Fundamentals of Nuclear Medicine

Edited by
Naomi P. Alazraki, M.D.
and
Fred S. Mishkin, M.D.

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EDITORS

Naomi P. Alazraki, M.D.
Chief, Nuclear Medicine Service
VA Medical Center
and Professor of Radiology
University of Utah Medical School
Salt Lake City, Utah

Fred S. Mishkin, M.D.
Director of Nuclear Medicine
King/Drew Medical Center
and Professor of Radiology
Drew Postgraduate School of Medicine
Los Angeles, California

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Preface

This basic guidebook for clinical nuclear medicine is written as an easily readable description of how nuclear medicine procedures should be used by clinicians in evaluating their patients. It is designed to assist medical students and physicians in becoming acquainted with the major useful nuclear medicine techniques for detecting and evaluating common disorders. The material provides an introduction to, not a textbook of, nuclear medicine; it has been written in a manner that will encourage a medical student or physician to read it in an evening or two.

Each chapter is devoted to a particular organ system or topic relevant to an understanding and appreciation of the risks and benefits involved in nuclear medicine studies. The basics of radiation and evaluation of radiation risk in the perspective of the levels of natural environmental radiation are presented to educate physicians. The awareness and sensitivities of the general public toward the topic of radiation demand that all clinicians who refer patients for studies using ionizing radiation have a basic understanding of radiation. Chapter 1 places the phenomenon of radiation in perspective.

The emphasis is on presenting the rationales for ordering the various clinical imaging procedures performed in most nuclear medicine departments. An Appendix summarizes the approximate sensitivities and specificities of various radionuclide studies for particular diseases or physiologic evaluations. The sensitivities and specificities listed represent the consensus of estimations submitted by a group of knowledgeable practicing nuclear medicine physicians. Selected Readings are listed at the end of each chapter for those interested in obtaining additional information.

A glossary of nomenclature and terms used in discussions of nuclear medicine and radiation is included. In addition to the clinical emphasis of this manual, a brief explanation of how the imaging equipment works is provided. Discussion of nonimaging studies, including the in vitro radioimmunoassay procedures, is included.

Although the chapters are primarily organized according to organ systems, some chapters deal with specific categories of problems or diseases; for example, Chapters 11–13 are devoted to evaluation of trauma, infectious or inflammatory lesions, and cancer. Where appropriate, alternative imaging modalities including ultrasound, computed tomography imaging, and radiographic special procedures are discussed. Comparative data between nuclear medicine imaging and other modalities are presented to help guide the practicing clinician in the selection of the most appropriate procedure for a given problem. Clinical experience with nuclear magnetic resonance as an imaging modality is not yet sufficiently established at the time of this writing to permit comparative data relative to radionuclide studies.

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The Editors

Contributors

Naomi P. Alazraki, M.D.
Chief, Nuclear Medicine Service,
VA Medical Center;
Professor of Radiology,
University of Utah Medical School,
Salt Lake City, Utah

Manuel L. Brown, M.D.
Physician of Nuclear Medicine,
Mayo Clinic;
Associate Professor of Laboratory Medicine and Radiology,
Mayo Medical School,
Rochester, Minnesota

Frederick L. Datz, M.D.
Staff Nuclear Medicine Physician,
The University of Utah Medical Center;
Assistant Professor of Radiology,
The University of Utah Medical School,
Salt Lake City, Utah

Leon S. Malmud, M.D.
Professor of Nuclear Medicine,
Temple University;
Chairman, Department of Diagnostic Imaging
Temple University Hospital
Philadelphia, Pennsylvania

Frederick S. Mishkin, M.D.
Director of Nuclear Medicine,
King/Drew Medical Center;
Professor of Radiology,
Drew Postgraduate School of Medicine,
Los Angeles, California

Isaac C. Reese, Ph.D.
Acting Chairman, Department of Radiology,
King/Drew Medical Center;
Professor of Radiology,
Drew Postgraduate School of Medicine
Los Angeles, California

Barry A. Siegel, M.D.
Director, Division of Nuclear Medicine,
Mallinckrodt Institute of Radiology,
Professor of Radiology and Medicine,
Washington University School of Medicine,
St. Louis, Missouri

James A. Sorenson, Ph.D.
Director of Medical Physics,
Professor of Radiology,

University of Utah Medical School,
Salt Lake City, Utah

Leroy A. Sugarman, M.D.
Attending Physician, Nuclear Medicine,
Montefiore Medical Center;
Associate Professor of Nuclear Medicine and Radiology,
Albert Einstein College of Medicine,
Bronx, New York

Andrew T. Taylor, Jr., M.D.
Director of Nuclear Medicine,
Professor of Radiology,
University of Utah Medical School,
Salt Lake City, Utah

Heidi S. Weissmann, M.D.
Attending Physician, Nuclear Medicine,
Montefiore Medical Center;
Associate Professor of Nuclear Medicine and Radiology,
Albert Einstein College of Medicine,
Bronx, New York

Henry N. Wellman, M.D.
Director of Nuclear Medicine Division,
Indiana University Hospital;
Professor of Medicine and Radiology,
Indiana University Medical Center,
Indianapolis, Indiana

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Radiation in Perspective

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Basic Science of Nuclear Medicine

RADIATION AND DOSE

Energy emitted by atoms undergoing internal change, transferred through space or matter, is called radiation. Medical diagnostic imaging chiefly has used ionizing radiation in the form of x-rays and γ-rays. β-particles and α-particles, also forms of ionizing radiation, may contribute to radiation dose in medical procedures, but are not useful for imaging, mainly because they travel distances of only a few millimeters in tissue. In addition to ionizing radiation, nonionizing radiation in the lower-energy portion of the electromagnetic spectrum, radiofrequency (RF), is used in the process of nuclear magnetic resonance (NMR) to induce changes in the nuclei of atoms that have been placed in a stable, uniformly graded magnetic field. Images are formed from the recorded tissue responses to the RF signal in the magnetic field. Medical imaging also employs ultrasound (coherent, high-frequency sound wave radiation) to form images by reflection from tissue interfaces of different acoustic impedances. This chapter deals with ionizing radiation and its effects on human beings.

Tissue exposed to radiation is said to be irradiated. The amount of radiation energy absorbed by tissue is called radiation dose and is specified in rads or millirads (1/1000 rad).* A dose

*Throughout this book we use traditional radiation units: rads, rems, roentgens, and curies. Recently, several national and international bodies have recommended a transition to S.I. (Système Internationale) units. Students and practioners are encouraged to become familiar with S.I. units (see Appendix) and of 1 rad implies 100 ergs of energy absorbed per gram of tissue. A closely related quantity, called dose equivalent, relates the dose to biologic risk and is specified in rems. For practical purposes, a dose of 1 rad from x-rays or radiation associated with nuclear medical procedures delivers a dose equivalent of 1 rem. Some types of radiation associated with nuclear weapons (e.g., α-particles and neutrons) have greater potential for biologic damage and deliver dose equivalents of 10–20 rem/rad of dose. Finally, the quantity exposure refers to the amount of ionization produced by a beam of x-rays or γ-rays in air and is used to specify radiation levels in the environment. The basic unit is the roentgen (R). Exposure levels are measured with radiation detection devices such as ionization chambers and Geiger counters. For x-rays and γ-rays, when the measured exposure level is 1 R, the dose that would be delivered to a mass of tissue located at that same point would be approximately 1 rad. Hence, for radiation used for medical diagnostic purposes, roentgens, rads, and rems turn out to be numerically equivalent, although they actually represent different quantities.

The major difference between electromagnetic radiation, such as x-rays and γ-rays, and particle-type radiation, such as β-particles and α-particles, lies in their ability to penetrate matter. Whereas β-particles travel only a few millimeters in soft tissue before expending all their energy, x-rays and γ-rays distribute their energy more diffusely and can traverse many centimeters of tissue. Hence, β-particles deliver highly localized radiation doses, whereas x-rays and γ-rays deliver doses more uniformly and in a less concentrated way throughout the irradiated tissues. The dose concentration of β-particles is used to advantage, for example, in the treatment of hyperthyroidism with radioiodine, because the selective uptake of iodine by the thyroid gland results in highly selective irradiation of that organ. In contrast, for external-beam therapy, x-rays or γ-rays from linear accelerators or cobalt-60 machines are used to treat larger volumes of tissue to a more uniform dose level. For a given dose level and dose distribution, however, x-, γ-, and β-radiation have similar biologic and therapeutic effects.

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to incorporate them into routine usage. However, in the interest of familiarity, we will continue to use traditional units in this book.

Although significant gaps in knowledge persist, we have learned a great deal about the deleterious effects associated with tissue radiation. We know that a sharp and decisive distinction must be made between the effects produced by massive amounts of radiation, for example, from nuclear bombs or radiation for cancer therapy, and those produced by the low levels of medical radiation for diagnosis, which differ in dose levels by factors of thousands or more. An understanding of natural environmental radiation, which also constitutes a source of low-level radiation exposure, is useful in placing medical radiation in proper perspective.

Background Radiation

Radiation from cosmic rays and from naturally occurring radioactive atoms results in variable background irradiation, depending on where we live. Major differences exist between sea level and high altitudes and between regions of different soil and rock compositions. In Florida, for example, the average annual background radiation approximates 80–100 mrem/year, whereas in some high regions of India, exposures measure up to 1300 mrem/year. Background radiation in the Denver–Boulder, Colorado area is twice that at sea level. If one lives in a brick building, the naturally occurring radioactivity in the material used to make the brick increases background irradiation above that of a wood building. There is no firm evidence to indicate harmful effects of these increased background levels of radiation, however.

The human body contains natural radioactivity as well. Approximately 0.01% of our body potassium is radioactive potassium-40 (about 0.1 μCi).* Our bodies also contain $\sim$ 0.1 μCi carbon-14. Currently, laboratory animals containing this amount of injected radioactivity are considered radioactive, yet no one considers the normal human body radioactive.

The chief source of increased radiation to human beings over background levels is medical diagnostic radiation. Although such levels are not delivered uniformly to the entire population, calcula-

*The microcurie (μCi) is a unit of radioactive quantity. See Appendix.