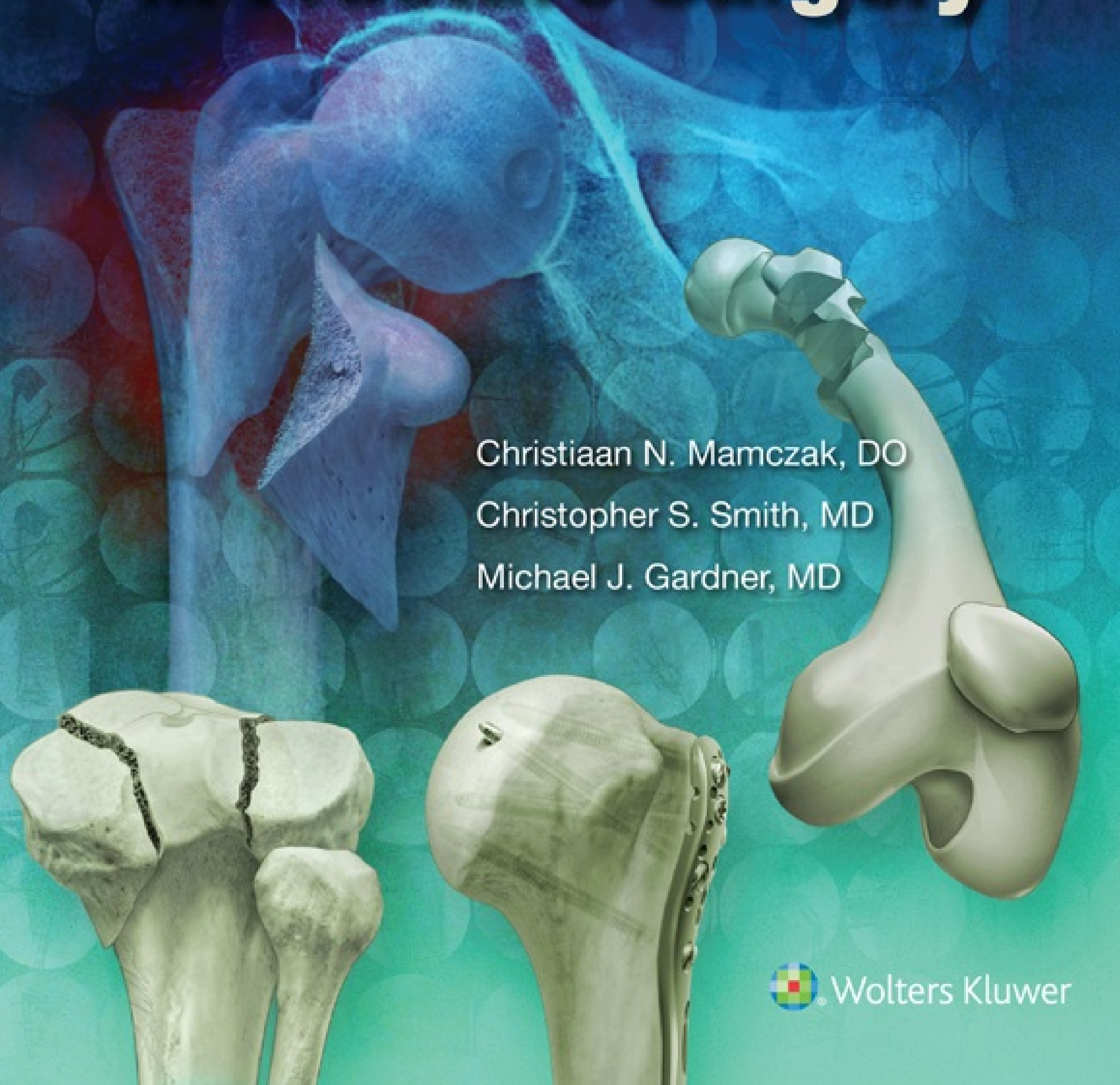
Illustrated Tips and Tricks for

Intraoperative Imaging in Fracture Surgery



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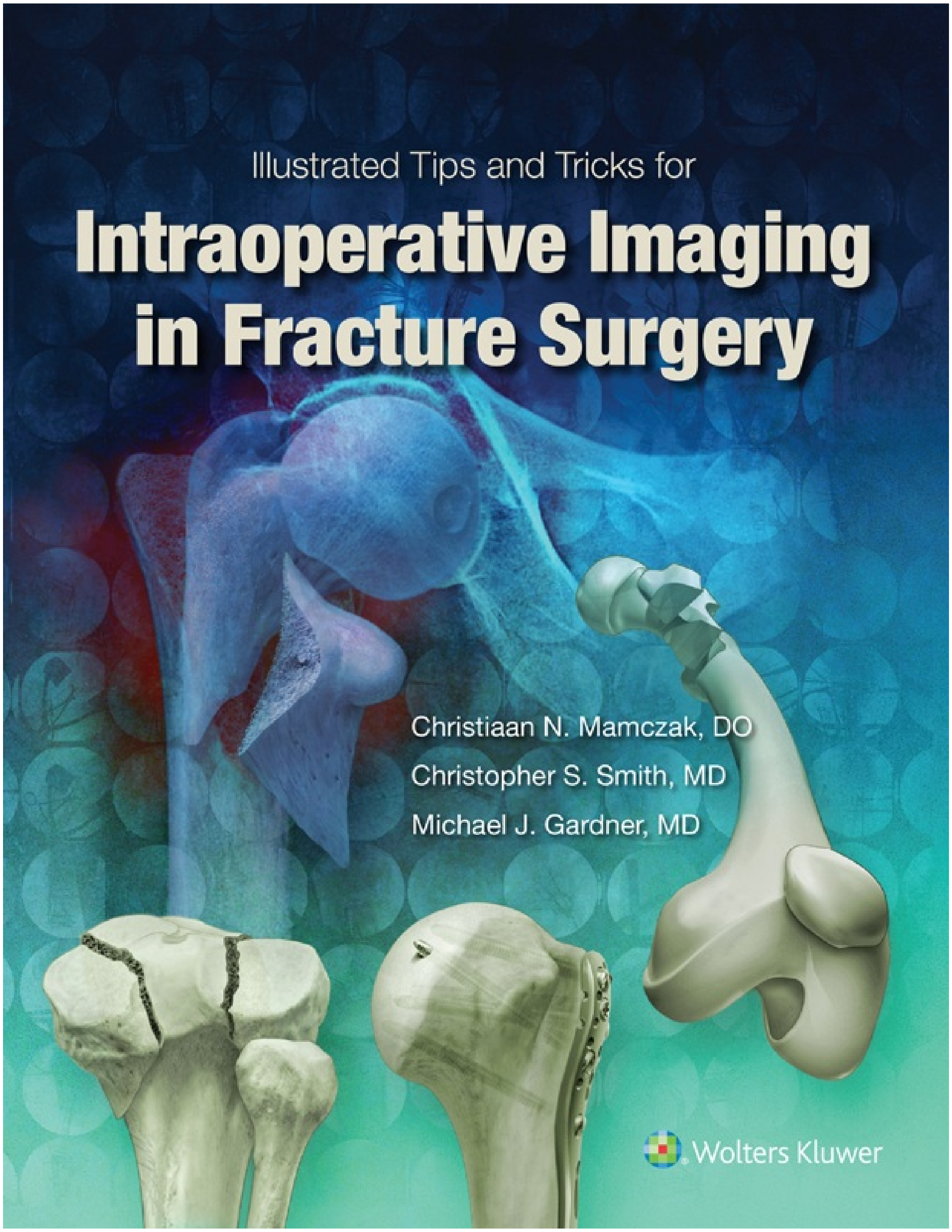
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Philadelphia • Baltimore • New York • London
Buenos Aires • Hong Kong • Sydney • Tokyo

Acquisitions Editor: Brian Brown
Editorial Coordinator: Dave Murphy
Marketing Manager: Dan Dressler
Production Project Manager: David Saltzberg
Design Coordinator: Stephen Druding
Manufacturing Coordinator: Beth Welsh
Illustrator: Scott Bodell
Prepress Vendor: SPi Global

9 8 7 6 5 4 3 2 1

Printed in China

Library of Congress Cataloging-in-Publication Data
Names: Mamczak, Christiaan N., editor. | Smith, Christopher S., editor. | Gardner, Michael J., editor.
Title: Illustrated tips and tricks for intraoperative imaging in fracture surgery / [edited by] Christiaan N. Mamczak, Christopher S. Smith, Michael J. Gardner ; illustrations by Scott Bodell.
Description: Philadelphia : Wolters Kluwer Health, [2018] | Includes bibliographical references and index.
Identifiers: LCCN 2017040691 | ISBN 9781975102210
Subjects: | MESH: Fracture Fixation, Internal—methods | Fluoroscopy—methods | Intraoperative Period | Patient Positioning—methods
Classification: LCC RD101 | NLM WE 185 | DDC 617.1/5—dc23 LC record available at https://lccn.loc.gov/2017040691

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I am grateful to my co-editors, Chris and Mike, and our friends (the authors) who were instrumental in composing this educational textbook. Together we have worked to create a valuable reference for orthopedic fracture surgeons. I'd also like to recognize all of the fluoro techs that I have worked with over the years.

Lastly, I would like to acknowledge and thank my family for the understanding and patience they have demonstrated in support of my career. It has been a long and tedious road with many call days and nights away from the people dearest to me. Luckily they embrace my passion for orthopedic trauma surgery and desire to publish. I have been blessed with unconditional love from my wife, Debbie, and children: Zac, Alexandra, Nadia, and Sophia. Coming home to them after each workday makes my life complete.

—Christiaan N. Mamczak

Thank you, my coeditors and chapter authors. It's been an honor and a privilege working with you to produce a great and timely practical reference. I am grateful to my mentors, who taught me the importance of getting the perfect fluoro shot and to the ortho trauma x-ray techs who performed magic in the OR. In addition, this book would not be possible if not for my residents past and present, keeping me on my toes with their thirst for knowledge. You guys continue to impress me every day.

I would like to thank my parents, Philip R. Smith and Susan E. Smith, for their encouraging support and for fostering my love for medicine and orthopaedics from an early age. Lastly, I would like to thank my family who have been by my side though

numerous deployments and long hours at the hospital. To my wife Ashley, and children Andrew and Megan, thank you for your love, patience, and understanding. You guys are my rock and my life.

—Christopher S. Smith

I'd like to dedicate this book to all of my mentors at Hospital for Special Surgery, Harborview Medical Center, and Washington University who have spent countless hours and limitless energy in teaching me about all aspects of fracture care. Their passion for perfection has been awe-inspiring and has driven me to continuously search for ways to improve. And a huge thanks to my family for continuing to support me in so many ways.

—Michael J. Gardner

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Foreword

Over the past 30 years, there have been countless important clinical and technical advances in orthopedic traumatology. This progress has been nothing short of amazing, and most of it has been directly correlated with improved knowledge of osteology and imaging.

In the late 1980s, Drs. Bob Winquist and S. Ted Hansen introduced closed reamed femoral medullary nailing to North America. Femoral nailing allowed early fracture stability and patient mobility and was quickly identified to be a life changing and often life-saving technique. The patient was freed from the deadly "orthopedic crucifix" position of prolonged skeletal traction. Intraoperative fluoroscopy was the key component that changed nailing procedures from extensive and morbid open operations to safe closed ones. And the game was on for intraoperative fluoroscopy as clinicians used it more and more to better assess the fracture reduction quality and implant construct safety.

The entire field of boney imaging advanced. Plain radiographs, intraoperative imaging, and computed tomography evolved as clinicians became more aware of their value to improving patient care quality. Injury imaging included traction views, oblique images, and CT scans and helped surgeons to refine their preoperative planning. As with medullary nailing, high-quality intraoperative fluoroscopy has been directly responsible for the evolution of modern percutaneous pelvic surgery. Long before any pelvic fixation screws were inserted, we had to completely understand the various osseous fixation pathways and their imaging details. The cortical surface limits had to be identified first and then the specific images necessary to reliably demonstrate them followed. Finally, the variants of pelvic osteology were defined so that the intraoperative fluoroscopic pelvic imaging would accurately assess the manipulative reductions and also guide the insertion of pubic ramus, pelvic brim, acetabular columnar, iliosacral, and other pelvic fixation screws.

Overall, intraoperative imaging serves numerous important clinical needs including (1) proper patient positioning, (2) fracture site instability and displacements, (3) reduction accuracy, (4) implant location, (5) inadvertent retained surgical devices, and (6) stability of the repair.

With this book, Drs. Mamczak, Smith, and Gardner provide practicing surgeons, residents, medical students, nurses, operating room staff, and radiology technicians with a clear, concise, detailed, and comprehensive reference for their individual intraoperative imaging needs. Each chapter has been authored by an experienced clinician and focuses on the indications, specifics, and common mistakes of modern intraoperative imaging. This book will help you to improve your overall knowledge of modern imaging, and more importantly, it will improve your awareness, abilities, and safety.

Milton L. Chip Routt, Jr, MD

It gives me great pleasure to be invited by Chris Smith to write a forward for "*Illustrated Tips and Tricks for Intraoperative Imaging in Fracture Surgery*", that is coauthored by Drs.' Mamczak, Smith, and Gardner. This, especially so, as I was honored to be one of Chris Smith's mentors, and he continues to flourish and make us all very proud!!

The more we know about orthopedic trauma the more we realize that restoration of normal anatomy, when feasible, usually assures the best outcome. Obviously, there are many variables, including the patient, timing, other injuries, soft tissues, age, comorbidities, etc., that are involved in the decision making, but when possible as determined by the preoperative plan, "perfect" must be the goal. Obviously if that can be achieved with less direct visualization/exposure, that is an advantage, that is, precisely what an intraoperative C-arm allows! In addition, the worst case scenario as a surgeon is to have a problem intraoperatively, which one cannot see, cannot even visualize adequately with the C-arm due to poor planning and being forced to expose more (unnecessarily) or accept a less than optimal outcome.

I do believe the authors have addressed those issues in "*Illustrated Tips and Tricks for Intraoperative Imaging in Fracture Surgery*" and assured with a complete preoperative plan that includes the patient, surgery, and C-arm positioning/views to allow intraoperative visualization and assessment of reduction, fixation, and hence the best chance for an optimal outcome.

Clearly this book is a must for all orthopedic surgeons but especially for those doing trauma and fracture surgery.

David L. Helfet, MD

Preface

It goes without saying that preoperative planning is a critical prerequisite for achieving optimal outcomes in fracture surgery. However, one aspect of the process that may be underappreciated and overlooked is the importance of strategically positioning the patient as a link to maximizing the efficiency of fluoroscopy. The advent of using an intraoperative C-arm has dramatically improved the quality of fracture reductions and fixation when compared to cases without imaging. Yet despite its commonplace use, a purposeful understanding of the C-arm's capabilities and limitations is paramount. This begins with proper positioning of the patient within a preferably radiolucent operative field. Various factors come into play within this decision process: fracture type, operating table, positioning adjuncts, patient body habitus, and the functional range of the fluoroscope. Surgeon preference should be a dynamic variable as one fixation technique, and method is usually not sufficient for all variations of a fracture. Although a surgeon's surgical training experience is the most influential factor in patient positioning and fluoroscopy use, continuing education is a critical component to refining one's skills, comfort level, and outcomes.

This textbook is meant to provide a valuable guide for the use of intraoperative fluoroscopy in fracture surgery. Based on the absence of such a resource, the editors envisioned an instructional manual of tips and tricks to set surgeons up for success in fracture care. We have all been taught that "one view is no view." Most of us have probably participated in a case where better preoperative planning may have optimized the ability to arrive at the desired fixation outcome. Nothing may be more frustrating during a case than the inability to achieve a symbiotic relationship between patient positioning and obtaining accurate imaging. Settling for suboptimal images because we improperly set up the case is a less than ideal outcome. Learning from our mistakes and recreating a consistent environment to allow fluoroscopy to guide fracture reduction and safe implant fixation is inherent to the development of a talented surgeon.

The chapters within this text are a culmination of recommendations for patient positioning and variations of C-arm use by experts within the field of orthopedics. The author’s tips and tricks are the result of a common desire to “get it right,” our mentor’s teaching, and our own struggles and experience. This book is geared to any surgeon who operates on extremity and pelvic fractures, both novice and seasoned. It is a concise review of the radiographic bony anatomy and understanding of what we should be “seeing” during fracture reduction and instrumentation. We trust that you will find this reference useful for confirming your knowledge base for the most practical cases as well as the most challenging ones. It represents a teaching tool full of illustrations for educators to use at academic centers and a quick visual refresher for any surgeon to absorb right before a case. It has been a fun challenge to create this textbook as we sought to consider the different methods of fixation and their connection to fluoroscopy. We encourage the reader to never undervalue the time spent in preoperatively planning a case and to embrace fluoroscopy as complimentary adjunct to fracture surgery. Position yourself (and the patient) for success and get it right.

Christiaan N. Mamczak, Christopher S. Smith, and Michael J. Gardner

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Introduction

WILLIAM M. RICCI

Brief History of Fluoroscopy

Fluoroscopy is an indispensable part of the orthopedic traumatologist's armamentarium. Although it could be argued that intraoperative imaging may be overutilized, it is almost unimaginable to consider embarking on the reduction and fixation of a complex fracture, especially when using indirect reduction techniques, without fluoroscopy. This technology dates back to the very earliest days of radiography. Within 1 year of Roentgen's discovery of x-rays, in 1896, Thomas Edison developed the "fluoroscope." This real-time viewing of x-ray images utilized a simple fluorescent screen in a light-tight viewing cone. The imaging process has since been known as "fluoroscopy."[1] For the first half of the 20th century, little changes were made to this basic practice. High doses of x-ray were required, and cumulative exposure times were often minutes long rather than seconds. This combination caused excessive exposure doses to patients and staff, limiting the utilization of this technology. In 1948, John Coltman developed the image intensifier that converted x-rays to an electron beam that could be accelerated and focused on a fluorescent screen. The light emitted could be thousands of times brighter with the image intensifier than without the image intensifier, thus reducing the doses of radiation required. Fluoroscopy could then be used with reasonable safety in more routine applications, including fracture care.

Technical Considerations

Fluoroscope Components

A typical fluoroscopic system (Fig. 1-1) includes the x-ray generating tube, a collimator, an image intensifier, and a video camera. The image intensifier is a tube with a fluorescent screen (input phosphor) that glows with the image produced by the x-ray pattern that exits the patient. The light from the input phosphor causes ejection of electrons from a photoelectric material adjacent to the input phosphor. These electrons are accelerated via a high voltage (30 kV) and focused onto a small (1-inch diameter) screen (the output phosphor). The output phosphor glows much more brightly than does the input phosphor (about 3,000 times) because of the energy gain provided by the acceleration of the electrons and also because of minification of the image. The image on the output phosphor is monitored via a video camera system.

X-Ray Basic Physics

X-rays generated by fluoroscopy and plain radiography are forms of electromagnetic radiation. Other examples of electromagnetic radiation include visible light and radio waves. X-rays are produced when a heated filament (negatively charged cathode) within a tube generates electrons that are accelerated by application of high voltage (50 to 150 kVp) toward a tungsten target (positively charged anode). The electrons, repelled by the cathode and pulled toward the anode, accelerate to more than one-half the speed of light in one inch of travel. The electrons impact the anode and suddenly slow. The energy lost by the slowed electrons is converted to heat and creation of electromagnetic radiation including infrared light, visible light, ultraviolet waves, and x-rays.

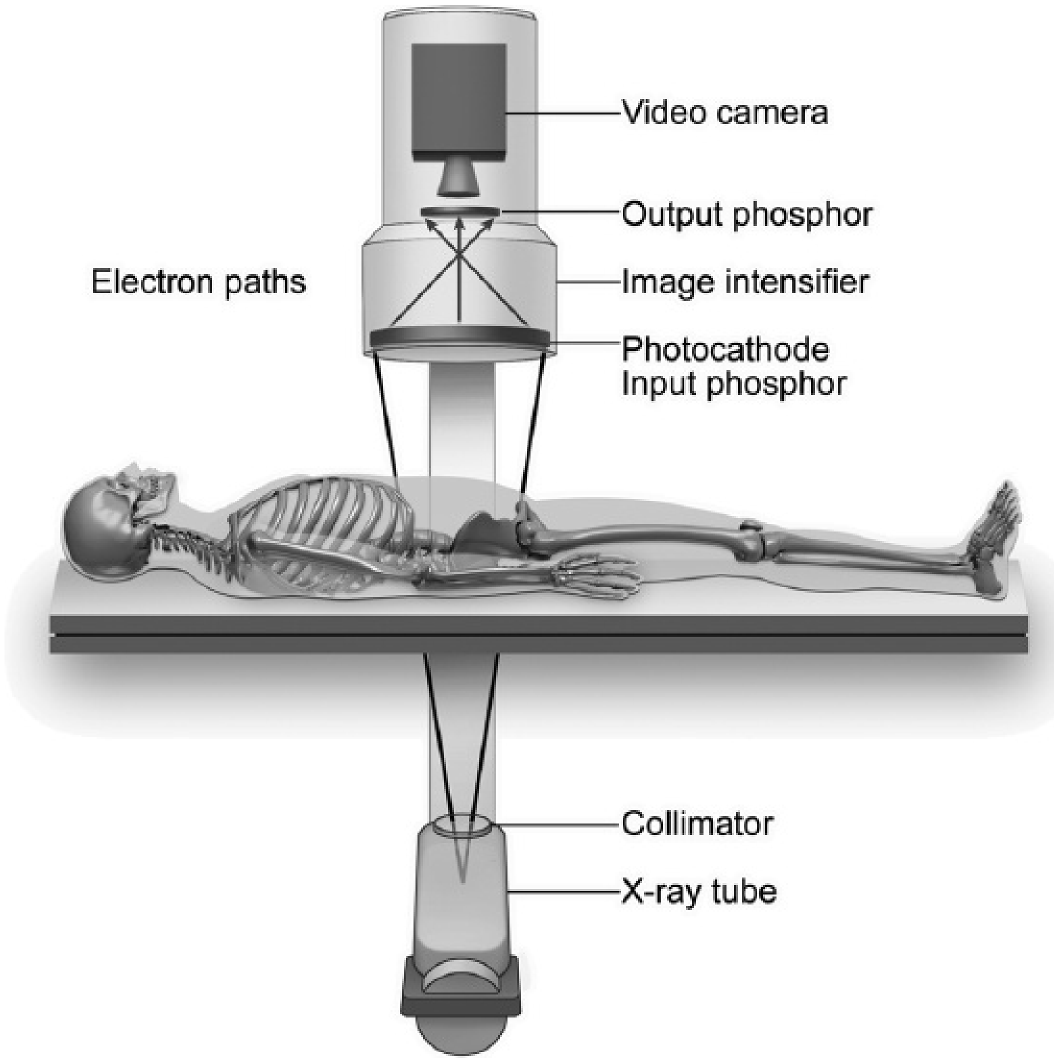

Figure 1-1 A schematic diagram of a fluoroscopy unit.

- **X-ray generator**—Produces electrical energy and allows selection of kilovolt peak (kVp) and tube current (mA) that is delivered to an x-ray tube.
- **X-ray tube**—Converts electrical energy of x-ray generator to x-ray beam.
- **Collimator**—Contains multiple sets of shutters (round and rectangular blades) that refine the x-ray beam shape. Collimating the beam to the area of interest reduces the exposed volume of tissue and results in less scatter and better image contrast. It also reduces the overall patient and surgeon radiation dose by minimizing scatter and direct exposure.
- **Image intensifier**—Converts x-rays to photoelectric energy. Major components include an input layer (input phosphor + photocathode) to convert x-rays to electrons, an image intensifier tube to accelerate and focus the electrons, and an output layer (output phosphor) to create a visible image.
- **Video camera** system—Captures the image and displays it on a video monitor.

The flow of electrons from the filament to the target is called the tube current and is measured in milliamperes (mA). Fluoroscopy is normally performed using 2 to 6 mA and an accelerating voltage of 75 to 125 kVp. The rate of x-ray production is directly proportional to the tube current, but is more sensitive to increasing voltage than current. For example, increasing the kVp by 15% is equivalent to a 200% increase in the mA.

When x-rays traverse tissue, they can result in (1) complete penetration, (2) total absorption, or (3) partial absorption with scatter. Complete penetration means that the x-rays completely passed through the tissue, resulting in an image. Total absorption means that the x-ray energy was completely absorbed by the tissue, resulting in no image. Partial absorption with scatter involves partial transfer of energy to tissue, with the scattered x-ray possessing less energy and following a different trajectory. The scattered radiation is responsible for causing radiation exposure to the operator and staff.

Units of Radiation Exposure and Dose

Radiation exposure is defined as the quantity of x-rays required to produce an amount of ionization in air at standard temperature and pressure. The traditional unit of exposure is the *Roentgen (R)*, which is defined as R = 2.58×10^{-4} C/kg air. The SI unit is Coulombs/kilogram (C/kg). The unit Roentgen, however, is only defined for air and cannot be used to describe dose to tissue. An absorbed dose of radiation can be measured in rad *(Radiation Absorbed Dose)*. The SI unit is the Gray (Gy) where 1 Gy = 100 rad. Dose equivalent accounts for differences in biological effectiveness of different types of ionizing radiation. Dose equivalent is equal to absorbed dose (Gy or rad) multiplied by a radiation quality factor specific to the type of radiation being used. The traditional unit is the *rem (Roentgen Equivalent in Man)*; the SI unit is the *sievert (Sv)* where 1 Sv = 100 rem. In diagnostic x-ray, the radiation quality factor is 1, so 1 rad is equivalent to 1 rem. The effective dose equivalent (EDE) takes into account that the potential health effect from single organ exposure is smaller than from whole body exposure. The EDE is defined as the sum of the absorbed dose to the tissue multiplied by a weighting factor, which calculates risk of cancer from partial body irradiation versus whole body irradiation. Units are also rem or sieverts.

Radiation Exposure

Background and Direct Exposures

Exposure to intraoperative radiation is of concern to all members of the surgical team. For perspective, the average yearly exposure of the public to ionizing radiation is about 360 millirems (mrem), of which 300 mrem is from background radiation and 60 mrem from diagnostic radiographs. A chest radiograph exposes the patient to approximately 25 mrem, a hip radiograph to 500 mrem, and a hip CT 1,000 mrem. A regular C-arm exposes the patient to approximately 1,200 to 4,000 mrem/min (lower for extremity and higher for pelvis). These values represent direct exposure. Recommended yearly limits of radiation are 2 to 5 rem (depending on the governing body) to the torso, 15 rem to the eyes, 30 rem to the thyroid, and 50 rem to the extremities (e.g., hands).[2] Fetal limits, relevant to fluoroscopy in pregnant patients, are 0.5 rem over 9 months.

Surgeon Exposure

Surgeon and staff may be exposed directly, most commonly to hands in the path of the x-ray beam, or exposed indirectly via scatter.2 Those in close proximity, <36 inches, are at highest risk for exposure.[3] Sanders et al., in 1993, found that average exposure of surgeon from scatter during femoral and tibial nailing was 100 mrem per operation.[4] At this dose, yearly limits to the eyes (the most sensitive organ not typically shielded) would be reached after 150 cases. Of note, average fluoroscopy time in this study was 6.26 minutes. Similar results were found by Muller et al., in 1998, where average exposure per case to the dominant index finger was 127 mrem for nailing procedures that averaged 4.6 minutes of fluoroscopy.[5] A number of other studies[6–9] specifically evaluated exposure to the hands. Exposure varied substantially between procedure and surgeon varying from undetectable to 570 mrem per procedure. It should be noted that more recent studies have shown shorter fluoroscopy times for long bone intramedullary nailing than in the aforementioned studies that described exposure doses. Ricci et al.[10] found the average time for antegrade femoral nailing to be 153 seconds (range: 16 to 662) when using a piriformis starting point and 95 seconds (range: 20 to 375 seconds) when using a greater trochanteric starting point and in a separate study found the average fluoroscopy time for tibial nailing to be 72.4 or 82.6 seconds depending on the surgery time of day.[11] Also, more advanced newer generation C-arm devices reduce the exposure per case.

Team Exposure

Exposures to operating personnel, other than surgeon, are of concern too. Many of these individuals spend more cumulative time being exposed than do surgeons by virtue of being in the OR on a daily basis. A study utilizing simulated pelvic surgery found first assistant exposure (2 feet away) of 6 mrem/min and no detectable exposure at the scrub nurse position (3 feet away) or the anesthesia position (5 feet away).3

Exposure Reduction Strategies

Standard strategies to mitigate exposure to scatter include decreasing exposure time, increasing distance, shielding, and contamination control. Typical shielding techniques used by orthopedic trauma surgeons include use of lead garments that shield the body core. Thyroid shields are a common adjunct. Because eye exposure can be many times higher than central exposure, leaded glasses have been recommended.[12] There is little debate that less exposure is better than more, and a number of studies have documented strategies to reduce exposure. Use of a real-time radiation exposure feedback from the Philips DoseAware device decreased radiation exposure by 60%.[13]

Differences Between Fluoroscopy and Plain Radiography

The fluoroscopic image generally has less contrast and less resolution of fine detail than does a radiographic image. A fundamental difference between plain radiographs and fluoroscopy is that fluoroscopy machines can automatically adjust exposure based on the density of the subject. Exposure for traditional plain radiography is set by the technician and is static. Fluoroscopy units are usually operated in an automatic brightness control (ABC) mode, in which a sensor in the image intensifier monitors the image brightness. When there is inadequate brightness, the ABC increases the kVp first, which increases the x-ray penetration through the patient, and then adjusts the mA to increase the brightness. Thicker soft tissue or larger cross-sectional areas will generate greater exposure to optimize brightness. However, radiodense metallic objects may inadvertently lead to overexposed images when automatic modes are used. Conversely, a field dominated by radiolucent material, such as air in a poorly centered image, will result in an underexposed image (Fig. 1-2).

Another difference is that the area of capture for fluoroscopy is generally more limited than with plain x-rays and is round rather than rectangular. The size of most image intensifiers is approximately 12 inches in diameter, although units, often used in vascular surgery, exist with larger sized intensifiers. The relatively small size of fluoroscopy images therefore limits the ability to evaluate alignment of long bone fixation. For these purposes, plain radiography has more utility.

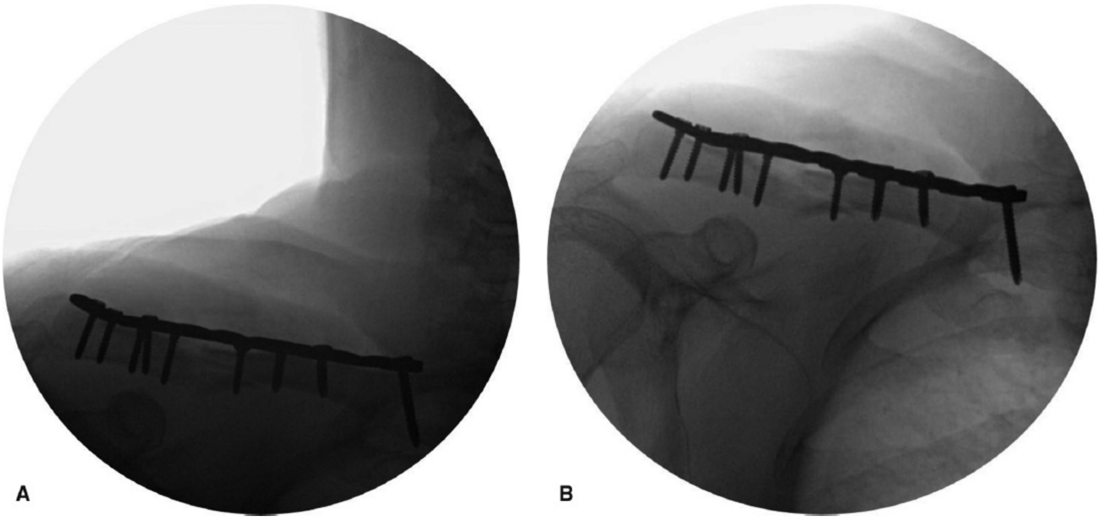

Figure 1-2 | **A:** This fluoroscopic image is centered such that a substantial portion of the field is air. Note that the tissue is underpenetrated due to the computer adjustments made by the fluoroscope being "fooled" to think the field is relatively radiolucent. The kVp and mA were 66 and 1.9, respectively. **B:** Centering the tissue to cover the majority of the field yields a properly exposed image with kVp and mA of 78 and 2.8, respectively.

Accuracy of Fluoroscopy

The ability to rely on fluoroscopy to definitively judge reduction has been debated. There is a general feeling in the orthopedic community that plain radiographs are more accurate than is fluoroscopy to judge fracture reduction, especially intra-articular reductions. However, critical analysis of this issue has led to varying conclusions. Several recent studies demonstrate inaccuracies of fluoroscopic evaluation of fracture reductions. Horst et al.[14] evaluated the quality of reduction and fixation based on fluoroscopy and compared results to postoperative plain radiographs. They found that in 8.2% of cases information was apparent on the postoperative plain radiographs such that a reviewer felt that the postoperative treatment plan should change. Haller et al.[15] found fluoroscopy inaccurate for evaluation of simulated tibial plateau fractures when fracture displacement was 2 mm or less. The accuracy of detecting reduction was 90%

when there was a 5-mm displacement, but decreased to 37% to 83% when displacement was 2 or 0 mm. Capo et al.[16] found that after closed reduction and percutaneous pinning of simulated Bennett's fractures in a cadaver model, the assessment of the articular gap, step-off, and displacement as detected by fluoroscopy was often in error compared to that detected by plain radiographs and direct examination.

On the other hand, there are also a number of studies that indicate fluoroscopy provides better accuracy than do plain radiographs. Norris et al.[17] found better results for fluoroscopy in evaluating positions of screws and reduction during acetabular fracture repair. Intraoperative fluoroscopy confirmed the extra-articular position of all screws evaluated. Postoperative CT scans confirmed the extra-articular placement of all screws assessed by fluoroscopy. Quality of reduction using intraoperative fluoroscopic images had a 100% correlation with reduction on final radiographs. One patient, with two screws placed without fluoroscopic evaluation, had intra-articular placement requiring revision surgery. Another study determined the accuracy of fluoroscopic imaging during closed reduction and percutaneous fixation of intra-articular thumb metacarpal fractures compared to direct vision and plain radiographs.[18] Fluoroscopy showed better correlation with direct vision than did plain radiographs for evaluation of displacement, and both fluoroscopy and plain radiographs showed excellent agreement when evaluating intra-articular step-off.

Terminology for Fluoroscopy Use in Orthopedic Trauma

There have been studies that have investigated the communication between the operative team and the fluoroscopy technician.[19,20] Poor communication can lead to unnecessary and/or poorly aligned fluoroscopy shots and therefore increased radiation exposure, frustration, and delay. Pally and Kreder[19] found that terminology used by surgeon members of the Canadian Orthopaedic Association to be tremendously diverse. They proposed that a standard lexicon be adopted and taught to orthopedic residents and technologists with the hope that efficient communication would be an unconscious part of operating the fluoroscope in every case. Although no such effort is underway in the United States at a national level, there is great utility in adopting a common terminology at the institutional level.

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Chapter 2
Scapula Fractures

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Bony Anatomy

- The scapula is a mostly flat, roughly triangular-shaped bone that is suspended off the posterolateral chest wall through the acromioclavicular articulation.
- The scapular spine arises from the upper posterior surface and gives rise superolaterally and anteriorly to the acromion.
- The coracoid process arises from the anterosuperior scapular neck. It runs in a superomedial direction before turning lateral and anterior as it thins at its "beak."
- The glenoid face is nearly perpendicular to the scapular body and forms the medial side of the glenohumeral articulation. Average glenoid version ranges from 5 degrees of anteversion to 15 degrees of retroversion.
- A majority of the scapular body bony surface area is only a few millimeters thick, limiting fixation constructs to the peripheral borders, scapular spine, glenoid neck, and coracoid.
- Imaging of the scapular body is complicated by the overlying thoracic wall and spine, while the acromion is difficult to image because of the overlying distal clavicle.
- Because of the complex anatomy and overlying structures, scapular fractures are easily missed or underestimated by plain radiographs.

Radiographic Anatomy

AP and Grashey AP View

- In the AP view, the glenohumeral articulation should be seen free from overlying structures, but the scapular body invariably overlies the thoracic wall, including the ribs and the lung fields. The medial border and inferior angle of the scapula should be included on the radiograph.
- Minimally displaced scapular body fractures, particularly over the medial half of the scapula, are difficult to appreciate secondary to overlying structures (Fig. 2-1A and B).
- To best visualize the glenohumeral joint, the beam should be rotated approximately 35 degrees aiming from the midline to lateral in order to profile the scapula, in line with the glenoid, generating a Grashey or "True AP" view (Figs. 2-2 and 2-3).
- Due to the slightly concave nature of the glenoid surface, the Grashey view allows confirmation that screws do not protrude into the glenohumeral joint (Fig. 2-4).
- The Grashey view is often best to ensure reduction of fracture fragments with spikes that exit the lateral border of the scapula. These fragments often have extension into the glenoid face, and articular reduction can be partially assessed with this view (Fig. 2-5A and B).
- The lateral and posterior displacement of the caudal fracture fragment can be due to the pull of the infraspinatus, teres major and minor, the latissimus dorsi, and the long head of the triceps, depending on the size of the fracture fragment.
- Overlying structures may obscure bony anatomy on the Grashey view, particularly toward the medial half of the scapula.

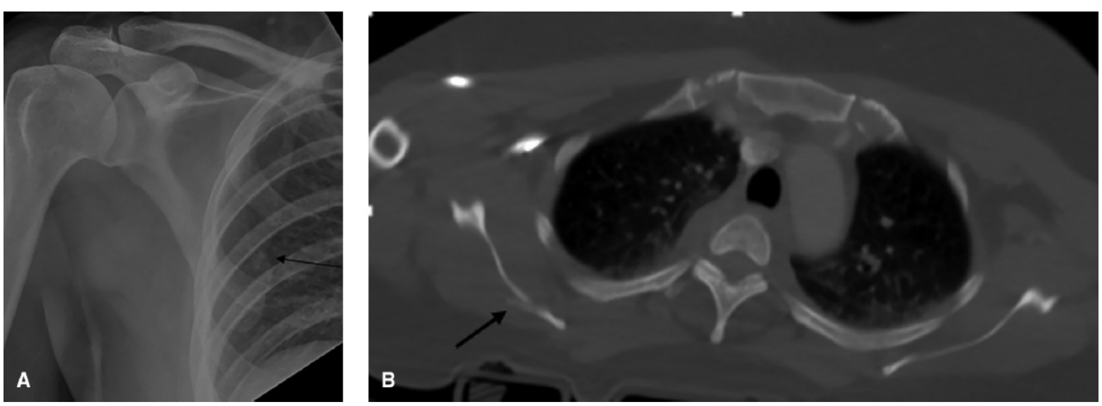

Figure 2-1 Suboptimal technique and overlying structures resulted in a missed diagnosis of a medial scapular body fracture (*arrows*). This injury was recognized on subsequent CT scan as part of a trauma protocol.