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

Quinn B. Carroll, M.Ed., R.T.

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REVIEWERS

Consulting Physicist

Daniel J. Sandoval, PhD, DABR

Diagnostic Medical Physicist, Dept. of Radiology
University of New Mexico Health Sciences Center
Albuquerque, New Mexico

Ajesh Singh Dip, BSc (Med Imaging), MEd, FHEA

Lecturer, School of Clinical Science
Queensland University of Technology
Brisbane, Australia

Robert L. Grossman, MS, RT (R) (CT)

Instructor, Radiography
Middlesex Community College
Middletown, Connecticut

Patrick Patterson, MS, RT (R) (N), CNMT

Director, Radiography Program
State College of Florida, Manatee-Sarasota
Bradenton, Florida

Philip Heintz, PhD

Professor Emeritus, Biomedical Physics
University of New Mexico Medical Center
Albuquerque, New Mexico

C. William Mulkey, PhD, RT (R), FASRT

Dean, Dept. of Radiologic Sciences (Retired)
Midlands Technical College
West Columbia, North Carolina

Donna Endicott, MEd, RT (R)

Director, Radiologic Technology
Xavier University
Cincinnati, Ohio

Miranda Poage, PhD

Associate Professor, Biology
Midland College
Midland, Texas

Dennis Bowman, AS, RT (R)

Clinical Instructor
Community Hospital of Monterey Peninsula
Marina, California

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 waivered 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.

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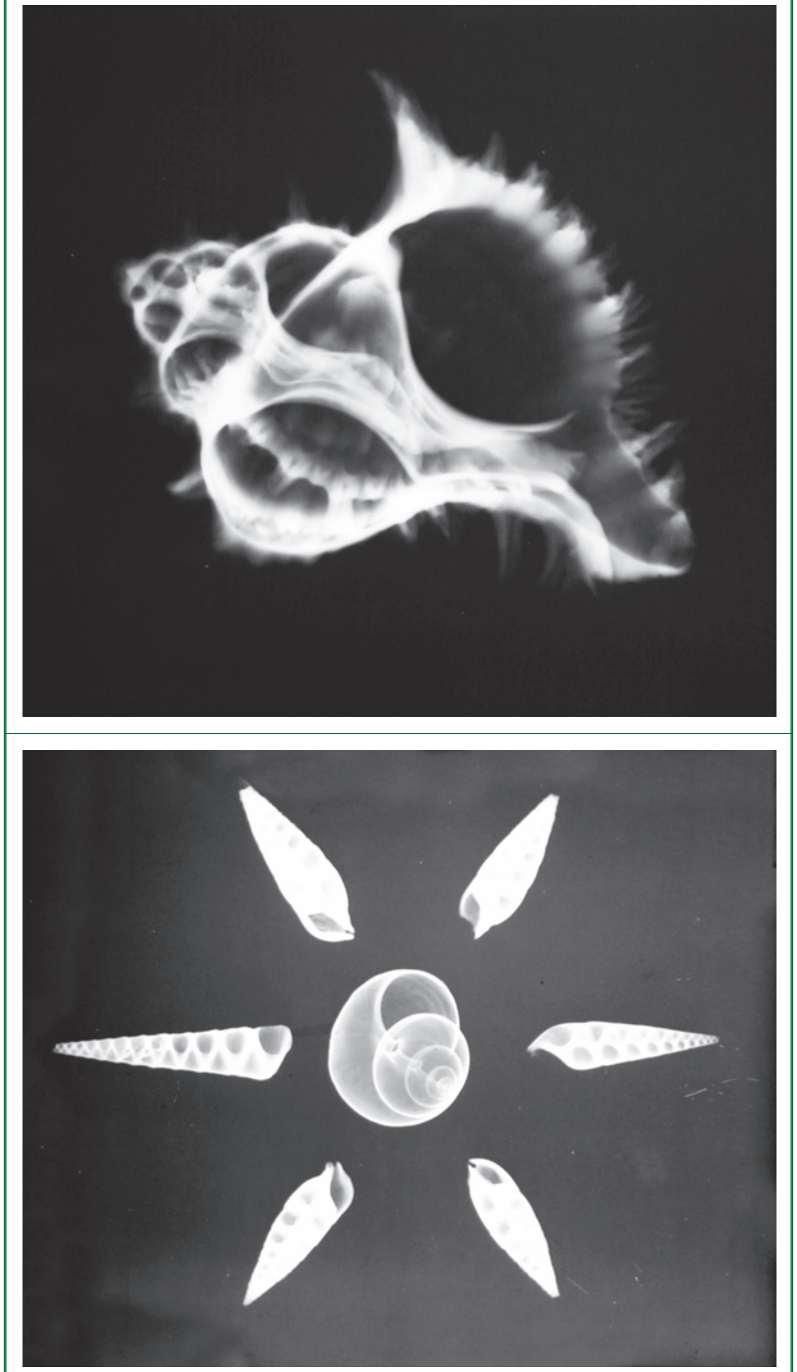
RADIOGRAPHY IN THE DIGITAL AGE

Part I

THE PHYSICS OF RADIOGRAPHY



Radiographs of various seashells.

Chapter 1

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.

Figure 1-1

Wilhelm Conrad Roentgen, discoverer of 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

Figure 1-2

Photograph of Crookes tubes employed by Roentgen in his experiments on cathode rays, which led to the discovery of x-rays. (From Quinn B. Carroll, *Practical Radiographic Imaging*, 8th ed. Springfield, IL: Charles C Thomas, Publisher, Ltd., 2007. Reprinted by permission.)