

RADIOGRAPHY IN THE DIGITAL AGE

Dedication

*To Jason and Stephanie,
Melissa and Tim,
Chad and Sarah,
Tiffani and Nate,
Brandon, and Tyson
a most remarkable family,
and to my cherished wife, Margaret,
who made it possible for them all
to come into my life*

THIRD EDITION

RADIOGRAPHY IN THE DIGITAL AGE

Physics—Exposure—
Radiation Biology

By

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PREFACE

New to This Edition

This 3rd edition was peer-reviewed by four colleagues who brought many valuable corrections and improvements to the text. The entire textbook has been converted to metric units, and to *Systeme International (SI)* units for radiation biology and protection. This was done to make it more usable for an international community of educators, and to align with the *American Registry of Radiologic Technologists'* adoption of SI units in 2016.

Medical imaging informatics was added to PACS in Chapter 36. *Applying Radiographic Technique* to Digital Imaging, Chapter 33, was substantially strengthened, including revised and updated material on the use of grids and new *virtual grid* software, all with an eye to reducing patient dose. The ability of digital processing not only to generally compensate for scatter radiation, but to correct *specific fog patterns* in the image is more fully explained.

Because we deal with several different kinds of “hard” and “soft” matrices, (the DR detector matrix, the light matrix of a CR reader, the “hardware pixel” matrix of a display monitor, and the “soft” matrix of the displayed light image), the relationship between field-of-view (FOV), matrix size, and spatial resolution is now completely covered in all these contexts. A new Table 13-1 lists *twenty* types of digital image noise organized into eight broad categories. These important topics relating to noise are comprehensively explored as no other radiography textbook has done to date.

In radiation biology, the section on *radiation units* in Chapter 40 has been vastly expanded to include the concepts of *air kerma*, exposure area product, surface integral exposure, absorbed dose, dose area product, integral dose, dose equivalent, effective dose, and collective effective dose. Optically stimulated luminescence (OSL) dosimeters were also added. Digital fluoroscopy was significantly strengthened in Chapter 37. Conventional tomography has been eliminated because of its clinical obsolescence.

Many crisp illustrations have been added, along with helpful tables and refinements to the text designed to make the entire presentation more student-friendly. Remarkable clarity and concise descriptions help the student with more complicated topics, especially in the digital domain. The practical limitations of digital features such as smoothing and edge enhancement are covered with their direct implications for clinical application.

Several sections have been deleted, moved or reorganized to provide smoother transitions and development of the topics, with particular focus on the digital imaging chapters. Material on rescaling the digital image has been greatly strengthened, and new graphs have been added that make histogram analysis and errors much easier to grasp.

The math review chapter (Chapter 3) includes a section on basic graphs. Along with material on the x-ray beam spectrum, a new section titled *Understanding the Digital Histogram* has been added, which includes foundational support exercises directly related to the later chapters on digital image processing.

A *glossary* of technical radiographic and digital imaging terms has been expanded. In addition, a deliberate effort has been made to include the content areas identified in the Curriculum Guide published by the American Society of Radiologic Technologists, and to address the Standard Definitions published by the American Registry of Radiologic Technologists.

Scope and Philosophical Approach

The advent of digital radiographic imaging has radically changed many paradigms in radiography education. In order to bring the material we present completely up-to-date, and in the final analysis to fully serve our students, much more is needed than simply adding two or three chapters on digital imaging to our textbooks:

First, the entire emphasis of the *foundational* physics our students learn must be adjusted in order to properly support the specific information on digital imaging that will follow. For example, a better basic understanding of waves, frequency, amplitude and interference is needed so that students can later grasp the concepts of spatial frequency processing to enhance image sharpness. A more thorough coverage of the basic construction and interpretation of graphs prepares the student for histograms and look-up tables. Lasers are also more thoroughly discussed here, since they have not only medical applications, but are such an integral part of computer technology and optical disc storage.

Second, there has been a paradigm shift in our use of image terminology. Perhaps the most disconcerting example is that we can no longer describe the direct effects of kVp upon image contrast; Rather, we can only describe the effects of kVp upon the subject contrast in the remnant beam signal reaching the image detector, a signal whose contrast will then be drastically manipulated by digital processing techniques. Considerable confusion continues to surround the subject of scatter radiation and its effects on the imaging chain. Great care is needed in choosing appropriate terminology, accurate descriptions and lucid illustrations for this material.

The elimination of much obsolete and extraneous material is long overdue. Our students need to know the electrical physics which directly bear upon the production of x-rays in the x-ray tube - they do not need to solve parallel and series circuit problems in their daily practice of radiography, nor do they need to be spending time solving problems on velocity. MRI is briefly overviewed when *radio* waves are discussed under basic physics, sonography is also discussed under the general heading of *waves*, and CT is described along with attenuation coefficients under digital imaging. But, none of these subspecialties has a whole chapter devoted to it.

It is time to bring our teaching of image display systems up to date by presenting the basics of LCD monitors and the basics of quality control for electronic images. These have been addressed in this work, as *part of ten* full chapters dealing specifically with digital and electronic imaging concepts. If you agree with this educational philosophy, you will find this textbook of great use.

Organization

The basic layout is as follows: In Part I, *The Physics of Radiography*, ten chapters are devoted to laying a firm foundation of math and basic physics skills. The descriptions of atomic structure and bonding go into a little more depth than previous textbooks have done. A focus is maintained on *energy* physics rather than mechanical physics. The nature of electromagnetic waves is more carefully and thoroughly discussed than most textbooks provide. Chapters on electricity are limited to only those concepts which bear directly upon the production of x-rays in the x-ray tube.

Part 2, *Production of the Radiographic Image*, presents a full discussion of the x-ray beam and its interactions within the patient, the production and characteristics of subject contrast within the remnant beam, and the proper use of radiographic technique. Image qualities are thoroughly covered. This is conventional information, but the terminology and descriptions used have been adapted with great care to the digital environment.

Part 3, *Digital Radiography*, includes nine chapters covering the physics of digital image capture, extensive information on digital processing techniques, and the practical application issues of both CR and DR. PACS and medical imaging informatics are included. There is a chapter on mobile radiography, fluoroscopy, and digital fluoroscopy, and an extensive chapter on quality control which includes digital image QC.

Finally, Part 4 consists of five chapters on *Radiation Biology and Protection*, including an unflinching look at current issues and practical applications including an unflinching look at current issues and practical applications.

Feedback

For a textbook to retain enduring value and usefulness, professional feedback is always needed. Colleagues who have adopted the text are invited to provide continuing input so that improvements might be made in the accuracy of the information as well as the presentation of the material. Personal contact information is available in the *Instructor and Laboratory Manual* on disc or download.

This is intended to be a textbook written “by technologists for technologists,” with proper focus and scope for the practice of radiography in this digital age. It is sincerely hoped that it will make a substantial contribution not only to the practice of radiography and to patient care, but to the satisfaction and fulfillment of radiographers in their career as well.

Instructional Resources

INSTRUCTOR RESOURCES CD FOR RADIOGRAPHY IN THE DIGITAL AGE. This disc includes the answer key for all chapter review questions and student workbook questions, and a bank of over 1500 multiple choice questions *with permission* for instructors’ use. It also includes 35 laboratory exercises with 15 demonstrating the applications of CR equipment. The manual is available on disc or download from Charles C Thomas, Publisher.

POWERPOINT SLIDES ON DISC. *PowerPoint*[™] slides are available for classroom

use, covering the entire textbook and as many as four courses in a typical radiography curriculum:

The Physics and Equipment of Radiography

Principles of Radiographic Imaging

Digital Image Acquisition and Display

Radiation Biology and Protection

Available from Charles C Thomas, Publisher.

STUDENT WORKBOOK FOR RADIOGRAPHY IN THE DIGITAL AGE. This classroom supplement covers everything in the textbook and as many as four courses in a typical radiography curriculum. It is deliberately organized in a concise “fill-in-the-blank” format that provokes students to participate in class without excessive note taking. Questions focus on key words that correlate perfectly with the above slide series. Available from Charles C Thomas, Publisher.

DVD MINI-LESSONS. To assist the instructor on particularly difficult digital topics, a series of 20-minute video mini-lessons are available from Digital Imaging Consultants that correlate with and supplement *Radiography in the Digital Age*. Video object-lessons are combined with lucid graphics and clear, progressive explanations to make difficult material “click” for the student. Visit the website at radiographypro.com



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Some material was adopted and adapted from contributing authors to my textbook, *Practical Radiographic Imaging*, (previously *Fuchs's Radiographic Exposure, Processing and Quality Control*). They include Robert DeAngelis, BSRT in Rutland, Vermont, Robert Parelli, MA, RT(R) in Cypress, California, and Euclid Seeram, RTR, MSc, in Burnaby, British Columbia, Canada. Their contributions are still greatly valued.

Many photographs and radiographs were made available by Kathy Ives, RT, Steven Hirt, RT, Jason Swopes, RT, Trevor Morris, RT, and Brady Widner, RT, all graduates whom I proudly claim, by Fyte Fire and Safety in Midland, Texas and Apogee Imaging Systems in Roseville, California, and made available in the public domain by the U.S. Army and U.S. Navy. Thanks, in particular to William S. Heathman, BSRT, my colleague in radiography education for many years, for his support and assistance.

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On a more personal note, I owe an eternal debt of gratitude to my sweet wife, Margaret for her acceptance, support and love throughout my life. I wish to express appreciation for the professional support and loyal friendship of Dr. Eileen Piwetz, which never wavered over 25 years, along with my love and admiration for all my colleagues in health sciences education, who, often against all odds, make miracles happen on the “front line” every day.



CONTENTS

<i>Reviewers</i>	v
<i>Preface</i>	vii
<i>Acknowledgments</i>	xi

PART I: THE PHYSICS OF RADIOGRAPHY

1. Introduction to Radiographic Science	5
The Scientific Approach	5
A Brief History of X-Rays	6
The Development of Modern Imaging Technology	9
The Development of Digital Imaging	11
Living with Radiation	12
Summary	14
Review Questions	15
2. Basic Physics for Radiography	17
The Base Quantities and Forces	17
Unit Systems	19
The Physics of Energy	20
Heat and States of Matter	23
Summary	27
Review Questions	28
3. Unit Conversions and Help with Math	31
Mathematical Terminology	31
Basic Operations	32
Converting Fractions to Decimals	32
Converting Decimals and Percentages	32
Extent of Rounding	32
Order of Operations	32
Algebraic Operations	33
Rules for Exponents	33
Converting to Scientific Notation	34
Calculating with Scientific Notation	34
Converting Units with Dimensional Analysis	35
Using Table 2-1	36
Areas and Volumes	37

The Inverse Square Law	38
Graphs	40
Reading a Graph	42
Understanding the X-Ray Beam Spectrum Curve	44
Understanding the Digital Histogram	46
Summary	48
Review Questions: Practice Exercise 3-1	49
4. The Atom	53
Matter	53
Physical Structure of Atoms	55
Electron Configuration	59
Chemical Bonding	60
Covalent Bonding	60
Ionic Bonding	61
Ionization	62
Structure of the Nucleus	64
Radioactivity	66
Summary	69
Review Questions	70
5. Electromagnetic Waves	73
Waves	73
The Electromagnetic Wave Formula	78
The Plank Formula	79
The Nature of Electromagnetic Waves	80
The Electromagnetic Spectrum	82
Medical Applications of Electromagnetic Waves	85
Magnetic Resonance Imaging (MRI)	85
Ultrasound	87
Lasers	87
Computed Radiography (CR) Readers	88
Laser Film Digitizers	89
Laser Film Printers	90
Optical Disc Reading and Writing	90
Characteristics of Visible Light vs. X-Rays	91
Dual Nature of All Matter and Radiation	93
Summary	97
Review Questions	98
6. Magnetism and Electrostatics	101
Magnets	104
Magnetic Fields	105
Electrostatics	107
The Five Laws of Electrostatics	107
Electrification	108

Using an Electroscope to Detect Radiation	110
Summary	112
Review Questions	113
7. Electrodynamics	115
Electrical Current	115
Electrical Circuits	117
Characteristics of Electricity	118
Electrical Power	119
Wave Forms of Electrical Current	121
Electromagnetic Induction	124
Summary	129
Review Questions	130
8. X-Ray Machine Circuits and Generators	133
A Basic X-Ray Machine Circuit	133
Rectification	134
The Filament Circuit	135
Meters	137
X-Ray Machine Generators	138
Exposure Timers	141
Automatic Exposure Controls (AEC)	141
Summary	143
Review Questions	144
9. The X-Ray Tube	147
X-Ray Production	147
Components of the X-Ray Tube	149
The Cathode	149
The Anode	152
The Glass Envelope	155
X-Ray Tube Failure	156
Rating Charts	156
Extending X-Ray Tube Life	158
Summary	159
Review Questions	160
10. X-Ray Production	163
Interactions in the Anode	164
Bremsstrahlung	164
Characteristic Radiation	167
Anode Heat	169
Factors Affecting the X-Ray Beam Spectrum	170
Target Material	170
Milliamper-Seconds (mAs)	171
Added Filtration	172

Kilovoltage-Peak (kVp)	173
Generator Type	174
Summary	175
Review Questions	176

PART II: PRODUCTION OF THE RADIOGRAPHIC IMAGE

11. Creation of the Radiographic Image 181

The X-Ray Beam	181
Radiographic Variables	182
Technical Variables	182
Geometrical Variables	182
Patient Status	183
Image Receptor Systems	183
Image Processing	183
Viewing Conditions	183
X-Ray Interactions within the Patient	183
The Photoelectric Effect	184
The Compton Effect	185
Coherent Scattering	188
Characteristic Radiation	189
Attenuation and Subject Contrast	190
Capturing the Image	192
Summary	192
Review Questions	193

12. Production of Subject Contrast 197

General Attenuation and Subject Contrast	197
Tissue Thickness	199
Tissue Density	200
Tissue Atomic Number	200
Scattered X-Rays and Subject Contrast	201
Predominance of Interactions and Subject Contrast	202
X-Ray Beam Energy (kVp)	202
Types of Tissue and Contrast Agents	204
Relative Importance of kVp in Controlling Subject Contrast	205
Summary	206
Review Questions	208

13. Visibility Qualities of the Image 211

The Components of Visibility	211
Qualities of the Radiographic Image	213
Brightness and Density	213
Contrast and Gray Scale	215

Noise	216
Signal-to-Noise Ratio	217
Artifacts	219
Summary	221
Review Questions	223
14. Geometrical Qualities of the Image	225
Recognizability (Geometrical Integrity)	225
Sharpness (Spatial Resolution)	225
Magnification (Size Distortion)	227
Shape Distortion	227
Measuring Unsharpness	227
Radiographic Sharpness	230
Radiographic Magnification	231
Magnification Formula	232
Radiographic Shape Distortion	234
Resolution	235
Hierarchy of Image Qualities	236
Summary	236
Review Questions	237
15. Milliampere-Seconds (mAs)	239
Control of X-Ray Exposure	240
Doing the Mental Math	241
Underexposure and Quantum Mottle	242
Subject Contrast and Other Image Qualities	244
Exposure Time and Motion	244
Summary	244
Review Questions	246
16. Kilovoltage-Peak (kVp)	249
Sufficient Penetration and Subject Contrast	250
The Fifteen Percent Rule	252
Doing the Mental Math	253
Optimum kVp	254
Patient Exposure and the 15 Percent Rule	255
Impact of Scatter Radiation on the Image	256
Conclusion	258
Other Image Qualities	258
Summary	259
Review Questions	260
17. Generators and Filtration	263
Generator Type	263
Effect of Rectification and Generators on Exposure	263

Other Image Qualities	265
Battery-Operated Mobile Units	265
Beam Filtration	265
Protective Filters	265
Half-Value Layer	267
Effects on Exposure and Beam Spectrum	267
Compensating Filtration	268
Summary	269
Review Questions	271
18. Field Size Limitation	273
Collimation Devices	273
Positive Beam Limitation	274
Over-Collimation	275
Scatter Radiation and Subject Contrast	275
Effect on Exposure	277
Other Image Qualities	277
Calculating Field Size Coverage	278
Summary	280
Review Questions	280
19. Patient Condition, Pathology, and Contrast Agents	283
General Patient Condition	283
Thickness of the Part	283
Thickness Ranges	284
The Four Centimeter Rule	286
Minimum Change Rule	286
Body Habitus	287
Sthenic	287
Hyposthenic	287
Asthenic	288
Hypersthenic	288
Large Muscular	289
Influence of Age	289
Anthropological Factors	289
Molecular Composition of Tissues	290
Contrast Agents	290
Stage of Respiration and Patient Cooperation	292
Pathology	293
Additive Diseases	294
Destructive Diseases	294
Trauma	295
Postmortem Radiography	295
Soft-Tissue Technique	296
Casts and Splints	297
Summary	298
Review Questions	298

20. Scattered Radiation and Grids	301
The Causes of Scatter	302
High kVp Levels	302
Large Field Sizes	303
Large Soft-Tissue Part Thicknesses	303
Conclusion	303
Scatter Versus Blur	303
Reducing Scatter with Grids	304
Grid Ratio and Effectiveness	306
Grid Frequency and Lead Content	307
Effect on Subject Contrast	307
Use of Grids with Digital Equipment	308
Conventional Indications for Grid Use	308
Part Thickness	309
Field Size	309
Kilovoltage	309
Measuring Grid Effectiveness	310
Bucky Factor	310
Selectivity	311
Technique Compensation for Grids	311
Other Image Qualities	312
Grid Cut-Off	312
Grid Radius	313
Alignment of the Beam and Grid	315
Summary	316
Review Questions	317
21. The Anode Bevel and Focal Spot	321
Line-Focus Principle	321
Anode Heel Effect	323
Focal Spot Size	327
Effect Upon Sharpness	327
Penumbra	327
Magnification	330
Other Image Qualities	330
Conclusion	331
Summary	331
Review Questions	332
22. Source-to-Image Receptor Distance (SID)	335
Effect on Sharpness	336
Effect on Magnification	336
Increased Field of View at Longer SID	337
Shape Distortion	337
Effect on Exposure	338
Radiographic Formula for the Inverse Square Law	339

Compensating Technique: The Square Law	341
Rules of Thumb for SID Changes	342
Other Image Qualities	345
Increased SID to Reduce Patient Dose	345
Summary	346
Review Questions	347
23. OID and Distance Ratios	349
Object-Image Receptor Distance	349
Effect on Subject Contrast	349
Effect on Exposure	352
Effect on Sharpness	352
Effect on Magnification	352
Intentional Use of Long OID	354
Shape Distortion	354
Distance Ratios for Magnification and Sharpness	354
Magnification: The SID/SOD Ratio	354
Sharpness: The SOD/OID Ratio	355
Visibility Functions and Distance Ratios	357
Summary	357
Review Questions	358
24. Alignment and Motion	361
Alignment and Shape Distortion	361
Off-Centering Versus Angling	362
Position, Shape, and Size of the Anatomical Part	362
Objects with a Distinct Long Axis	362
Ceiszynski's Law of Isometry	363
Objects without a Distinct Long Axis	365
Off-Centering and Beam Divergence	365
Rule for Beam Divergence	366
SID as a Contributing Factor	368
Maintaining Exposure: Compensating Tube-to-Tabletop	
Distance	368
Other Image Qualities	368
Geometric Functions of Positioning	368
Motion	370
Effect on Sharpness	371
Effect on Image Contrast	372
Other Image Qualities	372
Summary	373
Review Questions	374
25. Analyzing the Latent Radiographic Image	377
Variables Affecting Exposure at the Image Receptor	378
Variables Affecting Subject Contrast at the Image Receptor	378

Variables Affecting Image Noise at the Image Receptor	378
Variables Affecting Sharpness at the Image Receptor	378
Variables Affecting Magnification at the Image Receptor	379
Variables Affecting Shape Distortion at the Image Receptor	379
Absorption Penumbra	379
Overall Resolution	381
Resolution at the Microscopic Level	382
Spatial Resolution: Spatial Frequency	383
Contrast Resolution: MTF	384
Summary	387
Review Questions	388
26. Simplifying and Standardizing Technique	391
Variable kVp vs. Fixed kVp Approaches	392
Applying the Variable kVp Approach	393
The Proportional Anatomy Approach	394
Using Technique Charts	398
Developing a Chart from Scratch	401
Summary	406
Review Questions	407
27. Using Automatic Exposure Controls (AEC)	411
Minimum Response Time	412
Back-up mAs or Time	412
Preset Automatic Back-up mAs or Time	413
The AEC Intensity (Density) Control	414
Limitations of AEC	416
Detector Cell Configuration	419
Checklist of AEC Precautions	420
AEC Technique Charts	421
Programmed Exposure Controls	423
Summary	423
Review Questions	424

PART III: DIGITAL RADIOGRAPHY

28. Computer Basics	429
The Development of Computers	430
Computer Hardware Components	433
The Central Processing Unit	435
Secondary Storage Devices	437
Types of Memory	441
Managing Data	443
Analog vs. Digital Data	443

Binary Code	444
Computer Software	448
Processing Methods	449
Communications	449
Summary	451
Review Questions	453
29. Creating the Digital Image	457
The Nature of Digital Images	457
Digitizing an Analog Image	461
Role of X-Ray Attenuation in Forming the Digital Image	464
Enhancement of Contrast Resolution	465
Procedural Algorithms	467
Windowing	468
Workstations and Display Stations	470
Summary	473
Review Questions	474
30. Digital Image Preprocessing and Processing (Rescaling)	477
Introduction	477
Preprocessing I: Field Uniformity	478
Flat Field Uniformity Corrections	479
Electronic Response and Gain Offsets	479
Variable Scintillator Thickness	479
Light Guide Variations in CR	480
Preprocessing II: Noise Reduction for Dixel Drop-Out	480
Preprocessing III: Image Analysis	481
Segmentation and Exposure Field Recognition	481
Constructing the Histogram	482
Types of Histogram Analysis	486
Histogram Analysis Processing Errors	488
Maintaining the Spatial Matrix	490
Rescaling (Processing) the Image	490
Physicists' Terminology	495
Summary	495
Review Questions	496
31. Digital Image Postprocessing	499
Digital Processing Domains	499
Postprocessing I: Gradation Processing	502
Initial Gradation Processing	502
Parameters for Gradient Processing	507
Data Clipping	508
Dynamic Range Compression (DRC) or Equalization	509
Postprocessing II: Detail Processing	511
Applying Kernels in the Spatial Domain	511

Unsharp Mask Filtering	512
Using Kernels for Noise Reduction and Smoothing	516
Understanding the Frequency Domain	516
Processing in the Frequency Domain	517
Multiscale Processing and Band-Pass Filtering	522
Kernels as a Form of Band-Pass Filtering	524
Parameters for Frequency Processing	524
Postprocessing III: Preparation for Display	524
Noise Reduction	524
Contrast-Noise Ratio (CNR)	525
Additional Gradation Processing	526
Perceptual Tone Scaling	526
Formatting for Display	527
Digital Processing Suites	527
Postprocessing IV: Operator Adjustments	529
Postprocessing V: Special Postprocessing	529
Dual-Energy Subtraction	529
Grid Line Suppression	530
Conclusion	532
Summary	533
Review Questions	535
32. Postprocessing Operations in Practice	539
Navigating the Screen Menus	539
Speed Class	541
Exposure Indicators	542
Logarithmic Scales	545
CareStream	545
Agfa	546
Proportional Scales	546
Siemens	546
General Electric	546
Shimadzu and Canon	546
Inversely Proportional Scales	546
Fuji and Konica	546
Philips	547
Limitations for Exposure Indicators	547
Acceptable Parameters for Exposure	548
Inappropriate Clinical Use of the Deviation Index (DI)	550
Exposure Indicator Errors	550
Using Alternative Processing Algorithms	551
Examples of Alternative Processing Algorithms	552
Windowing	553
Smoothing and Edge Enhancement	554
Miscellaneous Processing Features	556
Dark Masking	556
Image Reversal (Black Bone)	557

Resizing	557
Image Stitching	557
Quality Criteria for the Displayed Digital Radiographic Image	557
Glossary and ARRT Standard Definitions	560
“Controlling” Factors for Displayed Image Qualities	560
Summary	561
Review Questions	562
33. Applying Radiographic Technique to Digital Imaging	565
Minimizing Patient Exposure	566
High kVp and Scatter Radiation	566
High kVp and Mottle	568
Recommendation for Reducing Patient Exposure	575
Does kVp Still Control Image Contrast?	576
Exposure Latitude, Overexposure, and Public Exposure	576
Sufficient Penetration and Signal-to-Noise Ratio	578
Effects of kVp Changes on the Image	578
Effects of Scatter Radiation on Digital Images	578
Fog Pattern Clean-up by Frequency Processing	582
Technique Myths	584
Proportional Anatomy and Manual Technique Rules	585
Automatic Exposure Controls (AECs)	585
Use of Grids with Digital Radiography	586
Aliasing (Moire Effect)	586
On Reducing the Use of Grids	587
Mottle or Scatter: Which is More Accetable?	587
Virtual Grid Software	588
Markers and Annotation	590
Alignment Issues	590
Centering of Anatomy	590
Aligning Multiple Fields	590
Overcollimation	590
Bilateral Views	592
Image Retention in Phosphor Plates	594
Summary	594
Review Questions	596
34. Capturing the Digital Image: DR and CR	599
Comparing CR and DR for Clinical Use	599
Direct-Capture Digital Radiography (DR)	600
The Dixel	601
Direct Conversion Systems	601
Indirect Conversion Systems	603
Computed Radiography (CR)	604
The CR Cassette and Phosphor Plate	604
The CR Reader (Processor)	607
Image Identification	610

Recent Developments in CR	610
Background and Scatter Radiation	610
Spatial Resolution of Digital Systems	611
Field of View, Matrix Size, and Spatial Resolution	612
Formula Relating FOV to Pixel Size	612
The DR Detector Hardware Matrix	613
The Light Matrix in a CR Reader	614
The Display Monitor Hardware Matrix	614
The “Soft” Matrix of the Displayed Light Image	614
Summary	615
Efficiency of Image Receptors	616
CR Phosphor Plates	616
K-Edge Effect	617
DR Detector Panels	618
Detective Quantum Efficiency (DQE)	618
Digital Artifacts	619
Digital Sampling and Aliasing	620
Summary	620
Review Questions	623
35. Display Systems and Electronic Images	627
Liquid Crystal Display Monitors (LCDs)	627
Other Flat Monitor Systems	632
Advantages and Disadvantages of LCDs	632
Nature of Pixels in Display Systems	634
Spatial Resolution of Display Monitors	635
Conclusion: The Weakest Link	635
Summary	636
Review Questions	636
36. PACS and Imaging Informatics	639
Hardware and Software	641
Functions	642
Image Access	643
Medical Imaging Informatics	646
HIS, RIS and PACS	647
Summary	648
Review Questions	650
37. Quality Control	653
Radiographic Equipment Testing	654
Radiographic Units	654
Exposure Timer	654
mA Linearity	654
Exposure Reproducibility	655
Half-Value Layer	655

kVp Calibration	657
Collimator and Distance	657
Focal Spot Size and Condition	658
Automatic Exposure Control (AEC)	659
Fluoroscopic Units	660
Monitoring of Digital Acquisition Systems	660
Field Uniformity	660
Erasure Thoroughness and “Ghosting”	661
Intrinsic (Dark) Noise	661
Spatial Resolution	661
Monitoring of Electronic Image Display Systems	661
Luminance	662
The Photometer	663
Illuminance	663
Luminance and Contrast Tests	663
Ambient Lighting (Illuminance) and Reflectance Tests	664
Noise	664
Resolution	664
Dead and Stuck Pixels	665
Viewing Angle Dependence	666
Stability of Self-Calibrating LCDs	666
Repeat Analysis	666
Summary	666
Review Questions	668
38. Mobile Radiography, Fluoroscopy, and Digital Fluoroscopy	671
Mobile Radiography	671
Mobile Generators	671
Geometrical Factors	672
Distance Considerations	672
Alignment and Positioning Considerations	672
Other Considerations	673
Development of Fluoroscopy	674
The Image Intensifier Tube	676
Input Phosphor and Photocathode	676
Electrostatic Focusing Lens	676
Accelerating Anode	677
Output Phosphor	678
Brightness Gain	678
Conversion Factor	678
Multifield Image Intensifiers and Magnification Modes	678
Automatic Stabilization of Brightness	679
Signal Sensing	680
Types of ABS Circuits	680
Fluoroscopic Technique	681
Fluoroscopic Image Quality	681

Scintillation	681
Contrast	682
Distortion	682
Pincushion Distortion	683
Veiling Glare	683
Vignetting	683
Processing the Image from the Intensifier Tube	683
Mobile Image Intensification (C-Arm)	684
Minimizing Patient and Operator Exposure	685
Fluoroscopic Exposure Time	685
Digital Fluoroscopy (DF)	686
Dynamic Flat-Panel Detectors	687
Digital Subtraction Techniques	688
Temporal Subtraction	688
Energy Subtraction	689
Roadmapping	690
Image Recording Devices: CCDs and CMOSs	690
Summary	692
Review Questions	693

PART IV: RADIATION BIOLOGY AND PROTECTION

39. Radiation Perspectives	699
Perceptions	699
On the Radiographer's Job	699
On Environmental Radiation	700
Developing a Frame of Reference	702
Sources of Radiation	704
Natural Background Radiation	704
Manmade Sources of Radiation	705
Radioactivity	707
Half-Life	709
Conclusion	711
Summary	711
Review Questions	712
40. Radiation Units and Measurement	715
Radiation Units	716
Radiation Exposure	716
Air Kerma	716
Exposure Area Product	717
Surface Integral Exposure	717
Absorbed Dose	717
Dose Area Product	718

Integral Dose	719
Dose Equivalent	719
Effective Dose	720
Proper Use of Units	720
Dose Equivalent Limits (DELs)	722
The Cumulative Lifetime Limit	722
The Prospective Limit	722
The Retrospective Limit	723
Current Limits	723
Genetically Significant Dose (GSD)	724
Radiation Detection Instruments	725
Characteristics of Radiation Detection Devices	725
Sensitivity	725
Accuracy	727
Resolving (Interrogation) Time	727
Range	728
Types of Radiation Detection Instruments	728
Scintillation Detectors	728
Optically Stimulated Luminescence (OSL) Dosimeters	729
Thermoluminescent Dosimeters (TLDs)	730
Film Badges	730
Gas-Filled Detectors	732
Pocket Dosimeters	732
Ionization Chambers	733
Proportional Counters	734
Geiger-Mueller Tubes	734
Personal Radiation Monitors	735
Voltage Dependence of Electronic Detection Instruments	736
Summary	738
Review Questions	739
41. Radiation Biology: Cellular Effects	743
Biological Review	744
Tissues of the Human Body	744
Human Cell Structure and Metabolism	745
Transfer of Genetic Information	747
Life Cycle of the Cell	748
Mitosis	751
Cell Life Cycle and Radiation Sensitivity	751
Meiosis	753
Cellular Radiation Effects	753
Cell Sensitivity	753
Law of Bergonie and Tribondeau	753
Cellular Response to Radiation	754
Theory of Cellular Damage	757
Radiolysis of Water	759
Damage to the Cell Membrane	761

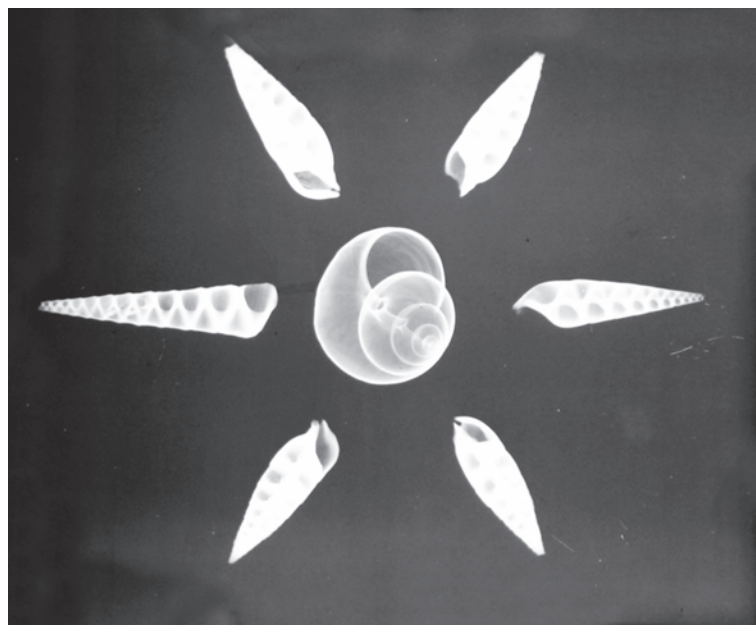
Types of Cell Death from Radiation Exposure	761
Types of Damage to Chromosomes	761
Main Chain Scission	762
Rung Damage	763
Mutations and Chromosome Aberrations	763
Visible Chromosome Aberrations	764
Linear Energy Transfer (LET)	765
Relative Biological Effectiveness (RBE)	766
Dose Rate	768
Protraction of Dose	768
Fractionation	768
Oxygen Enhancement Ratio (OER)	769
Other Biological Factors Affecting Radiosensitivity	769
Summary of Factors Affecting Radiosensitivity	770
Summary	770
Review Questions	772
42. Radiation Biology: Organism Effects	775
Measuring Risk	775
Stochastic Versus Deterministic Effects	776
Early Effects of Radiation	777
Lethal Doses	778
Acute Radiation Syndrome	778
Other Early Effects	782
Late Effects of Radiation	783
Teratogenic Effects of Radiation	783
Period #1: 0–2 Weeks Gestation	783
Period #2: 2–8 Weeks Gestation	783
Period #3: 8–12 Weeks Gestation	784
Period #4: After 3 Months Gestation	784
Mutagenic Effects of Radiation	784
Life-Span Shortening	785
Cataracts of the Eye Lens	785
Cancers	785
Leukemia	786
Mammograms and Breast Cancer	787
Summary	788
Review Questions	789
43. Radiation Protection: Procedures and Policies	793
Diagnostic Exposure Levels to Patients	794
Gonadal Exposure	796
Optimizing Radiographic Technique	796
mAs and kVp	796
Generators and Filtration	797
Field Size Limitation	797
Patient Status	797

Grids and Image Receptors	797
Increasing SID to Reduce Patient Dose	798
Radiographic Positioning	798
Radiographic Technique and AEC	800
Quality Control and HVL	800
Digital Processing Speed Class	800
Protecting the Patient	801
Patient Shielding	801
Policies for Patient Pregnancy	801
Guidelines for Equipment	802
Fluoroscope Technology	803
Current Issues	805
Protecting Personnel	806
Personnel Monitoring	806
The Cardinal Principles: Time, Distance and Shielding	807
Personnel Shielding Requirements	809
Equipment Shielding Requirements	811
Personnel Protection Policies	811
Policies for Technologist Pregnancy	812
Guidelines for Equipment	813
Structural Barrier Shielding	814
Factors for Adequacy of Barriers	816
Types of Radiation Areas	817
Posted Warnings	817
Advisory and Regulatory Agencies	817
A Final Word	818
Summary	819
Review Questions	821
<i>Appendix 1: Answers to Chapter Exercises</i>	<i>825</i>
<i>Appendix 2: ARRT Standard Definitions</i>	<i>829</i>
<i>Glossary of Radiographic Terms</i>	<i>831</i>
<i>Index</i>	<i>847</i>

RADIOGRAPHY IN THE DIGITAL AGE

Part I

THE PHYSICS OF RADIOGRAPHY



Radiographs of various seashells.

INTRODUCTION TO RADIOGRAPHIC SCIENCE

Objectives:

Upon completion of this chapter, you should be able to:

1. List the foundational principles of the scientific method and how they relate to the standard of practice for radiographers.
2. Describe landmark events in the development of medical radiography, with particular focus on those that brought about reductions in patient exposure.
3. Overview landmark events in the development of modern digital radiographic imaging.
4. Present a scientifically balanced perspective on the hazards of radiation in our environment and workplace.
5. Understand and appreciate the ALARA philosophy in modern radiographic imaging.

THE SCIENTIFIC APPROACH

Radiography is a branch of the modern *science* of medicine. Science is objective, observable, demonstrable knowledge. Try to imagine your doctor engaging in practices that were not grounded in scientific knowledge! What is it that sets science apart from art, philosophy, religion and other human endeavors? There are actually several foundational principles to scientific method. It is worthwhile to give a brief overview of them. They include:

Parsimony: The attempt to simplify concepts and formulas, to economize explanations; the philosophy that simple explanations are more likely to be true than elaborate, complex ones.

Reproducibility: The requirement that proofs (experiments) can be duplicated by different people at different times and in different locations with precisely the same results.

Falsifiability: The requirement that any theory or hypothesis can logically and logistically be proven *false*. Anything that cannot be proven

false is not science, but belongs in another realm of human experience.

Observation: The requirement that experiments and their results can be directly observed with the human senses.

Measurability: The requirement that results can be quantified mathematically and measured.

As a fun practice exercise, consider the following three statements. Which one is scientific?

1. *The moon is made of green cheese.*
2. *Intelligent life likely exists elsewhere in the universe.*
3. *Albert Einstein was the greatest physicist in the twentieth century.*

The most scientific statement is No. 1. Even though it may not be a true statement, it is nonetheless a statement that can be (and has been) proven false with modern travel technology, it is simple, and experiments proving that moon rocks do not consist of green cheese can be reproduced by anyone, anywhere on earth with the same, observable, measurable results. Statement No. 2 may be true or

false, but *cannot be proven false*, because to do so would require us to explore every planet in the entire universe, documenting that we have looked in every crevice and under every rock. It may be classified as a philosophical statement, but not as a scientific one. Statement No. 3 is, of course, a simple matter of personal opinion that depends upon how one defines the word “greatest.” It is a historical statement that defies standardized measurement or observation.

Perhaps the strongest aspect of the scientific method is that when it is used properly, it is *self-correcting*. That is, when a theory is found to be wrong, that field of science is expected to be capable of transcending all politics, prejudice, tradition and financial gain in order to establish the new truth that will replace it. Sometimes this process is painful to the scientific community, and it has been known to take years to complete. But, at least it presupposes a collective willingness to accept the *possibility* that a previous position may have been wrong, something one rarely sees in nonscientific endeavors.

This principle of *self-correction* is nicely illustrated in the story of Henri Becquerel and the discovery of natural radioactivity, related in the next section. Also demonstrated in both his story and that of Wilhelm Roentgen, the discoverer of x-rays, is the fact that many scientific truths are discovered by accident. Nonetheless, it is *because* scientific method is being followed, not in spite of it, that they have occurred, and *through* scientific method that they come to be fully understood.

How does this scientific approach apply to radiography, specifically? Even though some aspects of radiography, such as positioning, are sometimes thought of as an art, the end result is an image that contains a quantifiable amount of diagnostically useful details, a measurable amount of information. Image qualities such as contrast, brightness, noise, sharpness and distortion can all be mathematically measured. Even the usefulness of different approaches to positioning are subject to measurement through repeat rate analysis. In choosing good radiographic practices, rather than relying on the subjective assertion from a cohort that, “It works for me,” important matters can be objectively resolved by simply monitoring the repeats taken by those using the method compared to those using

another method. By using good sampling (several radiographers using one method and several using another over a period of weeks), reliable conclusions can be drawn.

The standard of practice for all radiographers is to use good common sense, sound judgment, logical consistency and objective knowledge in providing the best possible care for their patients.

A BRIEF HISTORY OF X-RAYS

It is fascinating to note that manmade radiation was invented *before* natural radioactivity was discovered. If this seems backward, it is partly because x-rays were discovered by accident. In the late 1800s, Wilhelm Conrad Roentgen (Fig. 1-1) was conducting experiments in his laboratory at Wurzburg University in Germany. It had been discovered that a beam of electricity (glowing a beautiful blue in a darkened room) could be caused to stream across a glass tube. With strong enough voltage, the electricity could be caused to “jump” from a negatively-charged *cathode* wire across the gap toward a positively-charged *anode* plate, although most of it actually struck the glass behind. Since they were emitted from the cathode, these streams of electricity were dubbed *cathode rays*.

Several researchers were studying the characteristics of cathode rays. These glass tubes, known as Crookes tubes, came in many configurations. Figure 1-2 shows several that Roentgen actually used in his experiments. If most of the air was vacuumed out of the tube, the cathode rays became invisible. (It was later understood that they were in fact the electrons from the current in the cathode, far too small for the human eye to see, and that the blue glow was the effect from the ionization of the air around them.)

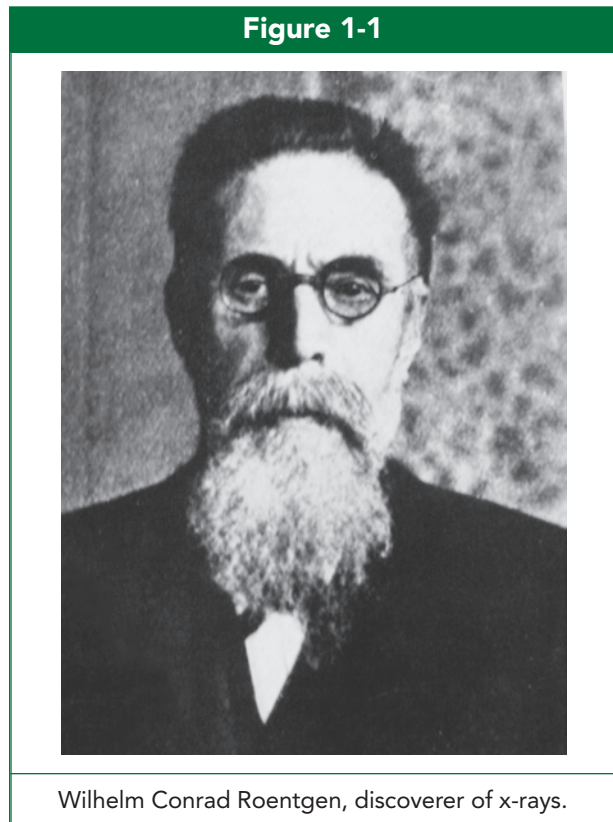
Other researchers had noticed that the glass at the anode end of the tube would fluoresce with a greenish glow when the cathode rays were flowing. They began experimenting with placing fluorescent materials in the path of the beam. They learned how to deflect the beam at right angles with a plate so it could exit the tube through a window of thin aluminum. In this way, cards or plates coated with

different materials could simply be placed alongside the tube, in the path of the electron beam, to see how they fluoresced. Researchers learned to surround the tube with black cardboard so as to not confuse any light that might be generated within the tube with the fluorescence of the material outside the tube.

This was the type of experiment Roentgen was engaged with on November 8, 1895, when he noticed that a piece of paper laying on a bench nearby was glowing while the tube was activated in its black cardboard box. This paper was coated with barium platinocyanide, but it was not in the direct path of the cathode rays (electron beam).

Roentgen quickly realized that there must be some other type of radiation being emitted from the tube, other than the electron beam. He dubbed this radiation as “x” indicating the unknown. This radiation seemed to be emitted in all directions from the tube and was able to affect objects such as the plate at some distance. Placing various objects between the tube and the plate, he saw that they cast partial shadows on the glowing screen, while lead cast a solid shadow, stopping the mysterious rays altogether. He deduced that they traveled in straight lines and were able to penetrate less dense materials. During the following days, Roentgen conducted brilliant experiments delineating the characteristics of the x-rays.

Early in his experiments, he was astonished to see the image of the bones in his own hands on the



screen, while the flesh was penetrated through by the x-rays. The field of radiography was born when he placed his wife’s hand in front of the screen and allowed the screen’s fluorescent light to expose a photographic film for about four minutes (Fig. 1-3). Along with three other radiographs, this image was

