest point. This word is often used in reference to blood counts, particularly white blood cells and platelets. Nadir time can occur within 10–14 days following high doses of chemotherapy. Suppression of blood cell production depends on the drugs administered.

13. Pruritus—

Itching that may be caused by inflammation.

14. Ecchymoses—

A hemorrhagic spot in the skin; looks round or irregular, blue or purplish .

Daunorubicin	Antitumor; Anthracycline-antibiotic
ALL, AML	BMD, toxicity of heart and GI.

15.

b . In the case of leukemia, immature white cells accumulate and impair the body's ability to produce adequate red blood cells.

16.

a . The type of leukemia seen mostly in children is acute lymphocytic leukemia (ALL).

17.

c . Chronic lymphocytic leukemia is not associated with previous radiation exposure.

18.

b . Location of the Philadelphia chromosome is a diagnostic factor for detecting CML.

19. TBI—

Total body irradiation may be used in the management of leukemia by having the patient positioned sitting in fetal position at an extended distance from the treatment machine or lying supine or standing. Small children may be treated lying supine as their bodies are small enough to be contained in the collimator area opening. Low dose TBI can be 10 cGy/day to total 4.5 Gy. Special care has to be taken to protect the lungs and lens by varying position or using shields.

20. Helmet—

This technique is a modification of the whole brain fields. The lower border should be to cervical spine #2 to make sure the fourth ventricle has proper coverage. Lateral fields are appropriate with daily dose of about 1.5 Gy to a total of 25–35 Gy.

21. CNS—

The total CNS is treated with two lateral brain fields as per the helmet technique and carefully matching a field covering the entire spine from cervical spine #2–3 junction to sacral bone #2 to give margin on the cauda equine. Daily dose is about 1.5 Gy to total 35 Gy to each field.

22.

c . Nadir can occur within 10–14 days in patients who have received methotrexate.

23.

d . Side effects seen in the skin, such as inflammation, change in pigment, and hair loss, are integumentary side effects from chemotherapy.

24.

c . The subarachnoid mater is not one of the layers of the meninges. They are the dura mater, arachnoid, and pia mater.

25.

b . For a definite diagnosis of ALL, a bone marrow biopsy is imperative.

26.

a . The spleen is in the left upper quadrant of the abdomen.

Lymphomas

1. Components include lymphatic vessels and nodes and lymphatic organs such as tonsils, spleen, thymus, and bone marrow. Responsible for immune defenses and circulation of lymph fluid. Filtration of foreign particles and production of lymphocytes.
2. Red blood cells transport oxygen and carbon dioxide. White blood cells are critical to immunity as neutrophils and monocytes carry out phagocytosis, lymphocytes produce antibodies, heparin is produced by basophils, and eosinophils help detoxify. Platelets initiate blood clotting and hemostasis.
3. T and B lymphocytes. B cells secrete antibodies. T cells kill cells bearing specific antigens.
4. Lymphatic capillaries merge to form the lymphatic vessels.

5. The lymph vessels lead to collecting ducts that unite with the veins in the thorax. After leaving the lymph nodes, the lymph vessels merge to form larger lymphatic trunks. The trunks drain the lymph from large regions of the body. The trunks join one of two collecting ducts known as the thoracic or right lymph duct.
6. The thoracic duct receives lymph from the cistern chyli and the right lymphatic duct empties into the cisterna.
7. Foreign substances that enter a lymph node are removed or filtered out by phagocytes.
8. Lymph flows into the node through afferent vessels and flows out by way of efferent vessels.
9. The spleen is responsible for hemopoiesis, and red blood cell and platelet destruction, and serves as a reservoir for blood.
10. Without a spleen, the other blood forming tissues can take over.
11. Lymphatic vessels have the capacity for repair and regeneration.
12. The thymus traps immature stem cells and preprocesses them so that they become sensitized and capable of maturing into types of lymphocytes essential to developing immunity. This happens in fetal life and typically reaches its maximum performance by puberty.
- 13.

b . The largest lymphatic organ is the spleen.

14.

d . The vallecula is not a tonsil.

15.

a . The thymus gland atrophies after puberty.

16.

b . The B lymphocyte develops from a stem cell in the hematopoietic tissues.

17.

c . The lymphatic system consists of lymph fluid, vessels, organs, and nodes.

18.

c . Lymph nodes are about 1–25 mm in diameter.

19.

b . The thymus gland produces T cells.

20.

d . NHL can occur in many sites including nodes, lymph tissue, or gastrointestinal tract. Unlike HL, NHL may spread randomly.

21.

b . The thoracic duct begins at the cistern chyli.

22.

c . Most Hodgkin disease cases will present as nodular sclerosis type.

23.

c . The most common presenting symptom of Hodgkin disease is a painless cervical node.

24.

b . The Reed-Sternberg cell is present in cases of Hodgkin disease.

25.

b . The staging system for lymphomas is traditionally the Ann Arbor staging system. Staging of lymphomas may also include the following letters denoting organ. (MATCH)

26.

d

27.

c

28.

b

29.

a

30.

g

31.

e

32.

f

33.

True and False . This is debatable today. Traditionally, radiation therapy has been the primary treatment for early-stage Hodgkin disease. Due to realization of late effects, treatment schemes are being reconsidered putting chemotherapy as the primary and radiation as an adjunct to involved fields.

34.

- c.** Although this patient has three lymph node areas involved, they are all above the diaphragm. This is classified as stage II according to Ann Arbor staging.

35.

- d.** Although pruritus can be an associated symptom of Hodgkin disease, it is not a classic B symptom.

36.

- d.** Both sides of the diaphragm positive with an extralymphatic site would be considered stage IIIE.

37.

- d.** As Waldeyer's ring includes the tonsillar tissues, the treatment field is in close proximity for a treatment field in the management of nasopharynx cancer.

38.

- d.** Treatment of the abdomen may cause the patient to experience nausea, vomiting, and fatigue.

39.

- b.** Lower neck and mediastinal nodes without classic symptoms would be classified as Stage IIA.

40.

- b.** Nodular sclerosis carries the most favorable histology. Although recent studies suggest that histological variation has little influence on prognosis.

41.

- d.** NHL may arise in nodes, gastrointestinal tract, or lymphatic tissues such as Waldeyer's ring.

42.

- c.** Non-Hodgkin lymphocytes may arrange themselves in follicular or nodular patterns.

43.

- b.** Dysphagia may be an early effect of mantle irradiation. Dysphagia is difficulty swallowing.

44.

- b.** The appropriate separation between upper and lower fields is known as the skin gap.

Pediatric

1.

- a .** If the entire width of the spine is not included in the radiation field, one portion of the spine will grow normally while the other portion will be stunted, resulting in spinal scoliosis.

2.

- a .** Parasites are not a known risk factor for solid tumors in children.

3.

- c .** Wilms' tumors, or nephroblastomas, are often found by parents feeling a mass in the abdomen of the child.

4.

b . Nephroblastomas, or Wilms' tumors, metastasize to the lung.

5.

a . Neuroblastomas originate in neural crest cells.

6.

a . Medulloblastomas, ependymomas and pineal gland tumors have high incidence of CSF spread.

7.

c . Ewing's sarcoma, or osteogenic cancer, has a common symptom of pain in the bone.

8.

a . Although rare, retinoblastoma is the most common malignancy found in the orbit of children.

9.

b . Wilms' tumors originate in immature kidney cells known as nephroblasts.

10.

d . ALL is associated with prophylactic irradiation of the brain or entire CNS to maintain remission.

11.

Allogeneic donor ____

B ____

A . self
Autologous donor ____

A ____

B . compatible match

Syngeneic donor ____

C ____

C . Identical two

12.

a and c . Late toxicities of therapy are of great concern when treating children. Delayed bone growth, secondary cancers, and mental deficits (brain) are a few adverse consequences of radiation therapy.

13.

c . An enucleation is the removal of the entire orbit.

14.

c . Preschool-aged children are just beginning to communicate and show some independence. Keep instructions honest and simple.

15.

d . The adolescent patient is concerned about privacy and personal appearance and can make independent decisions.

16.

c . This 17 year old is concerned with physical appearance so assuring her that there are some alternatives is promising.

Think About It

17.

Table kick = 6.1 degrees

Use the divergence formula:

1.

tan

⁻¹ (A/2 SSD)

2.

tan

⁻¹ (20/186)

3.

tan

⁻¹ (0.1075)

18.

Daily dose will be 1.5 Gy equally weighted; convert to cGy

Equivalent square using Sterling's formula = 2

$$(15 \times 20)/35 = 17.1$$

Treatment depth = 7 cm as per SSD given

$$75 \text{ cGy}/0.996 \times 1.028 \times 0.794 = 92$$

Answer: 92 MU per field

Soft Tissue Sarcoma

1.

b . Muscles are organized in parallel fibers along a longitudinal plane. This plane is less dense and easier to spread than across the fibers.

2.

b . Sarcomas originate in the mesoderm. The mesoderm is the middle layer of the primary germ layers in embryonic development. It differentiates into mesenchymal cells that generate connective tissue such as bone, cartilage, muscle, fat, and blood vessels.

3.

c .

Rhabdo- is the prefix for striated. Rhabdomyosarcomas arise from striated muscle.

4.

d .

Lipo- is the prefix for fat. Liposarcomas originate in fatty tissues.

5.

d . Primary tumors originating in the compact bone metastasize to the lung through the blood route. Bone tumors can invade nearby blood vessels, allowing or entrance into the bloodstream. The lungs receive a large amount of blood supply making them a frequent site for metastasis.

6.

b . A lytic lesion would appear moth-eaten with decreased density on x-ray.

7.

c . Weight loss and fever are rare symptoms of primary bone cancer except for Ewing sarcoma and multiple myeloma due to hypercalcemia. Bone tumors increase the activity of osteoclasts, the cells that break down bone tissue. This releases calcium into the blood, causing hypercalcemia. This inflammatory response can lead to fever. The high metabolic demands lead to increased energy expenditure and weight loss.

8.

c . 18–23 Gy is the TD 5/5 for the kidney. Nephrons have a limited ability to regenerate after damage and, due to their rich blood supply, are at higher risk of radiation damage.

9.

a . A plasmacytoma is another name for a solitary multiple myeloma. Originating from the antibody producing white blood cell, this bone tumor forms a single lesion.

10.

a . Soft tissue sarcomas are primarily controlled by total excision. Total tumor excision reduces risk of local recurrence. Limb-sparing surgery allows for preservation of the limb's function. Surgery is a highly effective localized treatment and often the only treatment needed if clear margins are obtained.

Palliative Care

1.

- a . Vision problems are symptoms of abnormality in the parietal or occipital lobes of the brain.
- 2. The lytic lesion would appear moth-eating and the blastic lesion would appear as dense, abnormal overgrowth of bone on x-ray.
- 3. Palliative doses for brain metastasis are typically 300 cGy per fraction to a total dose of 30–45 Gy. Doses for primary brain malignancy are typically 180–200 cGy per fraction to total of 60 Gy.

SRS for small, isolated, metastatic lesions may be given to total dose of 20–30 Gy.

SRT for small, isolated primary lesions may be given to total dose of >60 Gy.

4.

Superior vena cava syndrome—

a compression of the vena cava by tumors in the apex of the lung or mediastinum

Laminectomy—

removal of a portion of the lamina to decrease or prevent compression of the spinal cord

Partial hepatectomy—

removal of a portion of the liver

5.

d . Steroids are antiinflammatory substances.

6.

d . Brain metastasis may be characterized by many symptoms according to the location of malignancy.

7.

c . Cauda equine compression may cause incontinence; decreases urethral, vaginal, and rectal sensation.

8.

c . Strontium, samarium, phosphorus, and rhenium are commonly used radionuclides for bone metastasis.

9.

a . In the management of SVC syndrome and spinal cord compression, a more immediate response may be prompted by high doses such as 300–400 cGy the first few fractions, then tapering to lower doses depending on the confirmed diagnosis.

10.

d . Radiation pneumonitis is not managed by radiation therapy.

11.

a . Bone metastasis can occur anywhere in the bone; however, the long bones, pelvis, and spine are the most common areas for metastasis.

12.

a . Metastatic brain malignancy is usually identifiable by its multifocal lesions. Primary brain cancers are usually solitary.

13.

d . The cervical spine may be treated with the patient supine in neutral head position or prone with neutral head position so as not to put added stress on the cervical region.

14.

d . In the thoracic spine region, each thoracic vertebra is about 2.5 cm in length and about 6 cm in width, including the transverse processes.

15.

b . When treating spinal cord compression, the affected vertebra and one vertebra above and below should be included. A lower lumbar spine compression would require treatment of the sacrum, which is about 12 cm in width. To spare bowel, treatment of the lower lumbar spine and sacrum would be suitable for an upside-down T-shaped treatment field.

16.

a . Since the lumbar spine has concave curvature, it is most appropriate to use opposing anterior-posterior fields for even dose distribution.

17.

d . A patient having a major seizure should be assisted to a safe place to limit the risk of injury. A therapist should be available to monitor the patient once the event has ended.

18.

b . Fainting is a common symptom of SVC syndrome. Therapist should assess patient's breathing and circulation and notify the physician. Patient may resume consciousness without any intervention.

19.

a . A malignancy in the liver may prevent the normal flowing out of bile into the small intestine, leading to jaundice.

20. Using

[Figure 8.20](#) , draw the typical whole brain radiation treatment field(s).

21. Use

Figure 8.5 from previous

a . Primary adenocarcinoma of the lung.

22.

a . Lymph nodes are not usually a concern when the goal of treatment is palliation since the disease has already metastasized.

Index

Note: Page numbers followed by “

f” indicate figures, “

t” indicate tables, and “

b” indicate boxes.

A

Absolute neutrophil count (ANC)

calculation,

[83](#)

for neutropenia/anemia/thrombocytopenia,

[83](#)

[t](#)

Acute effect, of radiation exposure,

27

t,

28

Acute lymphocytic leukemia,

136

Acute radiation morbidity scoring criteria,

29

t

Acute radiation syndromes,

28

Administrative law, credentialing and,

75

Advance directive,

76

Airway obstructions,

156

Alpha decay,

19 ,

66

American Association of Physicists in Medicine (AAPM),

35

American Joint Committee on Cancer (AJCC) staging system,

103

American Registry for Radiologic Technologists (ARRT),

75

Anaphylactic shock, symptoms,

85

Anemia,

79 ,

83

t

Angiogenesis,

3

Anorexia

cause,

84

prevention,

84

Antidiarrheal therapy,

80

Antidiscrimination law,

76

Antiemetic drug

Benadryl (diphenhydramine) as,

79

Compazine (prochlorperazine) as,

78

dexamethasone as,

79

dolasetron (Anzemet) as,

79

dronabinol (Marinol) as,

79

granisetron (Kytril) as,

79

lorazepam (Ativan) as,

79

metoclopramide (Reglan) as,

79

ondansetron (Zofran) as,

79

Antifungal,

80

Antioncogenes,

1

Antiseptic,

86

Anus

clinical presentation,

107

detection,

107

diagnosis,

107

etiology,

107

staging,

107

treatment,

107

Anxiety, considerations and response to,

77

t

Anzemet (Dolasetron),

79

Asepsis

definition,

86

medical,

86

surgical,

86

Ativan (lorazepam),

79

Attenuation,

17

Autonomy

documentation,

76

advance directive as,

76

do not resuscitate as,

76

informed consent as,

76

Patient's Bill of Rights Act and,

75

principle,

76

limits to,

76

Avogadro's law,

13

B

Bacteria, single-hit, single target theory and,

25

Beam

attenuation,

17

directional devices,

49

eye view,

56 ,

57

f

modifiers,

49

quality,

17

Beam divergence,

17

formula,

60

illustration of,

18

f

Bell-shaped isodose,

60

Benadryl (diphenhydramine),

79

Beneficence

Elder Abuse and Neglect Act supporting,

75

principle,

75

tort law and,

75

Benign tumors,

1

Bergonie and Tribondeau, law,

24

Beta decay,

66

Beta negative decay,

19

Beta positive decay,

19

Betatron,

45

f

Biologic effective dose formula,

27

Biologic response modifiers (BRMs),

6

Biopsy,

2

Bite block systems,

55

Bladder

clinical presentation,

127

detection,

131

diagnosis,

131

etiology,

127

lymphatic drainage and spread patterns,

127

staging,

128

treatment,

128 ,

131

workup,

128

Blood count, assessment,

83

B-mode acquisition and targeting (BAT),

48

Body mechanics,

85

Bohr's atomic model,

13 ,

14

f

Bolus materials,

49

Bone marrow, radiation and

acute effects,

27

t

tolerance doses for,

27

t

Bone metastasis,

156

Brachytherapy equipment,

44

Brachytherapy,

9 ,

46

Brain metastasis,

154

BrainLab system,

48

Breast,

113

boards,

55

clinical presentation,

114

detection,

114

diagnosis,

[114](#)

etiology,

[114](#)

lymphatic drainage and spread patterns,

[114](#)

staging,

[114](#)

treatment,

[114](#)

C

Cancer

agents, causing,

[1](#)

cells,

[6](#)

management modalities,

9

tumors,

3

Cancer patient

constipation in,

79

drugs causing,

79

physiologic, psychological, social considerations,

76 ,

77

t

Carafate (sucralfate),

80

Carcinogenesis,

1 ,

2

f

Carcinogens,

1

Cardiac arrest,

85

Caution-airborne radioactivity,

36

Caution-high radiation area,

36

Caution-radiation area,

36

Caution-radioactive material,

36

Cell,

26

death,

24

standard fractionated radiation and,

25

mapping,

24

tissues in,

26

Cell division

chemotherapy and,

24

frequency,

24

meiosis

versus mitosis,

24

phases,

24 ,

25

f

purpose,

24

Cell survival curve,

8

f ,

25

models for plotting,

25

values for,

25

Central nervous system (CNS) radiation and, morbidity
scoring criteria,

29

t

Cervix

anatomy,

119

clinical presentation,

119

epidemiology,

119

etiology,

119

lymphatic spread patterns,

119

Chemotherapy,

6

antiemetic drugs for,

78

assessments during

normal blood count,

83

vital signs,

83

cell division and,

24

dermatologic effects,

78

late effects from,

83

t

performance scales during,

83

side effects,

76

as acute/latent,

76

assessment,

76

diarrhea,

78

mucositis/stomatitis/esophagitis,

77

myelosuppression,

78

nausea and vomiting,

77

xerostomia (dry mouth),

78

vesicant, types,

78

Chronic myelogenous leukemia,

139

Choking,

86

Civil rights law,

76

Clinical target volume (CTV),

59

Collision interactions,

16

Communication

challenges in

hearing/speech impairment,

76

impaired cognition,

76

languages,

76

literacy,

76

interpersonal,

76

modes,

76

tools for effective,

76

Compazine (prochlorperazine),

78– ,

79

Competence,

75

Compton effect,

17

Computerized treatment planning,

60

Concomitant,

9

Cone-shaped beam,

47

Confidentiality,

75

Constipation

in cancer patient,

79

drugs causing,

[79](#)

high fiber foods for,

[82](#)

b

interventions for,

[82](#)

laxatives for,

[82](#)

Contact isolation,

[87](#)

Conventional fractionated 3D-CRT, QUANTEC values for,

[30](#)

t

Coping/grief, stages,

[77](#)

t

Cosmic radiation,

14

t

Credentialing, competence and,

75

Cyclotron,

43 ,

45

f

Cytotoxic drugs,

6

D

Death, from radiation,

28

Dehydration, from diarrhea,

80

Deoxyribonucleic acid (DNA),

23

damage to, consequences,

24

direct radiation effect on,

24

location,

24

role,

24

Dermal punch,

2

Desquamation,

77

Deterministic effect

dose-response curve and,

27

of radiation exposure,

26

Dexamethasone,

79

Diarrhea

from chemotherapy,

79

dehydration from,

80

interventions for,

80

low-residue diet for,

80

b ,

80

from radiation

occurrence,

78

signs and symptoms,

78

Diet, low-residue,

80

b

Digital imagers,

47

Digitally reconstructed radiograph (DRR),

56 ,

57

f

Diphenhydramine (Benadryl),

79

Direct biopsy,

2

Direct radiation effect,

23

Disinfection,

86

Disintegration phenomenon,

19

Do not resuscitate (DNR),

76

Dolasetron (Anzemet),

79

Dose-response curve,

27 ,

28

f

Dose-volume histogram (DVH),

60 ,

62

f

Dronabinol (Marinol),

79

Drug

in radiation oncology,

87

vesicant chemotherapy,

78

Drug safety, rights,

87

Dry desquamation,

77

Dry mouth (xerostomia)

from chemotherapy,

79

interventions,

82

signs and symptoms,

78

D-shaped cavities,

43

Due process, and informed consent,

76

Dulcolax,

82

Durable power of attorney,

76

Dynamic therapy,

60

E

Early effect, dose-response curve and,

27

Eastern Cooperative Oncology Group (ECOG) performance scale,

84

Elder Abuse and Neglect Act,

75

Electromagnetic spectrum,

14 ,

15

f

Electron,

13 ,

41

beam,

42

capture,

19 ,

66

interactions,

15

Electronic portal imaging devices (EPIDs),

54

Ellis equation,

27

Embryo, radiation exposure and,

28

Endometrium

anatomy,

120

detection,

120

diagnosis,

120

epidemiology,

120

etiology,

120

histology and staging,

121

lymphatic spread patterns,

120

signs and symptoms,

120

treatment,

121

Endoscopy,

2

Environmental Protection Agency (EPA),

35

Epilation,

77

Epithelial tissues,

3

Erythema,

77

Esophagitis

from chemotherapy,

78

management,

80

management,

80

from radiation

occurrence,

77

signs and symptoms,

77

Esophagus

divisions of,

103

t ,

104

f

lymphatics,

104

f

radiation and

acute effects,

29

t

morbidity scoring criteria,

29

t

tolerance doses for,

27

t

Ethics

definition,

75

perception,

75

principles,

75

for radiation therapists,

75

Ewing sarcoma,

149

Excitation,

14

f

F

Fabricated Cerrobend blocks,

49

Fainting,

86

Familial cancers,

2

Fan-beam intensity modulated radiation therapy,

44

Fan beam versus cone beam,

47

f

Fatigue,

78 ,

82

Fetus radiation exposure and,

28

Fiduciary relationship,

76

Field arrangements and rationale,

63

t –65

t

Film badge monitor reports,

35

Fluence map,

63

f

Free radical

definition,

23

life span,

23

production,

23

and water molecule,

24

f

G

Gamma rays,

14

Gastrointestinal syndrome,

28

Generation time,

24

Genetic effects, of radiation exposure,

26

Germ

cell, division,

24

host for,

87

types,

87

Glasgow Coma Scale,

84

Granisetron (Kytril),

79

Grief/coping, stages,

77

t

Gross tumor volume (GTV),

59

Gynecologic brachytherapy procedures,

67

Gynecologic tumors,

117

H

Half-field technique,

60

Hand-foot syndrome,

78

Health care proxy,

76

Hearing/speech impairment, as communication challenge,

76

Hematocrit, assessment,

83

Hematopoietic syndrome,

[28](#)

Hemoglobin, assessment,

[83](#)

Hepatobiliary tumors

clinical presentation,

[111](#)

lymphatic drainage and spread patterns,

[111](#)

treatment,

[111](#)

Hippocratic Oath,

[76](#)

Hospital isolation,

[87](#)

types of

contact,

87

respiratory,

87

reverse,

87

strict,

87

Human body

radiation exposure, response to,

28

water in,

23

Hydrogen peroxide, radiation damage and,

23

Hydroxyl free radical, radiation damage and,

23

Hypopharynx,

93

clinical presentation,

93

detection,

93

diagnosis,

93

lymphatic drainage,

93

treatment,

94

I

Image-guided radiation therapy (IGRT),

48

Image registration,

57

Immobilization devices,

49 ,

55

Immunotherapy,

9 ,

78

Imodium (loperamide),

80

Impaired cognition, as communication challenge,

76

Indirect radiation effect,

23

Infection

breaking chain,

87

germs and

host for,

87

types,

Infection control

antiseptic and,

86

asepsis and,

86

disinfection and,

86

medical asepsis and,

86

sterilization and,

87

surgical asepsis and,

86

Informed consent,

76

Injury, signs,

26

b

Intensity,

17

Intensity-modulated radiation therapy (IMRT),

54

Intentional tort,

75

Internal conversion,

19 ,

66

Internal target volume (ITV),

59

International Commission on Radiological Protection (ICRP),

35

Interpersonal communication,

76

See also [Communication](#)

Interphase death,

[24](#)

Inverse square law,

[17](#)

Ion chambers,

[42](#)

Ionization,

[14](#)

[f](#)

Ionizing radiation,

[1](#) ,

[14](#) ,

[23](#)

Irradiation, of water,

[23](#)

Isocentric setup techniques,

60

J

Justice

antidiscrimination, civil rights, labor laws, and due process supporting,

76

constitution and amendments supporting,

76

Hippocratic Oath and code of ethics supporting,

76

principle,

75

K

Karnofsky performance scale,

83

Kidney (renal cell),

126

clinical presentation,

[127](#)

detection,

[127](#)

diagnosis,

[127](#)

etiology,

[126](#)

grading,

[127](#)

lymphatic drainage and spread patterns,

[127](#)

staging,

[127](#)

treatment,

[127](#)

Kinetic energy,

15

Kytril (granisetron),

79

L

Labor law,

76

Lactulose solution,

82

Language, as communication challenge,

76

Larynx

clinical presentation,

94

detection,

94

diagnosis,

94

lymphatic drainage,

94

treatment,

94

Lasers broadcast,

54

Laxative,

82

Leukemia, acute lymphocytic,

136

Lidocaine solution,

80

Life span, of free radical,

23

Linac gantry,

42

f

Linear accelerator,

41 ,

43

Linear attenuation coefficient,

17

Linear energy transfer, radiation with,

23

Literacy, as communication challenge,

76

Liver metastasis,

157

Living tissue

functional integrity,

23

ionization radiation effect on,

23

radiation exposure and,

23

Living will,

76

Logarithmic graph,

25

Loperamide (Imodium),

80

Lorazepam (Ativan),

79

Low-energy Crookes tubes,

41

Lower gastrointestinal system, radiation and, morbidity
scoring criteria,

29

t

Low-residue diet,

80

b

Lung,

99

clinical presentation,

99

detection,

100

diagnosis,

100

etiology,

99

lymphatic drainage,

99

radiation and, morbidity scoring criteria,

29

t

spread patterns,

99

treatment,

100

Lymphoma,

141

M

M phase, radiosensitivity,

24

Maalox,

80

Malignant tumors,

1

Mammalian cell, single-hit, multiple target theory and,

25

Mammography,

4

t ,

7

f

Manifest syndrome,

28

Man-made radiation,

34

Manual calculation parameters,

60

“Mapcheck” system,

50

Marinol (Dronabinol),

79

Maslow’s hierarchy, of needs,

77

t

Matter, and radiation, interaction,

23

Maxillary sinus,

95

clinical presentation,

95

detection,

95

diagnosis,

95

treatment,

95

Mayneord F Factor ,

66

Medical accelerator,

43

t ,

−44

t

Medical asepsis,

86

Medical emergency

anaphylactic shock as,

85

cardiac arrest as,

85

choking as,

86

fainting as,

86

respiratory arrest as,

86

seizure as,

86

stroke as,

86

Medical equipment, assisting patients with,

85

Medium energy tubes,

41

Medulloblastoma,

149

Megavoltage units,

41

Meiosis, mitosis

versus ,

24

Memorial system,

67

Metoclopramide (Reglan),

79

Mitosis, meiosis versus,

24

Mitotic index,

24

Mitotic phase

generation time in,

24

reentry delay,

24

Moist desquamation,

77

Molecule

formation,

23

water as,

23

Monitor unit calculations,

60

Monoclonal therapy, side effects,

78

Mores,

75

MRI simulation,

56

Mucositis,

77

from chemotherapy,

78

management,

80

from radiation

early signs and symptoms,

77

interventions for,

80

late signs and symptoms,

77

occurrence,

77

Mucous membrane, radiation and, morbidity scoring criteria,

29

t

Myelosuppression

from chemotherapy,

79

drugs causing,

79

occurrence,

79

severity,

79

interventions for,

83 ,

83

t
from radiation

occurrence,

78

signs and symptoms,

78

Mylanta,

80

N

Nasopharynx,

93

clinical presentation,

93

detection,

93

diagnosis,

93

treatment,

93

National Council on Radiation Protection and Measurements
(NCRP),

35

Nausea

from chemotherapy,

78

interventions for,

80

from radiation,

77

Necrosis,

77

Neoadjuvant therapy,

1

Nephroblastoma (Wilms' tumor),

147

t,

148

Neutrons,

13

Neutropenia,

79 ,

83

t

Nominal standard dose (NSD) formula,

27

Noninvasive prostate gland tumors,

67

Nonisocentric setup technique,

62

advantages,

63

disadvantages,

62–63

Nonmaleficence

credentialing and,

75

principle,

75

tort law and,

75

Non-phase-specific drugs,

6

Nonstochastic effect, of radiation exposure,

26

Nuclear accident,

26

Nuclear Regulatory Commission (NRC),

35

Nuclear transformations,

19

Nucleic acid,

23

Nutritional assessment/education,

84

anorexia and

cause,

84

prevention,

84

Nutritional supplements, types,

84

O

Occupational Safety and Health Administration (OSHA),

35

Oncology,

1 ,

87

Oncology patient care,

75

Ondansetron (Zofran),

79

Optimal stimulated luminescence (OSL),

35

Oral cavity,

92

clinical presentation,

92

detection,

92

diagnosis,

92

lymphatic drainage by site,

92

treatment,

92

Oral hygiene program,

96

b

Oral mucosa, radiation and

acute effects,

27

t

tolerance doses for,

27

t

Orbiting electrons,

16

Oropharynx

clinical presentation,

93

detection and diagnosis,

93

lymphatic drainage,

93

treatment,

93

Ovarian cancer

anatomy,

121

clinical presentation,

121

detection,

121

diagnosis,

121

risk factors,

121

treatment,

121

Oxygen enhancement ratio (OER),

26

Oxygenated cell, radiation exposure, response to,

26

P

Pain assessment/management,

84

Pain relief, considerations and response to,

77

t

Pancreas,

109

clinical presentation,

109

detection,

109

diagnosis,

109

etiology,

109

staging,

110

treatment,

110

Pancreatic neuroendocrine tumors (PanNET),

109

Paris system,

67

Particle interactions,

15

Patient's Bill of Rights Act,

75

Patterson-Parker or Manchester system,

67

Pelvic lymph nodes,

106

f ,

118

f

Performance scale, during radiation/chemotherapy,

83

Periodontal disease and caries,

95

Pharynx, radiation and, morbidity scoring criteria,

29

t

Phase-specific drugs,

6

Photoelectric effect,

17

Photon, interactions in,

17,

18

f

Physiologic needs, of cancer patient,

76 ,

77

t

Pituitary/hypophysis

clinical presentation,

131

etiology,

131

lymphatic drainage and spread patterns,

132

Plan data sheet,

61

f

Plank's constant,

15

Planning target volume (PTV),

59

Platelets, assessment,

83

Pocket ionization chambers,

35

Portal verification systems,

48

Positioning aids,

49 ,

55

Positioning devices,

49

Positron emission tomography (PET),

15

Positrons,

14

Power of attorney, durable,

76

Pregnancy, radiation exposure during,

30

Prochlorperazine (Compazine),

78

Prodromal symptoms,

28

Prostate cancer

clinical presentation,

123

etiology,

123

lymphatic drainage,

123

spread patterns,

123

treatment,

123

Proto-oncogenes,

1

Psychological needs, of cancer patient,

76 ,

77

t

Pyramid-shaped cavity,

95

Q

Quality assurance procedures,

43

t ,

43

QUANTEC values, for conventional fractionated 3D-CRT,

30

t

Quantum number,

13

Quasi-intentional tort,

75

Quimby systema,

67

R

Radiation

biology,

23

damage, cause,

24

detection mechanisms,

37

detectors and applications,

37

t
effects,

24

intensity and beam quality,

17

and matter, interaction,

23

morbidity scoring criteria,

29

t
protection,

13 ,

34

recall,

78

symbol,

14

f

systemic response to,

[26](#)

therapist, code of ethics for,

[75](#)

treatment borders,

[104](#)

Radiation exposure

atomic/molecular response to,

[23](#)

cause,

[23](#)

cellular factors,

[26](#)

cellular response to,

[24](#)

effects,

[23](#) ,

–24

living tissue response to,

23

tissue response to,

26

whole body system response to,

28

Radiation therapy,

6 ,

8

assessments during

normal blood count,

83

vital signs,

83

death from,

28

dosage,

24

drugs used in,

87

favorable effects,

24

late somatic effects,

28

performance scales during,

83

radiobiology and,

30

side effects of

as acute/latent,

76

assessment,

76

diarrhea,

78

esophagitis,

77

fatigue,

78

management,

79

mucositis/stomatitis,

77 ,

80

myelosuppression,

78

nausea,

77

skin reaction to,

76

management,

79

stages,

77

tissue response to,

26

Radiative collisions,

16

Radioactive

decay,

19

nuclides,

19

sources,

37

waste,

38

Radioactivity and nuclear transformation,

19

Radionuclide families,

19

t

Radioprotector, radiobiology and,

30

Radiosensitivity, of M phase,

24

Radiosensitizer, radiobiology and,

30

Reassortment, radiobiology and,

30

Rectum

clinical presentation,

106

etiology,

106

radiation and

acute effects,

27

t
tolerance doses for,

27

t
staging,

106

treatment,

106

workup,

106

Red blood count, assessment,

83

Redistribution, radiobiology and,

30

Reglan (Metoclopramide),

79

Relative biologic effectiveness,

24

Reoxygenation, radiobiology and,

30

Repair, radiobiology and,

30

Repopulation, radiobiology and,

30

Reproductive failure, cause,

24

Respiratory

arrest,

86

distress,

86

gating systems,

48

isolation,

87

Reverse isolation,

87

Rhabdomyosarcoma,

148

Ribonucleic acid (RNA), role of,

23– ,

24

Role fidelity,

75

Rotational therapy,

63

Rutherford's atomic model,

13

S

Salivary glands

clinical presentation,

94

detection,

94

diagnosis,

94

lymphatic drainage,

94

treatment,

94

Salivary glands, radiation and

acute effects,

27

t

tolerance doses for,

27

t

Salivary glands-parotid,

94

Scalpel incision,

[2](#)

Seizure,

[86](#)

Senokot,

[82](#)

Sewer system,

[38](#)

Simulation process,

[54](#)

Single-hit

multiple-target theory,

[25](#)

single-target theory,

[25](#)

Skin

care program,

96

b

gap formula,

60

Skin, radiation and

acute effects,

27

t ,

76

interventions for,

79

morbidity scoring criteria,

29

t

stages of response to,

26 ,

27

b

tolerance doses for,

27

t

Skin cancer,

134

clinical presentation,

134

detection,

134

diagnosis,

134

etiology,

134

lymphatic drainage and spread patterns,

134

staging,

134

treatment,

134

Small bowel

clinical presentation,

105

etiology,

105

staging,

105

treatment,

105

Social needs, of cancer patient,

76 ,

77

t

Source to skin distance (SSD)

calculation formula,

66

electron calculation,

66

treatment techniques,

62

Source-based teletherapy,

62

Source-based treatment unit,

65

Speech/hearing impairment, as communication challenge,

76

Spinal cord compression,

155

Sporadic cancers,

2

Standard fractionated radiation,

25

Standard fractionation,

27

b ,

27

Standard precaution,

87

Stereotactic head rings/frames,

49

Stereotactic radiation therapy (SRT),

49

Stereotactic radiosurgery (SRS) techniques,

49

Sterilization,

87

Stochastic effect

dose-response curve and,

27

of radiation exposure,

26

Stomach,

104

clinical presentation,

104

detection,

104

diagnosis,

104

etiology,

104

spread patterns,

105

staging,

105

treatment,

105

Stomach, radiation and

acute effects,

27

t

tolerance doses for,

27

t

Stomatitis

from chemotherapy,

78

management,

80

from radiation,

77

early signs and symptoms,

77

late signs and symptoms,

77

occurrence,

77

Strict isolation,

87

Stroke,

86

Sucralfate (Carafate),

80

Superior vena cava (SVC) syndrome,

157

Surgical asepsis,

86

Syncope,

86

T

Target volume terminology,

57

Terrestrial radiation,

14

t

Testis, radiation and

acute effects,

27

t

tolerance doses for,

27

t

Therapeutic ratio diagrams,

8

f

Therapy equipment evolution,

41

Therapy machines,

41

Thermoluminescent dosimeters,

35

Thrombocytopenia,

79 ,

83

t

Tissue, in cells,

26

radiation and

damage from,

27

response to,

26

types,

26

Tissue damage, manifestations,

78

Tomotherapy machine,

44

Tort

definition,

75

intentional,

75

quasi-intentional,

75

as unintentional,

75

Tort law

beneficence and,

75

nonmaleficence and,

75

Toxicity scoring system,

28

Transmission,

17

Treatment accessories,

49

Treatment planning systems,

49

Tumor

benign,

1

cells,

3

as hypoxic,

26

localization,

60

malignant,

U

Ultrasonography,

4

t

Unintentional tort,

75

Units of exposure,

35

Upper gastrointestinal system, radiation and, morbidity scoring criteria,

29

t

Urinary hemorrhage,

158

V

Vac-Loc bag,

56

Vac-Loc system,

56

Vagina,

119

detection,

119

diagnosis,

119

epidemiology,

119

etiology,

119

histology,

119

staging,

119

treatment,

119

Value, mores as,

75

Veracity,

75

Vesicant chemotherapy drug,

78

Virus, single-hit, single target theory and,

25

Vital signs

assessment,

83

normal, by age,

84

t

Vomiting

from chemotherapy,

[78](#)

interventions for,

[80](#)

Vulva

anatomy,

[117](#)

clinical presentation,

[117](#)

detection,

[117](#)

diagnosis,

[117](#)

epidemiology,

[117](#)

etiology,

[117](#)

histology,

[117](#)

lymphatic spread patterns,

[117](#)

prognosis,

[117](#)

staging,

[117](#)

treatment,

[117](#)

W

Water

in body,

[23](#)

irradiation,

[23](#)

as molecule,

23

molecule, free radicals and,

24

f

radiation and living tissue,

23

White blood count, assessment,

83

Whole body radiation syndrome,

30

t

X

Xerostomia (dry mouth)

from chemotherapy,

79

interventions for,

82

occurrence,

78

signs and symptoms,

78

X-ray

production,

15– ,

16 ,

16

f

tube,

16

f

Xylocaine,

80

XYZ coordinate system,

54 ,

55

f ,

56

Z

Zofran (ondansetron),

79