Radiation Safety in Nuclear Medicine

Second Edition

Max H. Lombardi

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To my students
in Oak Ridge, Tampa, and in
Central and South America —
my best wishes
wherever they may be

Preface to the Second Edition

The main objectives of this book remain unchanged in this second edition. They are to teach the students of nuclear medicine (NM) technology: (1) the principles of radiation physics, (2) the units of radioactivity, radiation exposure, and radiation dosimetry, (3) the principles of instrumentation needed for radiation detection and measurement, (4) the basis of NM imaging, (5) the scientific basis of radiation safety, (6) the rules and regulations of radiation safety, (7) the practice of radiation safety in hospitals and clinics in the United States, and (8) the fundamentals of radiobiology.

The field of NM has made many advances in the few years since this book was first published in 1999. Thanks to the efforts of the global biomedical community, those advances are making the diagnosis, the management, and the treatment of illnesses more sensitive, more specific, more accurate, and safer for patients of all ages. In this second edition, those advances are introduced keeping in mind that the final scope is the teaching of the radiological safety of the patients, the NM personnel, and all visitors to the NM department of hospitals and clinics. Some examples of those advancements follow.

1. The progress made in positron emission tomography (PET), its related radiopharmaceuticals, instrumentation, and procedures has been remarkable. This has been possible for two reasons: (1) the expansion of Medicare coverage and other insurance plans for PET imaging procedures and (2) the subsequent multiplication of medical cyclotron facilities (PET centers) in metropolitan areas. These facilities produce the necessary positron-emitting radionuclides and the labeled compounds using robotic radiochemical synthesizers.
2. The merging of two imaging modalities: (1) the metabolic images of PET using ^{18}F-labeled deoxyglucose (FDG) and (2) the exquisite anatomical images of computerized tomography (CT), in one scanning procedure lasting less than eight minutes. This combination is, without a doubt, of utmost importance to the patient.
3. Many new imaging and therapeutic radiopharmaceuticals that use "molecular targeting" as a method of localization are being tested now and soon shall become routine in NM. This should not surprise us since for years radiolabeled antibodies have been used to target specific antigens within tissues both for imaging and for treatment. The "magic bullets" and the age of molecular medicine are here to stay.

Recent revisions in the U.S. Code of Federal Regulations, Title 10, (10CFR), parts 19, 20, 30, and 35, which apply to the use of radiopharmaceuticals in medicine, are also introduced in this second edition of the book. The CFR is the document

enforced by the Nuclear Regulatory Commission (NRC) in 18 states and the designated agencies in the remaining 32 "agreement states" within the U.S.

The role played by nuclear medicine technologists (NMTs) in the everyday practice of NM must be recognized. As their responsibilities become more and more complex with the arrival of new methodologies, they must participate in "on-site" training programs and in continuing education plans to earn and maintain accreditation. The efforts of the Society of Nuclear Medicine, Technology Section (SNMTS), in this regard must be recognized and appreciated, also. Its "Performance and Responsibility Guidelines for NMTs," approved at the SNM annual meeting of June 2003, is contributing to the update and upgrade of educational programs for NMTs.

The author wishes to express his gratitude to the many persons who directly or indirectly participated in making this second edition a reality. Special recognition and appreciation is given to Martin Sabarsky, vice president of corporate development, Diversa Corporation, San Diego, for his invaluable assistance in the editing of the original manuscript and in the remaking of six illustrations. My gratitude is extended also to Pete Shackett, B.A., C.N.M.T., A.R.R.T.(N), of Palmetto, Florida, and to Beverly Ammidown, C.N.M.T., of Gainesville, Florida, for their assistance in the literature research. My love goes to all the members of my family for their constant encouragement in the pursuit of this worthwhile project.

Max H. Lombardi

Author

Max H. Lombardi was born in Peru, South America. He attended primary and secondary schools in Mollendo and Lima. He earned his B.V.M. and D.V.M. degrees at the University of San Marcos in 1957 and 1958, respectively. In 1960, he earned a fellowship from the Rockefeller Foundation to study radiation biology at Cornell. The following year, he earned his M.S. degree with a major in radiation biology and minors in biochemistry and animal nutrition. He then returned to the University of San Marcos where he took the position of assistant professor.

In 1964, the Oak Ridge Institute of Nuclear Studies (ORINS) asked Dr. Lombardi to organize and coordinate the training programs of "Atoms in Action" for Latin America, an exhibit sponsored by the U.S. Atomic Energy Commission (USAEC). Between 1964 and 1969, the exhibit was successfully presented in nine countries of Central and South America. In 1965, he was asked to join the staff of ORINS as a scientist.

In 1968, Dr. Lombardi was promoted to senior scientist, assuming responsibility for the coordination of radiation biology training programs for college teachers sponsored by the National Science Foundation. At the time, he developed a number of training experiments using animals and computers and published a number of articles in the *Journal of Veterinary Research.*

In 1969, he took responsibility for the Medical Radioisotopes Qualification Course, which, under the USAEC, trained physicians in the science and practice of nuclear medicine (NM). He remained in that position until 1977. More than 1,000 physicians were trained in that period. In December of 1970, he became a U.S. citizen.

In 1977, Dr. Lombardi competed for and won the position of full-time professor of nuclear medicine at the Hillsborough Community College (HCC) in Tampa, Florida. In 1979, he earned certification by the American Board of Science in Nuclear Medicine (ABSNM). In 1982, he became director of the NMT Program and radiation safety officer of HCC, positions which he held until his retirement in 1997. During his tenure, he has trained over 300 nuclear medicine technologists.

During his career, Dr. Lombardi has participated in many conferences and continuing education programs by the Society of NM, the Florida NMT Association, the Health Physics Society, the Clinical Ligand Assays Society, the World Federation of Nuclear Medicine and Biology, and the Association of Latin American NM. He has lectured in the U.S. and twelve foreign countries. Dr. Lombardi is fluent in Spanish, English, Portuguese, and Italian. At present, he resides in San Diego, California.

Contents

1 Principles of Radiation Physics

I. RATIONALE

Radiopharmaceuticals (RPs) are radiation-emitting substances used as radiotracers in radiation biology, in biomedical research, and in the practice of nuclear medicine (NM). There is no question about the usefulness of radiotracers in these fields of science. In the hands of well-trained persons, radiotracers are wonderful tools that can save time and effort in solving problems. When improperly used, however, radioactive materials can result in unnecessary exposures to personnel, patients, and visitors to the NM department of a hospital or clinic.

To comprehend the hazards of radiation and to avoid unnecessary exposures, we must first understand the nature and properties of those radiations: how they are emitted and how they interact with materials such as lead, the most important shielding material, and with the human body. This chapter begins with a review of the history of radiation science. In this manner we honor the pioneers who laid the foundations of modern science, including NM. That is followed by a review of the nature and properties of those radiations that are of immediate concern in the practice of NM.

II. BRIEF HISTORY OF RADIATION SCIENCE

A. The Nature of Matter

From 530 to 240 B.C.E., Greek philosophers developed their own ideas about the nature of matter. Pythagoras explained that matter was made of four elements: earth, water, air, and fire. Their properties were hot, cold, wet, and dry. Democritus proposed that matter was discontinuous, made of tiny, indivisible particles, which he called *atoms*, and the rest, he said, was vacuum. Aristotle later endorsed Pythagoras's hypothesis. However, Pythagoras is best known for his theorem of rectangular triangles: $c^2 = a^2 + b^2$. In 240 B.C.E., Archimedes was the first to measure the density of solids. He discovered the principle of buoyancy, according to which a body submerged in a fluid is lifted by a buoyant force equal to the weight of the fluid displaced. Supposedly, he discovered it while taking a bath. He then ran, yelling, "eureka, eureka" — "I found it! I found it!"