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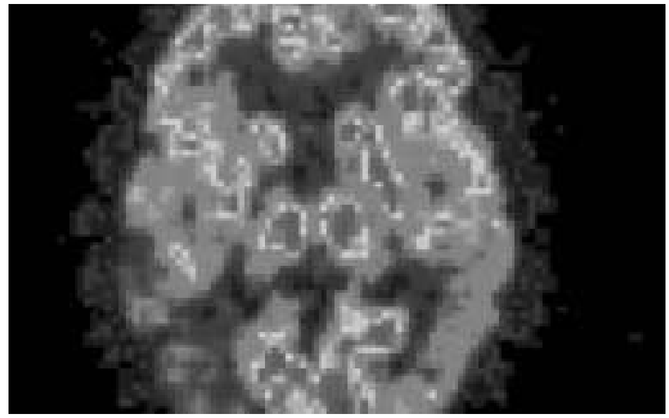

Nuclear Medicine INSTRUMENTATION

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BRIEF CONTENTS

CONTENTS

PREFACE

As a first-time author, I have a tremendous sense of satisfaction to be asked to prepare a second edition. Many thanks to my fellow nuclear medicine technology program directors who were willing to give a brand-new textbook a try. I am delighted to have the opportunity to correct mistakes, concepts, clarify and bring various topics to a more current state of affairs. I am also quite pleased to have two contributing authors for this edition. Michael Teters and Fady Kassem are medical physicists with wide experience in radiology and a deep understanding of nuclear medicine instrumentation. Both have been of great assistance to me in the process of preparing the Second Edition. Fady in particular contributed the initial draft of the chapter on magnetic resonance imaging, for which I am very grateful.

I have made major changes in a number of chapters and have added two new chapters. I would like to call your attention to these:

- Chapter 2—there is a new concept map elucidating the operation of a scintillation detector, a better description of calibration, and clarification of energy resolution (the property being measured) vs FWHM (the mechanism by which it is measured).
- Chapter 5—the section on non-Anger cameras was rewritten to address planar devices only, with descriptions of non-Anger SPECT systems in Chapter 12.
- Chapter 12—this chapter was updated to include recent improvements, a section on noise regularization, and more information on implementation and clinical benefits. Both software methods of incorporating improvements and non-Anger 3D imaging systems are discussed.
- Chapter 15—photos of a PET tomograph taken apart are included so that the reader can see crystals, septa, electronics, and a rod source. The description of direct and cross-planes is expanded. There is decreased emphasis on 2D vs 3D imaging, and new sections on dynamic and gated imaging and organ-specific PET systems are included.
- Chapter 16—the section on the SUV is rewritten to reflect its increasing importance, and a new section on the benefits of time-of-flight PET is included.
- Chapter 19—this is a completely new chapter on MRI, written as the first PET/MRI scanners are coming into clinical use. It aims to provide a modest rather than in-depth level of understanding of MRI as well as the technological challenges and clinical benefits of combining MRI with PET imaging.
- Appendix A—this has been extensively rewritten to emphasize the consequences of radiation interactions.
- Appendix F—this is a new appendix on laboratory accreditation; references to the requirements of accrediting agencies are also sprinkled throughout the text as appropriate.

How to Use this Text

- **Parts:** The text is broken into four parts that, for the most part, can be comprehended separately, without reference to the others. The only exception is that an understanding of Part II (Gamma Cameras) is assumed in Part III (Single-Photon Emission Computed Tomography).
- **Key terms:** Important words and phrases are italicized when they are introduced. These terms are defined in the new glossary found at the end of the book.
- **Abbreviations:** All abbreviations are spelled out at their first mention in each chapter. A comprehensive list of abbreviations and scientific units are provided in the front matter and a general list is printed inside the back cover as a helpful reference.
- **Sample calculations:** These are included to illustrate the mathematical application of the referenced equations throughout the text.
- **Appendices:** The appendices provide a deeper level of understanding for those who are interested in greater insight on specific topics.
- **References:** I have cited resources used in writing and updating this edition. They may or may not be helpful in expanding learning.
- **Additional resources:** I have compiled a list of additional resources to provide readers with helpful books and articles that will aide in further learning.

ACKNOWLEDGMENTS

When I was in graduate school, I wrote a paper on the environmental effects of the practice of nuclear medicine. In the paper, I referred a number of times to nuclear medicine *technologists*. The professor, a nuclear engineer, crossed out every occurrence of that word and wrote the word *technician* in its place. When I asked why he did that, he replied that "technologist" implied an understanding of the technology. I was quite insulted by that and vowed that my students would have a good understanding of the technology that underlies nuclear medicine. So, my first (somewhat backhanded) acknowledgment is to Dr. Maurice Robkin for providing the impetus for me to write this textbook.

As is true of many books, this work reflects my own understanding, which has been shaped by many other people, a few of whom I would therefore like to acknowledge. Dr. Paul Brown taught me nuclear medicine and has always been a role model. Barbara Ratliff, CNMT, taught the instrumentation course in my training program for many years, and the chapters on gamma cameras and SPECT imaging were originally based on her lecture notes. I have benefitted from a number of continuing-education sessions at national nuclear medicine meetings and the insights of those who truly are experts in the field. Drs. Mike Yester and Tom Lewellen, and Robert Hobbs, MS, provided initial reviews of different sections of the first edition. Tony Knight read through the entire manuscript of the first edition several times.

For this second edition, I would like to express my deep gratitude to Fady Kassem and Michael Teters for assisting me with this edition; their advice, guidance, and clarification on the finer points of medical physics were invaluable. Fady provided the first draft of the chapter on MRI, and tirelessly reviewed my additions and edits. Several people who I consider giants in the field of nuclear medicine, including Dr. F. David Rollo, Dr. Michael Phelps, and Dr. Thomas Budinger, allowed me to use figures that they had created. I am grateful to my publisher, Jones & Bartlett Learning, my production editor Amy Rose, and my art editor Joanna Lundeen. Some of the work was done by people I did not have the pleasure of meeting, but the copyeditor and proofreader provided several rounds of careful reading and editing (and certainly got an education in nuclear medicine instrumentation while doing so).

I would especially like to acknowledge my fellow nuclear medicine educators. I appreciate those who let me know about errors in the first edition and made suggestions for improvements. I am grateful to those who have given me encouragement, especially those who have indicated that their ability to teach this subject has been enhanced by the textbook. My goal in writing this text was to address a significant deficit in our available resources, and your praise has given me the assurance that I have indeed met that goal.

My students continue to give me inspiration, as I see their understanding of the field reach higher and higher levels. Every year, through their struggles, I gain new insights. My coworkers at Virginia Mason Medical Center, and more recently at Bellevue College, have been supportive and encouraging. Finally and most importantly, I thank my husband, Peter, and my daughter, Krysta, for their patience through the many, many hours spent preparing the first and then the second edition. Publication of this text has been a labor of love for my profession, but it has been possible only because of the love and support of my family.

ABOUT THE AUTHOR

Jennifer Prekeges, MS, CNMT, graduated from the nuclear medicine technology program at the Veterans Administration Medical Center in Portland, Oregon, in 1980. Prior to attending that program, she received a bachelor of arts degree in biology and chemistry from Whitman College in Walla Walla, Washington. Jennifer worked as a nuclear medicine technologist for 20 years in the Seattle, Washington, area, and has been involved in nuclear medicine education since about 1983. She started the nuclear medicine technology program at Bellevue College in 1989, after receiving a master of science degree in radiological sciences from the University of Washington. She simultaneously directed the program and worked as a staff technologist at Virginia Mason Medical Center for the first 14 years of its existence, moving to a full-time position at Bellevue College in 2003. In addition to her work as an educator, Jennifer has served as a director and secretary of the Nuclear Medicine Technology Certification Board (1997–2005), reviewer for the *Journal of Nuclear Medicine Technology* (1995–present), member of the Academic Affairs committee of the Society of Nuclear Medicine Technologist Section (1995–1997 and 1998–1999), and copresident of the Pacific Northwest Chapter, Society of Nuclear Medicine Technologist Section (1999–2000). She has authored eight journal articles and one book chapter in addition to this text. In her spare time, she enjoys reading, birdwatching, cross-stitching, and Sudoku puzzles.

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LIST OF ABBREVIATIONS

General Scientific Abbreviations

g = gram
m = meter
cm = 0.01 meter; cm^2 = square centimeter, cm^3 = cubic centimeter
ml = milliliter
in = inch
sec = second
hr = hour
° = degrees of a circle
°C, °F = degrees on the Celsius (centigrade) or Fahrenheit temperature scales
Hz = Hertz (cycles/sec)
V = volts
eV = electron volt
kVp = kilovolt peak
ΔV = electrical potential difference between two charged objects
A = ampere
C = capacitance or Coulomb
cts = counts
cps = counts/second
cpm = counts/minute
dpm = disintegrations per minute
dps = disintegrations per second
Ci = Curie
Bq = Becquerel
ppm = parts per million
R = Roentgen
rem = Roentgen-equivalent man
s.d. = standard deviation
σ = standard deviation based on Poisson estimation
Sv = Sievert
τ = time constant (e.g., in a RC circuit)
T = tesla
μ_ℓ = linear attenuation coefficient
μ_m = mass attenuation coefficient
1D = one-dimensional
2D = two-dimensional
3D = three-dimensional
4D = four-dimensional

Standard order-of-magnitude abbreviations:

G = giga = $\times 10^9$
M = mega = $\times 10^6$
k = kilo = $\times 10^3$
m = milli = $\times 10^{-3}$
μ = micro = $\times 10^{-6}$
n = nano = $\times 10^{-9}$
p = pico = $\times 10^{-12}$

Greek Letters

Uppercase	Lowercase	Name
Α	α	alpha
Β	β	beta
Γ	γ	gamma
Δ	δ	delta
Ε	ϵ	epsilon
Ζ	ζ	zeta
Η	η	eta
Θ	θ	theta
Ι	ι	iota
Κ	κ	kappa
Λ	λ	lambda
Μ	μ	mu
Ν	ν	nu
Ξ	ξ	xi
Ο	o	omicron
Π	π	pi
Ρ	ρ	rho
Σ	σ	sigma
Τ	τ	tau
Υ	υ	upsilon
Φ	ϕ	phi
Χ	χ	chi
Ψ	ψ	psi
Ω	ω	omega

Other Abbreviations

AAPM = American Association of Physicists in Medicine
AC = attenuation correction
ACF = attenuation correction factor
ACR = American College of Radiology
ADC = analog-to-digital converter
ALU = arithmetic-logic unit
AOR = axis of rotation
ARRT = American Registry of Radiologic Technologists
BGO = bismuth germanate

CFOV = central field of view
CNR = contrast–noise ratio
COR = center of rotation
CPU = central processing unit
CR = capacitor-resistor (circuit)
CRT = cathode ray tube
CSF = cerebrospinal fluid
CT = computed tomography
CTDI = CT dose index
CTW = coincidence timing window
CV = coefficient of variation
CZT = cadmium–zinc–tellurium
DAS = data acquisition system
DCA = decimal counting assembly
DICOM = Digital Imaging and Communications in Medicine
DLP = dose-length product
E = emission image
ECG = electrocardiogram
EM = expectation maximization
FBP = filtered backprojection
FDA = (United States) Food and Drug Administration
FDG = F-18 fluorodeoxyglucose
FID = free induction decay
fMRI = functional MRI
FORE = Fourier rebinning
FOV = field of view
FT = Fourier transform
FWHM = full-width at half-maximum
FWTM = full-width at tenth-maximum
GI = gastrointestinal
GSO = gadolinium oxyorthosilicate
GUI = graphical user interface
HIS = hospital information system
HU = Hounsfield units
IAC = Intersocietal Accreditation Commission
ICANL = Intersocietal Commission on Accreditation of Nuclear Laboratories
IEC = International Electrotechnical Commission
IMRT = intensity-modulated radiation therapy
IV = intravenous
JCAHO = Joint Commission on Accreditation of Healthcare Organizations
LAN = local-area network
LCD = liquid crystal display
LEAP = low-energy all-purpose
LED = light-emitting diode
LLD = lower-level discriminator
LOR = line of response
LSF = line-spread function
LSO = lutetium oxyorthosilicate
LUT = look-up table
LYSO = lutetium yttrium oxyorthosilicate
MAP = maximum a posteriori
MCA = multichannel analyzer
MIP = maximum intensity projection
MIPPA = Medicare Improvements for Patients and Providers Act
ML = maximum likelihood
MLEM = maximum-likelihood expectation maximization
MPI = myocardial perfusion imaging
MR, MRI = magnetic resonance imaging
MTF = modulation transfer function
MWSR = multiple window spatial registration
NaI (Tl) = thallium-activated sodium iodide scintillation crystal
NECR = noise-equivalent count rate
NEMA = National Electrical Manufacturers Association
NEX = number of excitations
NIST = National Institute of Standards and Testing
NMR = nuclear magnetic resonance
NR = noise regularization
NSA = number of signal averages
OS = operating system
OSEM = ordered-subsets expectation maximization
PACS = picture archiving and communications system
PET = positron emission tomography
PHA = pulse-height analyzer
PLES = parallel-line equal-spacing
PMT = photomultiplier tube
PP = pulse programmer
PROM = programmable read-only memory
PSF = point-spread function
PSPMT = position-sensitive photomultiplier tube
PVE = partial volume effect
q, Q = electrical charge
QC = quality control
R_{coll} = collimator resolution
R_{int} = intrinsic resolution
R_{system} = system resolution
RAM = random access memory
RC = resistor-capacitor (circuit)
RF = radio frequency
RIS = radiology information system
ROM = read-only memory
RR = resolution recovery
rSF = residual scatter fraction
SC = scatter compensation
SCA = single-channel analyzer
SI = Systeme International
SMPTE = Society of Motion Picture and Television Engineers
SNM = Society of Nuclear Medicine
SNMTS = Society of Nuclear Medicine Technologist Section
SNR = signal-to-noise ratio
SPECT = single-photon emission computed tomography
SUV = standardized uptake value
T = transmission image
TBAC = transmission-based attenuation correction
TE = time to echo
TJC = The Joint Commission
TOF = time of flight
TR = time to repetition
UBP = unfiltered backprojection
UFOV = useful field of view
ULD = upper-level discriminator
UV = ultraviolet
VDT = video display terminal
WAN = wide-area network