2nd edition

Fundamentals of NUCLEAR MEDICINE

Edited by
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Fundamentals of Nuclear Medicine

Second Edition

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Fundamentals of Nuclear Medicine

Preface to Second Edition

The widespread acceptance of this small volume to help introduce fundamental nuclear medicine principles to medical students has prompted this update. In a continually changing diagnostic field, currency and perspective without bulk pose a difficult challenge. We have tried to present a balanced approach to the diagnostic value of nuclear medicine procedures, emphasizing what they do best, as well as pointing out their limitations. The exciting promise of positron emission tomography, which is providing unique insights into body chemistry and function, is outlined in this update. Our intent is to provide an introduction to this rapidly evolving technology as it emerges from the investigative into the clinical stage.

We appreciate the cooperation of all contributors and many others without whose contributed efforts this work could not have been completed in a timely fashion. We would especially like to acknowledge the efforts of Richard Witcofski, Ph.D., Chairman of the Publications Committee, and William D. Kaplan, M.D., Chairman of the Education and Training Committee of the Society of Nuclear Medicine. We are indebted to those in the Central Office of the Society of Nuclear Medicine, particularly David Teisler, Toni Ann Scaramuzzo, and Eleanore Tapscott, whose patience and generous help brought forth this new edition with a minimum of delay and aggravation.

The Editors

Preface to First Edition

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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Contents

Radiation in Perspective

1

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 has used chiefly *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 magnetic resonance imaging (MRI) 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.

The amount of radiation energy absorbed by irradiated tissue is called radiation dose and is specified in grays (1 Gy = 100 rad)* or in rads or millirads (1/1000 rad).* A dose of 1 rad

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*Throughout this book we use both traditional radiation units: rads, rems, roentgens, curies, and SI (Système Internationale) units. Students and practitioners are encouraged to become familiar with SI units (see Appendix).

implies 100 erg of energy absorbed per gram of tissue and 1 gray implies 1 joule of energy per kilogram of tissue. A closely related quantity, called dose equivalent, relates the dose to biologic risk and is specified in sieverts (1 Sv = 100 rem) or rems. For practical purposes, a dose of 0.01 Gy or 1 rad from x-rays or radiation associated with nuclear medical procedures delivers a dose equivalent of 0.01 Sv or 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 Sv/Gy or 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 ~0.01 Gy or 1 rad. 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 particulate radiation, such as β-particles and α-particles, lies in their ability to penetrate matter. Whereas β-particles travel only a few millimeters and α-particles travel less than 100 μm 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 and α-particles deliver highly localized radiation doses, whereas x-rays and γ-rays deliver doses more uniformly 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.