Get Full Access and More at **ExpertConsult.com**

Diagnostic Imaging

Musculoskeletal Trauma

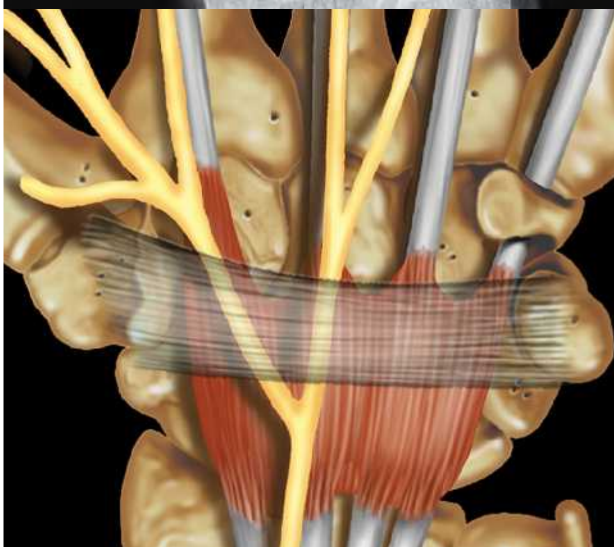
SECOND EDITION

Blankenbaker | Davis

SONIN • CRIM • TUITE • ANDREWS

AMIRSYS®

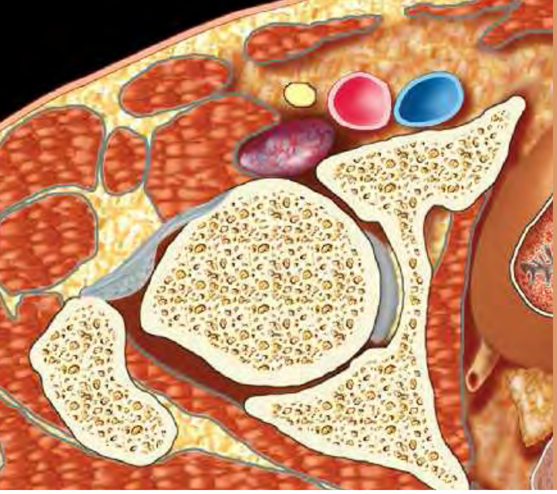
ELSEVIER

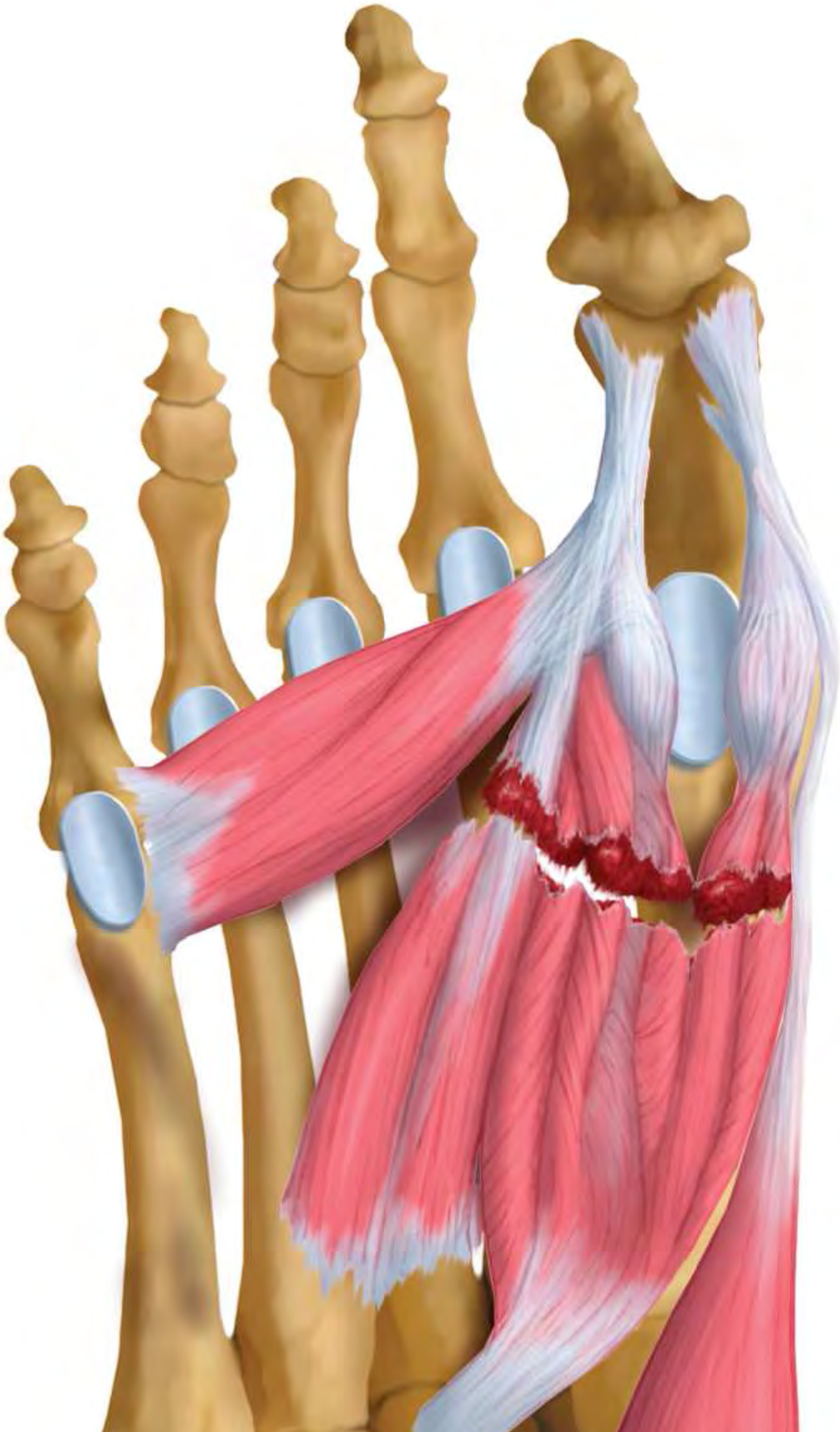


Diagnostic Imaging

Musculoskeletal Trauma

SECOND EDITION





Diagnostic Imaging

Musculoskeletal Trauma

SECOND EDITION

Donna G. Blankenbaker, MD
Professor of Radiology
Musculoskeletal Imaging and Intervention
Department of Radiology
University of Wisconsin School of Medicine and Public Health
Madison, Wisconsin

Kirkland W. Davis, MD
Professor of Radiology
Musculoskeletal Imaging and Intervention
Department of Radiology
University of Wisconsin School of Medicine and Public Health
Madison, Wisconsin

Andrew Sonin, MD, FACR
Musculoskeletal Radiology
Radiology Imaging Associates
Englewood, Colorado

Julia R. Crim, MD
Chief of Musculoskeletal Radiology
Vice Chair for Clinical Affairs
Professor of Radiology
University of Missouri at Columbia
Columbia, Missouri

Michael J. Tuite, MD
Vice-Chair of Operations
Professor of Musculoskeletal Radiology
University of Wisconsin Medical School
Madison, Wisconsin

Carol L. Andrews, MD
Associate Professor
Division Chief, Musculoskeletal Radiology
University of Pittsburgh Medical Center
Pittsburgh, Pennsylvania

ELSEVIER

1600 John F. Kennedy Blvd.
Ste 1800
Philadelphia, PA 19103-2899

DIAGNOSTIC IMAGING: MUSCULOSKELETAL: TRAUMA, SECOND EDITION ISBN: 978-0-323-39253-2

Notices

Knowledge and best practice in this field are constantly changing. As new research and experience broaden our understanding, changes in research methods, professional practices, or medical treatment may become necessary.

Practitioners and researchers must always rely on their own experience and knowledge in evaluating and using any information, methods, compounds, or experiments described herein. In using such information or methods they should be mindful of their own safety and the safety of others, including parties for whom they have a professional responsibility.

With respect to any drug or pharmaceutical products identified, readers are advised to check the most current information provided (i) on procedures featured or (ii) by the manufacturer of each product to be administered, to verify the recommended dose or formula, the method and duration of administration, and contraindications. It is the responsibility of practitioners, relying on their own experience and knowledge of their patients, to make diagnoses, to determine dosages and the best treatment for each individual patient, and to take all appropriate safety precautions.

To the fullest extent of the law, neither the Publisher nor the authors, contributors, or editors, assume any liability for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

Publisher Cataloging-in-Publication Data

Names: Blankenbaker, Donna G. | Davis, Kirkland W.
Title: Diagnostic imaging. Musculoskeletal trauma / [edited by] Donna G. Blankenbaker and Kirkland W. Davis.
Other titles: Musculoskeletal trauma.
Description: Second edition. | Salt Lake City, UT : Elsevier, Inc., [2016] | Includes bibliographical references and index.
Identifiers: ISBN 978-0-323-39253-2
Subjects: LCSH: Musculoskeletal system--Wounds and injuries--Imaging--Handbooks, manuals, etc. | MESH: Musculoskeletal system--injuries--Atlases. | Musculoskeletal system--radiography--Atlases. | Fractures, Bone--diagnosis--Atlases.
Classification: LCC RD680.D53 2016 | NLM WE 39 | DDC 617.4'7044--dc23

International Standard Book Number: 978-0-323-39253-2

Cover Designer: Tom M. Olson, BA
Cover Art: Laura C. Sesto, MA

Printed in Canada by Friesens, Altona, Manitoba, Canada

Last digit is the print number: 9 8 7 6 5 4 3 2 1

Dedications

I would like to thank my family, colleagues, and friends for their support. Additionally, I would like to recognize those mentors who have influenced my career: Drs. Arthur De Smet, Tom Berquist, and B.J. Manaster.

DGB

To my beautiful wife, Jenni, and our wonderful children, Katherine, Tom, Emily, and Margaret: Thank you for your love, support, and forbearance.

KWD

To my beautiful wife, Karen, and our three lovely children, Kaitlyn, Aaron, and Evan, for putting up with another "free time" project. Also to mom and dad, for giving me the tools to accomplish all that I have.

AS

To Lester, Philip, and Eleanor, who are always in my heart.

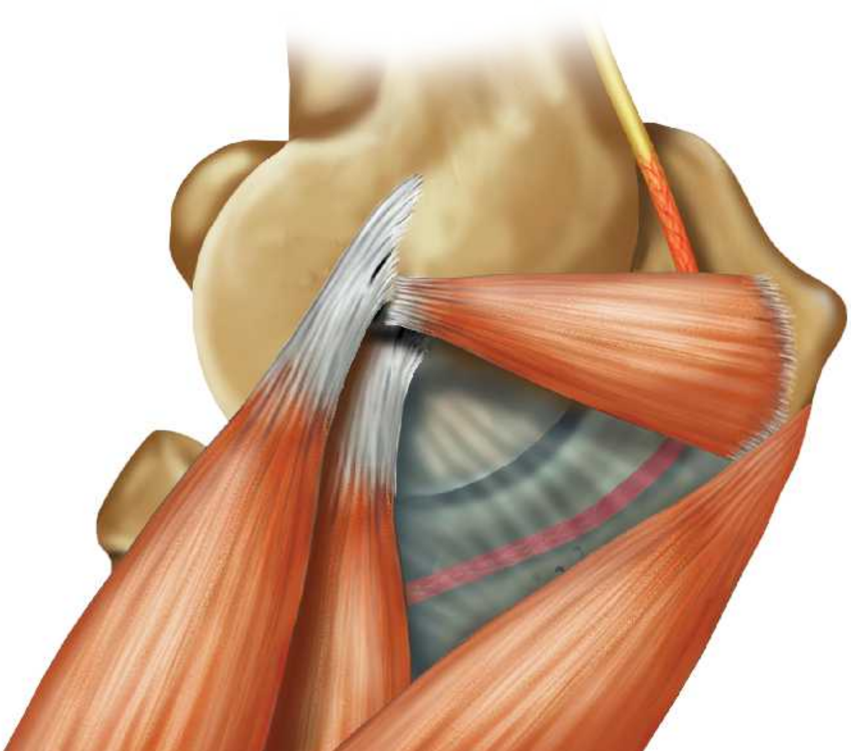
JRC

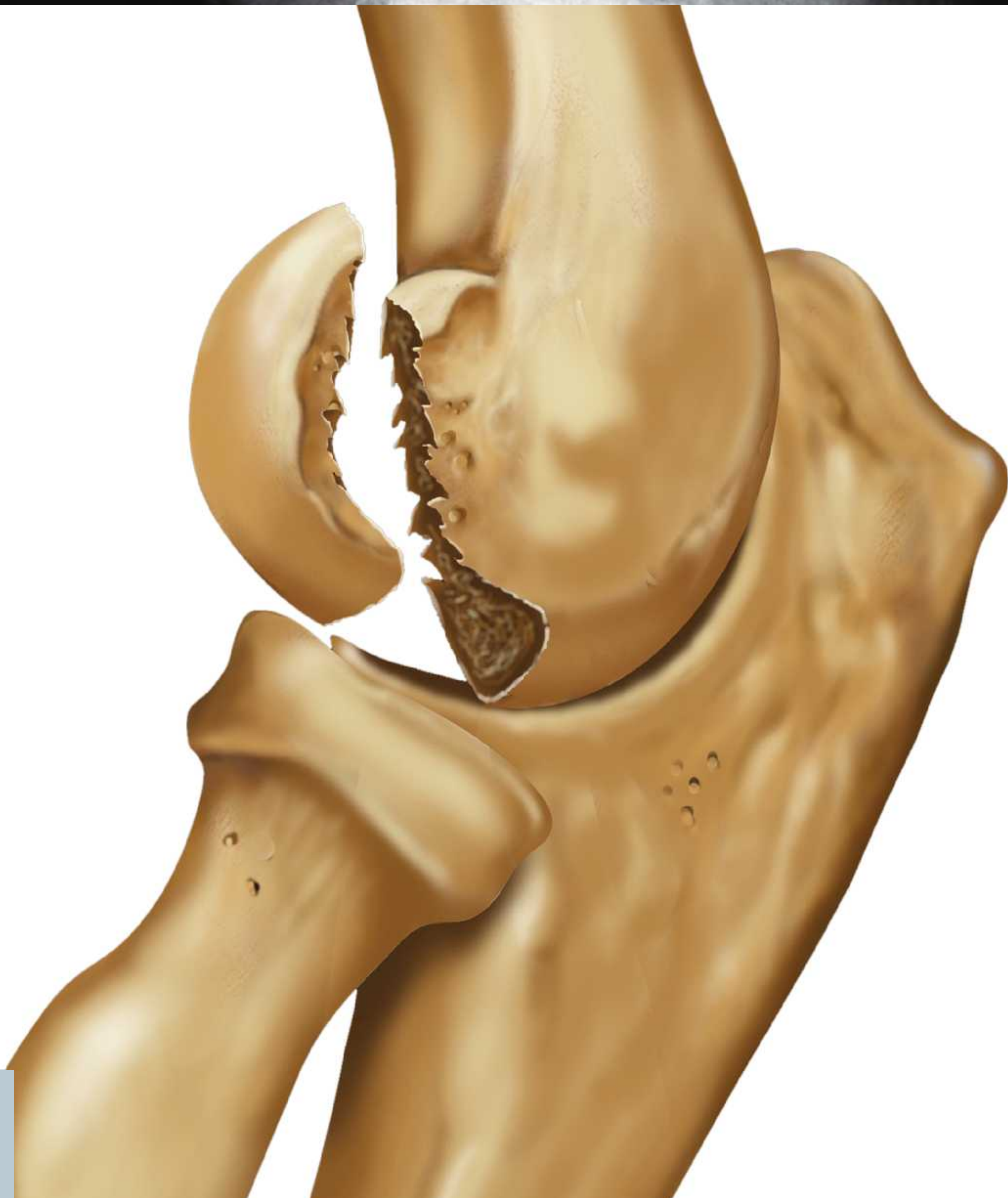
I thank my wife and soulmate Monica, who graciously supported the extra time spent on this book on top of my work and travel. And our daughter, Phoebe, a fantastic writer who would have written much more eloquent chapters than the ones I did.

MJT

To John Andrews.

CLA

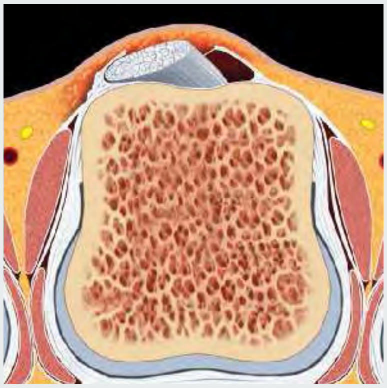


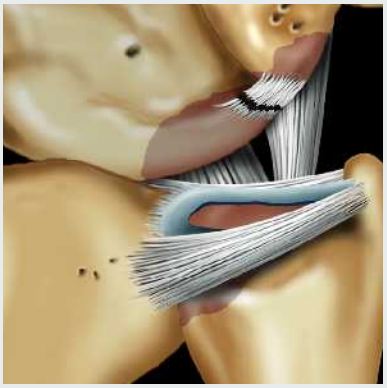


Contributing Authors

B.J. Manaster, MD, PhD, FACR
Emeritus Professor
Department of Radiology
University of Utah School of Medicine
Salt Lake City, Utah

Adam C. Zoga, MD
Associate Professor of Radiology
Vice Chair for Clinical Practice
Director of Musculoskeletal MRI
Thomas Jefferson University
Philadelphia, Pennsylvania





Preface

Though the ways we can injure ourselves have not changed much since the prior edition in 2010, our understanding of the human musculoskeletal system and its injuries continues to evolve, and our ability to accurately diagnose those injuries continues to improve. This book builds on the wonderful previous edition. We maintain the eminently readable and searchable Amirsys style and organization, allowing quick access to important imaging and clinical tips.

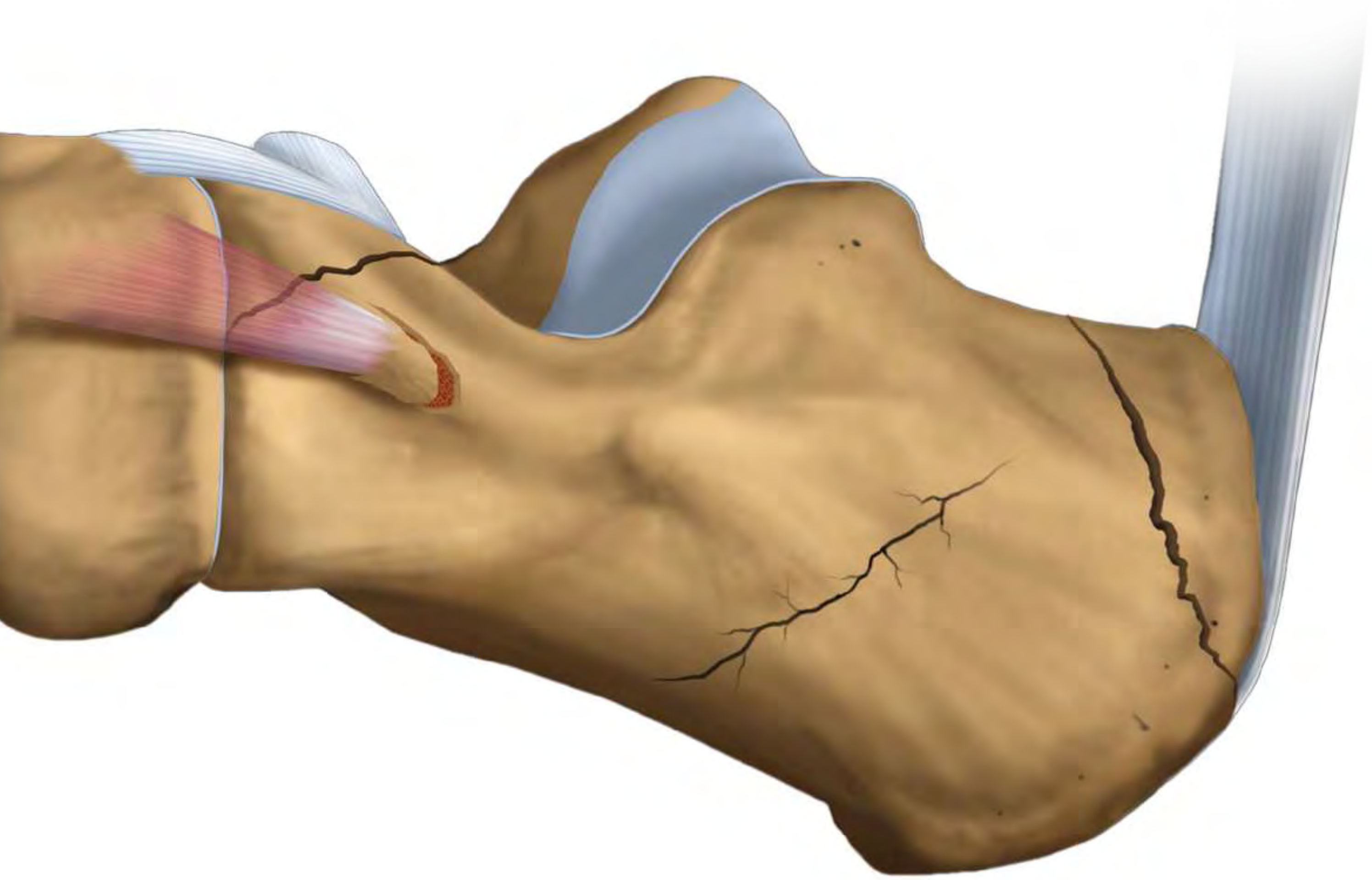
Ultrasound continues to gain importance as an imaging tool in the musculoskeletal system. As such, this edition includes expanded descriptions and images of MSK ultrasound in many of the chapters. Moreover, new chapters in this edition discuss fracture healing, posterior elbow impingement, fractures of the sacrum, and ischiofemoral impingement.

The authors have included the latest information for all topics and added references and an extensive number of cases to all chapters. The hardcopy version of this work includes all the critical text and imaging examples of all important entities. However, further clinical information, and, in many cases, numerous additional imaging examples, have been added to the electronic version, Expert Consult. Graphic diagrams of anatomy and injuries have been enhanced to demonstrate points more clearly, and graphics have been added to clarify complex topics. In addition, several chapters have been reworked to improve readability and match our evolving understanding of certain injuries.

We are grateful to Drs. Andrews, Crim, Sonin, and Tuite for their willingness to update and improve their work from the prior edition. Their thoughtful approach and dedication to this edition have made the experience pleasurable for us. We thank the excellent editorial and art personnel at Amirsys/Elsevier. This team has produced a comprehensive yet readable reference with fantastic imaging and graphic representations of the subject. We hope that radiologists and nonradiologists at all levels of expertise will find this a valuable tool in their practice.

Donna G. Blankenbaker, MD
Professor of Radiology
Musculoskeletal Imaging and Intervention
Department of Radiology
University of Wisconsin School of Medicine and Public Health
Madison, Wisconsin

Kirkland W. Davis, MD
Professor of Radiology
Musculoskeletal Imaging and Intervention
Department of Radiology
University of Wisconsin School of Medicine and Public Health
Madison, Wisconsin



Acknowledgments

Text Editors
Arthur G. Gelsinger, MA
Karen E. Concannon, MA, PhD
Terry W. Ferrell, MS
Lisa A. Gervais, BS
Emily C. Fassett, BA
Matt Hoecherl, BA
Tricia L. Cannon, BA

Image Editors
Jeffrey J. Marmorstone, BS
Lisa A. M. Steadman, BS

Medical Editor
Scott E. Sheehan, MD

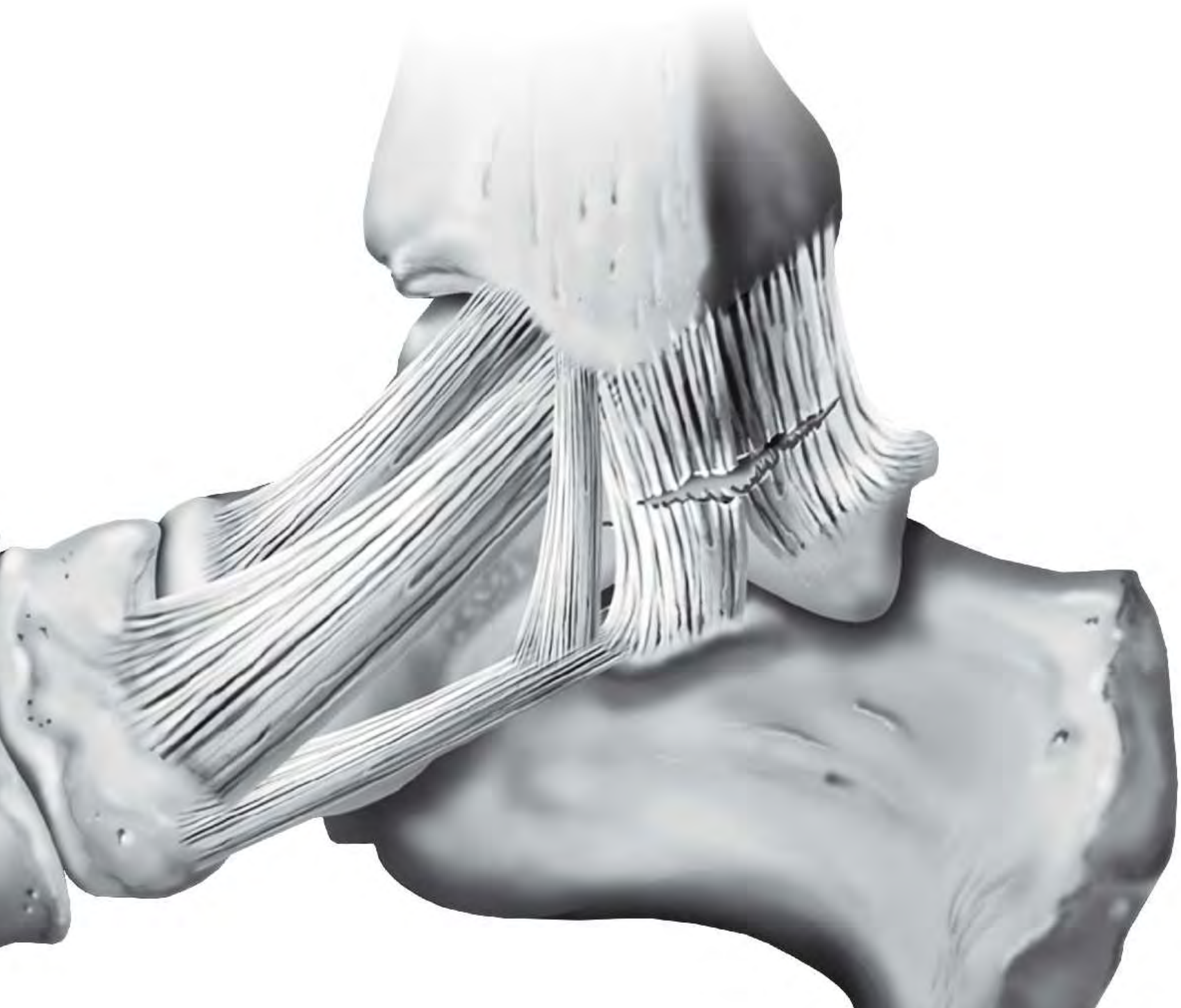
Illustrations
Laura C. Sesto, MA
Richard Coombs, MS
Lane R. Bennion, MS

Art Direction and Design
Tom M. Olson, BA
Laura C. Sesto, MA

Lead Editor
Nina I. Bennett, BA

Production Coordinators
Angela M. G. Terry, BA
Rebecca L. Hutchinson, BA

ELSEVIER



Sections

TABLE OF CONTENTS

TABLE OF CONTENTS

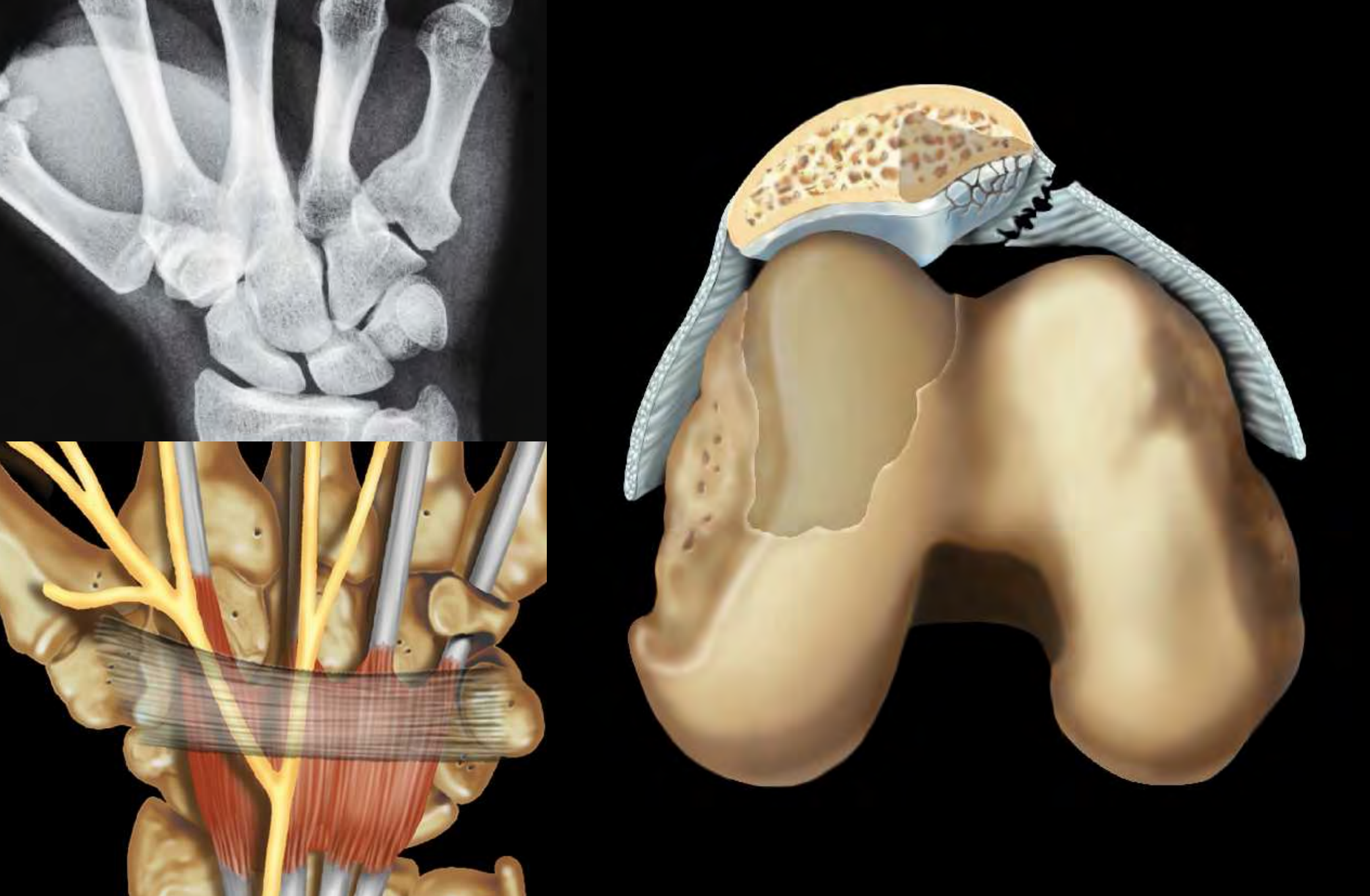
TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

This page intentionally left blank



Diagnostic Imaging

Musculoskeletal Trauma

SECOND EDITION

This page intentionally left blank

SECTION 1
Introduction

Overview

Traumatic Injury, Special Topics

Terminology

Anatomic terminology used in this book follows conventional medical literature guidelines. For example, the radial aspects of the elbow, forearm, and wrist are termed "lateral" and the ulnar aspects "medial." The terms "superior" and "inferior" have been used to indicate direction in the z-axis of the body instead of "cephalad" and "caudad." The term "mesial" is used to indicate direction toward the center of a limb but not necessarily the center of the body. Specific terminology used for each anatomic region is described in the introductory chapter for that section.

A variety of acronyms are found in the medical literature to refer to injury patterns, imaging findings, and operative approaches. Commonly used acronyms are presented in this book but are spelled out on their first use in each chapter.

The commonly encountered clinical entity of tendon injury is described in this book using the term "tendinopathy," as opposed to "tendinosis" or "tendinitis." This is based on the etymologic origins of these terms. The suffix "-osis" refers to "a process, condition, or state" without being extremely specific about what the process is. The suffix "-itis" refers to "inflammation of"; thus, the term "tendinitis" may be appropriate in rare circumstances in which the tendon is inflamed due to acute trauma or infection. However, most cases of tendon pathology encountered in sports imaging are the result of a process of chronic repetitive microscopic injury and repair, resulting in a weakened tendon unit that is more prone to macroscopic tear. The resultant pathologic process has been termed "angiofibroblastic hyperplasia" and is characterized by ingrowth of fibroblastic repair tissue and neovascularity; there is very little inflammatory component. Thus, the suffix "-opathy," meaning "disease or disorder of," most accurately describes the underlying process.

Although the imaging of some areas (e.g., the shoulder) typically requires nonorthogonal imaging planes to provide anatomically appropriate images, the terms "coronal" and "sagittal" have been used to imply "oblique coronal" and "oblique sagittal" planes conventionally used in those regions. When a nonconventional obliquity is illustrated, a description of the imaging plane used is provided. The terms "CT" and "MR" have been used throughout the book to indicate "computed tomography" and "magnetic resonance" imaging techniques.

Imaging Protocols

While some specific description is provided for the acquisition of certain radiographic views, description of most CT and MR imaging techniques is given only in general terms. This was done with the understanding that imaging equipment from different manufacturers, and often different levels of equipment from the same manufacturers, has very different capabilities and uses a wide range of descriptive language to provide similar imaging results. Thus, terms such as "T2-weighted fat-suppressed MR images" describe the generic appearance of anatomy that may be accomplished using a wide variety of proprietary MR techniques. In addition, the armamentarium of imaging techniques changes constantly, and new pulse sequences and hardware devices become available that may alter the method used by a particular radiologist to accomplish the same end.

In general, CT imaging of joints or extremities is best accomplished using a multislice scanner to acquire very thin slices through the affected anatomic region, with subsequent creation of anatomically appropriate reformatted images in additional planes from the acquired data. To avoid reconstruction artifact in small joints, a minimum of 6-8 detector rows is advisable, and higher quality images are produced with higher detector counts (typically 32-64).

MR imaging of joints and extremities is best accomplished using volume coils in order to maximize signal-to-noise ratio (SNR) of the images and minimize field inhomogeneity that may degrade or prevent chemical fat suppression. Joint-specific volume coils are available from many manufacturers for commonly imaged anatomic regions. Optimization of images is usually a trade-off between minimizing the field of view to cover the area of interest and the maintenance of appropriate SNR on the images through manipulation of pulse sequence parameters. The increasing availability of multichannel extremity coils and higher-strength magnets provides greater opportunity to improve both of these goals simultaneously.

The use of gadolinium arthrography can be very helpful in the detection and description of certain intraarticular pathologies. The application of this technique is described and illustrated where appropriate. This may be accomplished by direct injection of the joint (direct MR arthrography) or by intravenous injection of gadolinium followed by delayed MR imaging of the joint (indirect MR arthrography). Direct arthrography has the advantage of distending the joint but is invasive. Indirect arthrography is less invasive but provides no joint distension and may result in enhancement of tissues (such as a hyperemic but intact rotator cuff) that can confuse image interpretation. With continued improvement in imaging equipment and development of new sequences, noncontrast MR imaging has closed the gap with MR arthrography; indeed, some authors contend that the two are equivalent for some joints. The current authors take no side on this issue but attempt to show comprehensive imaging of joint-based pathology of joints, including MR arthrograms and nonarthrographic MR scans where appropriate.

The clinical utility of ultrasound in the evaluation of musculoskeletal injury continues to grow and is currently an area of intense research and publication. Ultrasound can provide exquisite anatomic detail of soft tissues, particularly in areas close to the body surface; because the ultrasound beam deteriorates with the depth of tissue it needs to penetrate, technical limitations are often encountered in the evaluation of deeper structures (and particularly in large patients). The technique uses no ionizing radiation and is noninvasive. However, musculoskeletal ultrasound is heavily dependent on operator skill, and a steep learning curve may be encountered as one seeks to gain expertise in this field. In geographic regions where access to MR imaging is limited, musculoskeletal ultrasound has grown to be a reliable and ubiquitous problem-solving imaging modality. In most of the United States, probably because of the relative availability of MR imaging in most communities, the use of ultrasound in the imaging diagnosis of sports injury lags behind that in other parts of the world, though the last few years have seen an exponential spread of musculoskeletal ultrasound in the United States. The current edition includes substantial expansion of its description of ultrasound with a marked increase in ultrasound cases to help the practitioner ascend the learning curve.

Pathologic Issues

In many cases, the manifestations and etiologies of trauma and injury are very different for children than they are for adults. Descriptions and illustrations of issues specific to pediatric patients are provided where appropriate. Dedicated chapters are presented on the topics of child abuse and physeal injuries.

Orthopedic surgeons commonly use classification and grading systems to categorize injuries. These systems are usually helpful in determining appropriate therapy for a particular injury. The commonly used classification and grading systems for each injury are provided and illustrated.

Pathology-Based Imaging Issues

Each chapter contains discussions of the advantages and disadvantages of particular imaging techniques in diagnosing and characterizing a particular entity. Some generalizations may be made, however.

Radiography is usually the first-line tool in the evaluation of acute traumatic injury to the limbs, especially to detect fractures and dislocations. Soft tissue injury is much less well delineated on radiographs, though, and the information provided regarding the soft tissue components of an injury tends to be nonspecific.

CT, because of its superior tissue density differentiation, can be more helpful in detecting and characterizing some soft tissue findings, but its clinical utility is mainly based on evaluation of osseous abnormalities. Small fractures are generally better demonstrated on CT than on radiographs because of the former's tomographic nature, which alleviates confusion due to overlapping structures. The addition of contrast arthrography to CT can be helpful in evaluating certain intraarticular structures and provides value in the detection of rotator cuff tear, labral injury in the shoulder and hip, meniscal injury in the knee, and cartilage injury throughout the extremities.

MR imaging uses a strong magnetic field and radiofrequency energy pulses to manipulate the energy state of protons within tissue. Complex machinery detects subtle differences in how different tissues respond to this energy deposition and provides exquisitely detailed information about soft tissues. For this reason, MR imaging has been the mainstay of diagnosis in acute and chronic injury to soft tissues, such as ligaments, tendons, and muscles. In addition, MR can provide detailed evaluation of intraarticular structures, often without the injection of contrast material, so that pathology of fibrocartilage (meniscus and labrum), articular cartilage, and synovium is well demonstrated. There are some specific situations in which the use of intraarticular contrast injection can increase the diagnostic accuracy of MR, such as in the postoperative patient. MR imaging also provides a sensitive method for the detection of bone marrow abnormalities, such as marrow edema, osteonecrosis, and tumor infiltration, but is not particularly sensitive for disruption of cortical bone unless a fracture is displaced.

Ultrasound provides another excellent method for studying the soft tissues of the extremities and, as indicated above, is particularly useful in the evaluation of structures closer to the skin surface. In addition, ultrasound provides real-time information regarding the motion of structures and is thus valuable in the evaluation of transient phenomena, such as tendon impingement or subluxation. Limitations of ultrasound include the inability of the beam to penetrate dense material so that bone and metal effectively block the evaluation of anything located deeper in the body. For this reason, ultrasound is not commonly useful for the evaluation of intraarticular pathology. Ultrasound also does not perform well when encountering air collections because sound waves travel poorly through air.

Selected References

1. Major NM et al: Evaluation of the glenoid labrum with 3-T MRI: is intraarticular contrast necessary? AJR Am J Roentgenol. 196(5):1139-44, 2011
2. Buckwalter KA: Current concepts and advances: computerized tomography in sports medicine. Sports Med Arthrosc. 17(1):13-20, 2009
3. Coris EE et al: Imaging in sports medicine: an overview. Sports Med Arthrosc. 17(1):2-12, 2009
4. Jacobson JA: Musculoskeletal ultrasound: focused impact on MRI. AJR Am J Roentgenol. 193(3):619-27, 2009
5. Krug R et al: Imaging of the musculoskeletal system in vivo using ultra-high field magnetic resonance at 7 T. Invest Radiol. 44(9):613-8, 2009
6. Renner JB: Conventional radiography in musculoskeletal imaging. Radiol Clin North Am. 47(3):357-72, 2009
7. Sanchez TR et al: MR imaging of pediatric trauma. Magn Reson Imaging Clin N Am. 17(3):439-50, v, 2009
8. Sofka CM et al: The history of clinical musculoskeletal radiology. Radiol Clin North Am. 47(3):349-56, 2009
9. Gandhi RT et al: Technical considerations and potential advantages of musculoskeletal imaging at 3.0 Tesla. Semin Musculoskelet Radiol. 12(3):185-95, 2008
10. Jaramillo D et al: Pediatric musculoskeletal MRI: basic principles to optimize success. Pediatr Radiol. 38(4):379-91, 2008
11. Meyer JS et al: Musculoskeletal MR imaging at 3 T. Magn Reson Imaging Clin N Am. 16(3):533-45, vi, 2008
12. Buckwalter KA: Optimizing imaging techniques in the postoperative patient. Semin Musculoskelet Radiol. 11(3):261-72, 2007
13. Illustrated Stedman's Medical Dictionary. 24th ed. Baltimore, MD: Williams & Wilkins, 1982

KEY FACTS

TERMINOLOGY

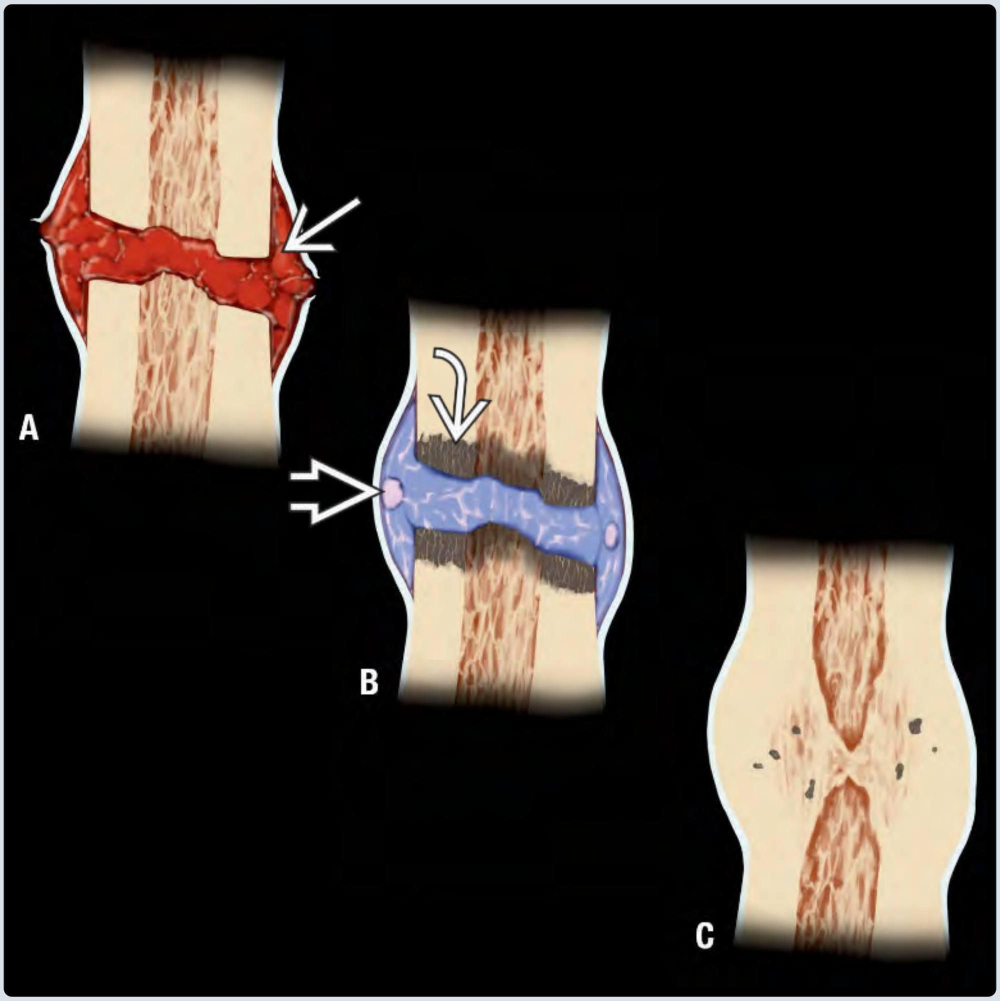
- Clinical union: Sufficient bone growth across fx, irrespective of radiographic obliteration of fx lucency, to restore original function
- Radiographic union: Ossified callus bridges fx line, uniting fragments; callus as dense or nearly as dense as normal bone
- Nonunion: Fx fragments not bridged by mature bone and healing process has arrested
- Delayed union: Lack of clinical or radiographic union within expected time frame but appropriate care may lead to ultimate fx union
- Malunion: Fracture fragments heal with angulation &/or rotation across fracture, improper length, or articular incongruity that is functionally or cosmetically unacceptable

IMAGING

- Widening of fx gap, blurring of fx margins are 1st radiographic signs of healing
- Fluffy calcified immature callus (primary callus or soft callus) appears around and across fx next
- Arc of peripheral callus must extend across fx line before bone will bridge centrally
- Hypertrophic nonunion: Abundant peripheral callus develops but never crosses fx line
- Atrophic nonunion: No substantial callus develops
- In cases of clinical and radiographic uncertainty regarding union/nonunion, CT is method of choice to assess fx healing

DIAGNOSTIC CHECKLIST

- Failure of fixation hardware suggests nonunion or incomplete union
- Expected time to union varies with patient age and bone in question



Graphic depicts snapshots during progressive healing of bone. A: Acute fx is accompanied by tissue damage; hematoma ➡ fills the gap, lifts up the periosteum and begins the inflammatory phase. B: Granulation tissue is being transformed into immature osteoid (blue) and chondroid ➡ callus bridging the gap externally and internally. Devitalized bone ➡ continues to be resorbed (started in inflammatory phase). C: Immature callus is now replaced by mature bone and continues to undergo remodeling. Bone fills the entire gap. (Adapted from Rogers LF. Radiology of Skeletal Trauma, 2nd ed.)

TERMINOLOGY

Definitions

- Clinical union: Sufficient bone growth across fx, irrespective of radiographic obliteration of the fx lucency, to restore original function
  - Determined clinically: Stability on physical exam, absence of pain at site, ability to use fractured extremity in activities of daily living
  - Expected time to fx union varies with patient age and bone involved
- Radiographic union: Ossified callus bridges fx line, uniting fragments; callus as dense or nearly as dense as normal bone
  - Radiographic union often lags clinical union
  - Radiographic criteria do not correlate well with fracture strength and stiffness
- Nonunion: Fx fragments not bridged by mature bone and healing process has arrested
- Delayed union: Lack of clinical or radiographic union within an expected timeframe; in many of these instances, improved immobilization, patient adherence to rehabilitation instructions will lead to ultimate fx union
- Pseudoarthrosis: False joint that may develop in setting of nonunion, precluding any further healing until intervening synovial tissue is removed
- Malunion: Fracture fragments heal with angulation &/or rotation across fracture, improper length, or articular incongruity that is functionally or cosmetically unacceptable
- Osteosynthesis: Process of augmenting fx healing via surgical fixation, sometimes with bone graft or other accelerants added

IMAGING

General Features

- Best diagnostic clue
  - Ossified callus bridges fx line, as dense or nearly as dense as normal bone
  - Confirmed on at least 2 projections

Radiographic Findings

- Radiography
  - Acute fx: Sharp, irregular margins at fx lucency, associated soft tissue swelling
  - Widening of fx gap, blurring of fx margins are 1st radiographic signs of healing as inflammatory response resorbs dead bone at the ends of fx
    - Visible at 10-14 days
  - Fluffy calcified immature callus (primary callus or soft callus) appears around and across fx next
    - As early as 10 days in young children, as early as 2 weeks in adults
  - Arc of peripheral callus must extend across fx line before bone will bridge centrally
  - Immature callus develops radiographic features/texture of bone as it matures
  - Greater amounts of peripheral callus develop with: Long bone fxs (versus short tubular bones, marginal prominences such as tuberosities, carpal and tarsal fxs), diaphyseal fxs, greater fx gap, and inadequate immobilization
  - Fxs of cancellous bone and intraarticular fxs do not develop peripheral callus; instead, fx line will become less distinct and there may be sclerotic internal callus within medullary canal
    - This process is called primary fx healing as opposed to secondary fx healing in which peripheral callus develops
    - Also may occur in very rigidly fixed fxs: Peripheral callus formation requires at least minimal motion at fracture
  - Disuse atrophy of bone (disuse osteoporosis) is expected appearance with fx immobilization and healing; occurs universally after 7-8 weeks of immobilization, often sooner
    - Generalized demineralization of bones at and distal to fx
  - Nonunion: Lack of osseous bridging of fx gap in expected time frame (clinical diagnosis)
    - Hypertrophic nonunion: Abundant peripheral callus develops but never crosses fx line
    - Atrophic nonunion: No substantial callus develops
    - Ends of bones at fx line develop cortex along entire surface, precluding subsequent union without operative revision
    - Fibrous union: Successful union clinically but with fibrous tissue bridging gap instead of bone
      - Usually fills in with bone subsequently
    - Fixation hardware cannot be expected to stabilize fractures forever: Eventually hardware will pull out or break if there is no clinical union
      - Hardware failure strongly suggests nonunion or incomplete union

CT Findings

- Often used in initial fx assessment, especially to assess presence and severity of intraarticular fxs and for surgical planning
- In cases of clinical and radiographic uncertainty regarding union/nonunion, CT is method of choice to assess fx healing
  - Multiplanar reformatted images required
  - Primary determination is whether or not any callus bridges fx line; secondary is estimate of what percentage of fx line is bridged
  - Increasingly abundant peripheral callus is not advantageous if it does not cross fx line
  - Often the earliest CT finding of union is single strut of peripheral callus that fully crosses fx line
    - Can be reported as evidence of early healing
  - Immature callus bridging fx line is positive prognostic sign
    - Initially denser (greater attenuation) than fx, but not as dense as normal bone
    - Will mature into bone eventually

MR Findings

- MR generally not used or helpful to assess fx healing
- Can be helpful to assess for complications that may impede healing, e.g., infection, entrapped tissues
- Pseudoarthrosis: Defined fluid in gap of ununited fx
  - Collection of high-signal fluid that does not enhance with contrast

Imaging Recommendations

- Best imaging tool
  - Radiographs usually sufficient
  - CT reliable when radiographs and clinical findings inconclusive
- Protocol advice
  - Radiographs: At least 2 projections required to assess healing
    - Additional views, including obliques, often needed to fully assess fx line, especially if fixation hardware obscures fx
  - CT: If sizable hardware present, consider increasing mAs; multidetector row scanner needed with overlapping reconstructions, multiplanar reformatted images

DIFFERENTIAL DIAGNOSIS

Fibrous Union

- Persistent lucency at fx site may be clinically united/stable
- Can be mistaken for nonunion radiographically
- Often fully unites with time

PATHOLOGY

Staging, Grading, & Classification

- Stages of healing
  - Acute fracture event
    - Includes tissue destruction related to fx, hematoma formation, and inflammatory response
    - Devitalized bone at edge of fx resorbed
  - Formation of granulation tissue within, around fracture gap
    - Continued resorption of dead bone along fx margins
  - Development of immature callus
    - Chondroblasts and osteoblasts begin to lay down cartilage and osteoid matrix
    - Mineralization of matrix may begin as early as 1 week
    - Consists of woven (immature) bone
  - Transition of callus to lamellar bone
    - This is long process that continues for months or years
  - Remodeling of bone toward normal pre-fx contour
    - More efficient and complete process in younger patients
    - In children, greater degrees of displacement of fracture can be tolerated because their remodeling process is able to generate normal contour

CLINICAL ISSUES

Demographics

- Age
  - Children heal fractures more quickly and efficiently than adults
  - Fx healing capacity diminishes in elderly

Natural History & Prognosis

- Factors that delay healing include
  - Higher energy injuries with greater comminution of bone and greater injury to surrounding soft tissues
  - Distal 1/3 of humerus, ulna, and tibia less well vascularized → slower healing than other bones
  - Segmental fractures
  - Gap between fracture fragments
  - Inadequate immobilization
  - Infection at fx site
  - Pathologic etiology to fracture: Underlying neoplasm, Paget disease, fibrous dysplasia, radiation necrosis
  - Intraarticular location: Synovial fluid lyses clot; and no periosteal reaction forms inside joint
  - Advanced age, including osteoporosis and diminished muscle mass
  - Other treatments & medications: Radiation therapy, chemotherapy, NSAIDs, bisphosphonates (debated)
  - Patient smoking
  - Medical comorbidities, including diabetes mellitus; and malnutrition

Treatment

- Fx healing requires stability of fx fragments, as well as reduction of fx fragments into close enough apposition for healing process to be effective
  - Reduction, if necessary because of sufficient fx displacement, may be achieved via closed or open (surgical) procedures
  - Fx stabilization may be achieved via closed (sling, splint, cast), percutaneous (external fixator, Kirschner wires), or open surgical methods
- Malunion: Revision surgery required to overcome malunion
  - Typically involves osteotomy, realignment, bone grafting
- Nonunion: Different strategies exist and are affected by patient age, clinical status, site of fx, and time interval since initial fx/surgery
  - Surgical debridement of nonunited fracture to provide fresh bone surfaces with fx immobilization and often bone grafting
    - Bone morphogenic protein (BMP) and other accelerants often added
  - Ongoing investigation into many novel therapies, such as extracorporeal shockwave therapy, tissue engineering, gene therapy, and systemic enhancement of bone healing

DIAGNOSTIC CHECKLIST

Image Interpretation Pearls

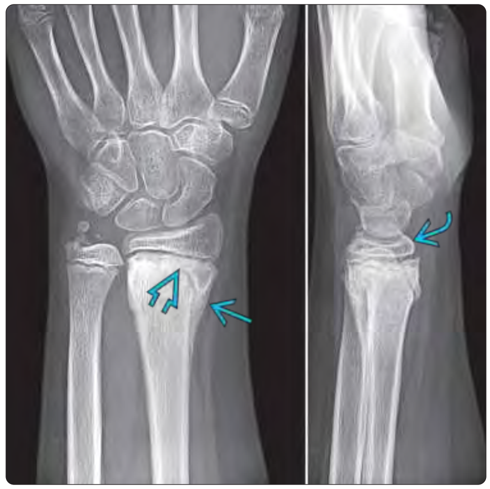
- Comparison of current radiographs with the **series** of prior radiographs is indispensable to making determination of progressive healing or lack thereof
- Failure of fixation hardware suggests nonunion or incomplete union

Reporting Tips

- Expected time to union varies with patient age and bone in question: Be very cautious about reporting nonunion as such, unless it is clear that referring team considers nonunion likely

SELECTED REFERENCES

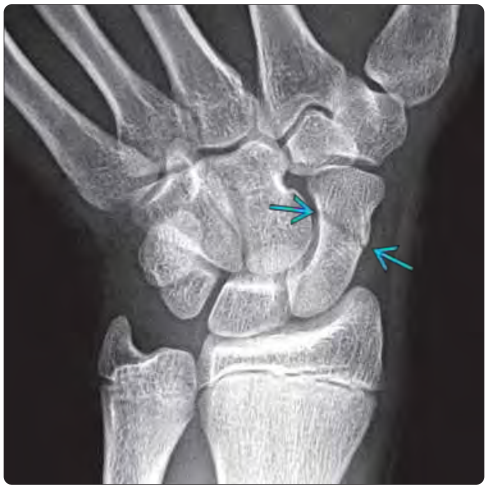
1. Dijkman BG et al: When is a fracture healed? Radiographic and clinical criteria revisited. J Orthop Trauma. 24 Suppl 1:S76-80, 2010



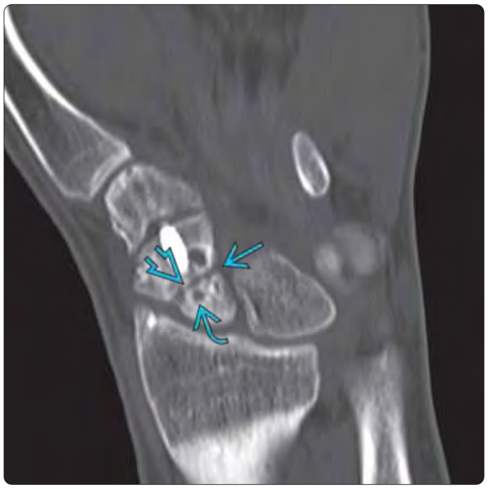
(Left) *PA (left) and lateral views show the wrist in an 11-year-old boy 1 month after Salter-Harris II fx of the distal radius. The fx line is somewhat indistinct and there is immature callus crossing the fx line externally. Reduction of the fx is incomplete.* **(Right)** *PA (left) and lateral views in the same patient one month later show increased callus deposition and further indistinctness of the fx line. Displacement is still evident but does not seem as severe, despite immobilization during the entire interval.*

(Left) *PA (left) and lateral views in same patient 1 month later demonstrate near complete obliteration of the fx line, with remodeling of callus. The callus is beginning to resemble mature bone. At this point, the fx is probably clinically stable.* **(Right)** *PA (left) and lateral views in same patient 9 months later show complete healing of Salter-Harris II distal radius fx. Alignment and position are restored despite seeming substantial displacement on the initial images. Young patients can remodel fxs more than older patients.*

(Left) *Lateral (left) and PA views of the wrist in a 14-year-old boy shortly after casting his both-bone forearm fx shows prominent offset of both the radius and ulna fxs.* **(Right)** *Follow-up lateral (left) and PA views in the same patient 6 months later show complete healing of both fractures. The remodeling process has diminished the degree of displacement of both fxs. Based on the patient's young age, further remodeling likely will render the fxs imperceptible in a few years.*

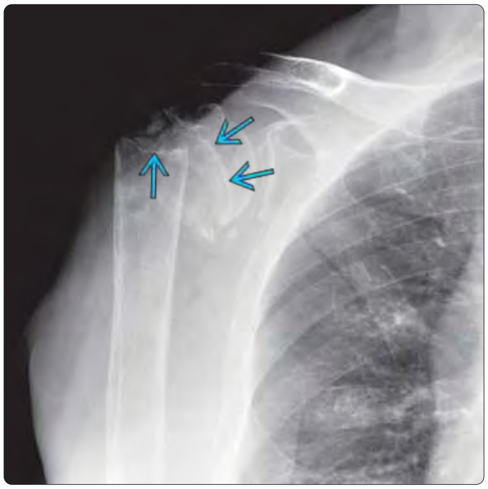


(Left) *Navicular view (ulnar deviated PA) of the wrist in a 15-year-old boy who injured his wrist playing football shows a nondisplaced acute fx of the scaphoid waist ➔. Degree of displacement should be reported, as almost any displacement will result in surgical fixation.* **(Right)** *Navicular view in same patient 3 months later demonstrates evidence of primary healing. Fx line is nearly obliterated but without peripheral callus and only minimal sclerosis ➔, indicating internal callus. Intraarticular fxs do not form external callus.*

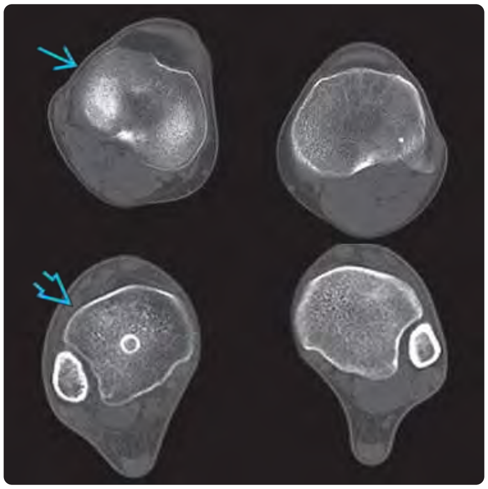


(Left) *Coronal reformat CT demonstrates persistence of the fx line ➔ from a scaphoid waist fx with cortication of the fx margins ⇨ and secondary degenerative cyst formation ↷, all features of nonunion. CT is more accurate than radiographs for defining nonunion.* **(Right)** *Oblique sagittal CT reformation designed to lay out the entire scaphoid again shows the ununited fx ➔. The variably threaded screw has loosened, evidenced by lucency about its proximal portion ⇨, and the screw is proud distally ↷.*

(Left) *PA view shows wrist and distal forearm in a 41-year-old man referred for treatment of a nonunited radius fx more than a year following fixation. Though there is abundant callus ⇨ in the vicinity of the fx, the fx line ➔ remains partially evident.* **(Right)** *Coronal (left) and sagittal CT reformations in the same patient reveal complete lack of callus crossing the fx ➔ in this hypertrophic nonunion. Multiplanar CT is better able to define areas of osseous bridging and persistent gaps. Images are diagnostic despite the presence of metal screws.*



(Left) *Grashey view of the shoulder in a 66-year-old man 10 months following a proximal humerus fx shows cortication of the fx margins and continued malalignment. There are scattered small calcifications but no convincing bridging callus.* **(Right)** *Coronal reformat CT in the same patient confirms cortication of the ununited fx margins with no callus. This is atrophic nonunion, which is much less common than hypertrophic nonunion.*



(Left) *Lateral (left) and AP views of the leg show an intramedullary nail across a healing spiral fx of the distal tibia . Though the proximal portions of the tibia appear well positioned on both images, the distal portions do not appear straight.* **(Right)** *Axial CT images of upper (above) and lower tibia were performed in same patient to assess rotation. The proximal tibia is more internally rotated on the right than on the normal left side, and distal right tibia is more externally rotated, indicating rotational malunion.*

(Left) *AP (left) and lateral views show the leg in a patient who had fixation of a tibial fx after a dirt bike accident 19 years ago. He did not follow non-weight-bearing instructions and developed a malunion, with lateral and anterior bowing . His malalignment led to premature osteoarthritis of the knee .* **(Right)** *AP view of the femur shows exuberant peripheral callus about a healed fx. Extensive callus is common in the femur, tibia, and humerus and often remodels eventually.*

KEY FACTS

TERMINOLOGY

- Fracture through abnormal osseous lesion

IMAGING

- Diagnostic clues
    - Fracture line extending through focal lucent lesion
    - Avulsion fracture in unusual location
    - Transverse fracture common
    - Surrounding permeative change in bone
    - Endosteal scalloping, cortical destruction
    - Chondroid or osteoid matrix
    - Associated soft tissue mass
    - Additional tumor deposits
- Typical locations
    - Metastatic deposit or multiple myeloma: Spine, pelvis, femur, humerus
    - Enchondroma: Phalanges of fingers
    - Unicameral bone cyst: Long bones in children, especially proximal humerus

PATHOLOGY

- Primary bone tumor
    - Benign: Unicameral bone cyst, enchondroma, fibrous cortical defect/nonossifying fibroma, lipoma
    - Malignant: Osteosarcoma, chondrosarcoma, fibrosarcoma, primary lymphoma of bone
- Multifocal processes: Metastases, multiple myeloma
- Postsurgical defect, metabolic disease, infection

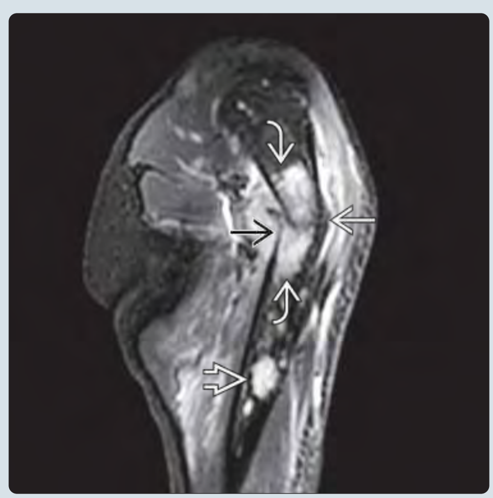
CLINICAL ISSUES

- Tumors most frequently metastatic to bone in adults: Breast, prostate, lung

DIAGNOSTIC CHECKLIST

- Consider pathologic fracture when fracture is in unusual location, transverse orientation without substantial trauma, or any fracture pattern in absence of appropriate trauma history

(Left) *AP radiograph shows a transverse fracture through an expansile lucent lesion of the 2nd metacarpal. Chondroid matrix is seen in the center of the lesion, confirming an underlying enchondroma. Many enchondromas of the hand and fingers have no visible matrix.* **(Right)** *Oblique radiograph of the distal femur shows a fracture of the distal femoral shaft through an area of lucency in the bone that raises the suspicion of a pathologic fracture. This was a breast cancer metastasis.*



(Left) *AP radiograph of the left hip reveals a transverse fracture through the proximal femur, through an expansile lucent lesion with ground-glass matrix. This fibrous dysplasia lesion accounts for the unusual location for a fracture.* **(Right)** *Sagittal T2WI FS MR shows a pathologic fracture through an osseous metastasis in the humerus. Additional metastatic deposits are present more distally. Clues to an underlying lesion are well-defined borders and scalloping or destruction of the cortex.*

TERMINOLOGY

Definitions

- Fracture through abnormal osseous lesion
  - Tumor
  - Infection
  - Postsurgical
  - Metabolic
  - Congenital

IMAGING

General Features

- Best diagnostic clue
  - Fracture line extending through focal destructive lesion in bone
  - Avulsion fracture in unusual location
- Location
  - Metastatic deposit or multiple myeloma: Typically femur or humerus
    - Avulsion of lesser trochanter or ischial tuberosity in adult
    - Subtrochanteric femoral shaft
  - Enchondroma: Finger phalanges
  - Unicameral bone cyst: Long bones in children, especially proximal humerus
- Size
  - Underlying lesion may range from small cortical lesion to large destructive process
  - Injury may range from subtle cortical interruption to comminuted fracture complex
- Morphology
  - Transverse fracture common
    - Compared to oblique or spiral patterns usually seen in trauma of long bones

Radiographic Findings

- Surrounding permeative change in bone
- Lucent lesion
  - May have chondroid, osteoid, or ground-glass matrix
- Endosteal scalloping
- Associated soft tissue mass

CT Findings

- Cortical destruction
- Tumor matrix
- Aggressive periosteal reaction
- Endosteal scalloping
- Associated soft tissue mass

MR Findings

- Factors suggesting pathologic fracture
  - Well-defined, mass-like ↓ T1 marrow signal in pathologic fracture (83% vs. 7% in nonpathologic fractures)
  - Abnormal muscle signal in pathologic fracture (83% vs. 48%)
  - Soft tissue mass in pathologic fracture (67% vs. 0%)
  - Endosteal scalloping in pathologic fracture (58% vs. 0%)
  - May see additional tumor deposits in metastatic disease or multiple myeloma
- Fracture-related hematoma may confuse issue of soft tissue mass
  - Postcontrast MR may be confusing; posttraumatic hemorrhage and neovascularity may mimic underlying tumor
- In- and out-of-phase T1WI may be useful in differentiating marrow edema from infiltrative process
  - Marrow edema: Signal dropout on out-of-phase images since marrow fat is retained
  - Infiltrative process: No signal dropout since marrow fat is replaced
- Diffusion-weighted imaging
  - Tumor infiltration of marrow → decreased diffusion

Imaging Recommendations

- Best imaging tool
  - Radiograph + high level of suspicion as initial modality
  - MR to identify underlying focal lesion
- Protocol advice
  - Radiographs: Multiple views to characterize lesion
  - MR: T2WI without FS to evaluate possible underlying mass and differentiate from hematoma

DIFFERENTIAL DIAGNOSIS

Insufficiency Fracture

- Fracture through osteoporotic/otherwise generally weak bone
- Usually no focal underlying lesion
- "Atypical femur fracture" can occur in the proximal-mid femur in patients on longterm bisphosphonates
  - Focal thickening of lateral cortex of proximal-mid femur, sometimes with transverse insufficiency fracture line

Fatigue Fracture

- Injury due to excessive repetitive force
- Normal underlying bone

Surgical Defect

- Surgical history important
  - Previous biopsy, osteotomy, bone graft harvest site

PATHOLOGY

General Features

- Etiology
  - Primary bone tumor
    - Benign: Unicameral (solitary) bone cyst, enchondroma, fibrous cortical defect/non-ossifying fibroma, lipoma
    - Malignant: Plasmacytoma, chondrosarcoma, osteosarcoma, fibrosarcoma, primary lymphoma of bone
  - Multifocal process
    - Metastatic disease, multiple myeloma, lymphoma
  - Postsurgical defect
    - Biopsy site, bone graft harvest, osteotomy
  - Metabolic: Fragile bone in renal osteodystrophy
  - Radiation osteitis: Fragile bone at risk for fracture
  - Bone infarct: Usually osteonecrosis at end of bone with collapse
  - Arthritis: Degenerative or inflammatory cyst
  - Congenital: Osteogenesis imperfecta
  - Infection
    - Bone abscess

- Osteomyelitis: Fracture rare; consider underlying squamous cell carcinoma
- Associated abnormalities
  - Adjacent soft tissue mass
  - Osseous lesions in other locations

Gross Pathologic & Surgical Features

- Malignant underlying lesion
  - Tumor may spread along fracture planes
  - Tumor may enter bloodstream through disrupted blood vessels

CLINICAL ISSUES

Presentation

- Most common signs/symptoms
  - Acute pain, often without significant trauma
  - Swelling and pain in area often predates trauma

Demographics

- Age
  - Any, but older adults are more likely to have osseous metastatic disease
- Epidemiology
  - Tumors most frequently metastatic to bone in adults
    - Breast
    - Prostate
    - Lung
  - Common benign lesions with pathologic fracture
    - Unicameral (solitary) bone cyst
    - Enchondroma (especially in fingers)
    - Fibrous dysplasia

Treatment

- Benign lesion
  - Curettage
  - Bone graft or cement
  - Hardware for support as necessary
  - Some benign lesions thought by some to react to fracture with healing response: Unicameral bone cyst and nonossifying fibroma (fibroxanthoma) may heal with only external support (casting)
  - Fibrous dysplasia, though benign, generally is not cured by curettage; only complications of this disease are treated
- Malignant lesion (primary)
  - Reduction and support of fracture
    - Note: Must identify fractures as suspicious for pathologic lesion; intramedullary (IM) nailing must be avoided so as to not spread tumor locally
  - Biopsy; if positive for tumor, staging work-up
- Malignant lesion (metastatic)
  - For weight-bearing long bone, IM nailing is considered superior to ORIF
  - Radiation may be considered if lesion is responsive; may help alleviate pain but may retard osseous healing
  - Cement or bone graft may be used to fill significant defect
  - Image-guided thermal ablation may be used in selected lesions for pain control
    - Sometimes combined with cementing

DIAGNOSTIC CHECKLIST

Consider

- Pathologic fracture when fracture is in unusual location, including pelvic avulsions in adults; transverse orientation without substantial trauma; or any fracture pattern in absence of appropriate trauma history

Image Interpretation Pearls

- Look for other focal lesions to confirm presence of metastatic disease
- Underlying lesion may be difficult to characterize due to trauma, hematoma, healing response, or surgery

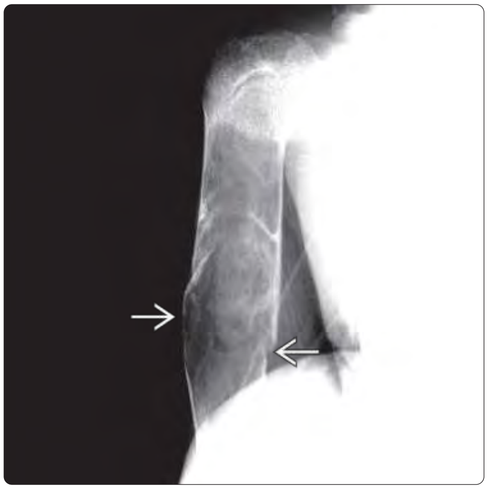
Reporting Tips

- Suggest metastatic work-up in appropriate setting
- Prior to fracture, more than 50% cortical scalloping or involvement of the peritrochanteric femur should suggest referral to surgeon to assess for impending pathologic fracture

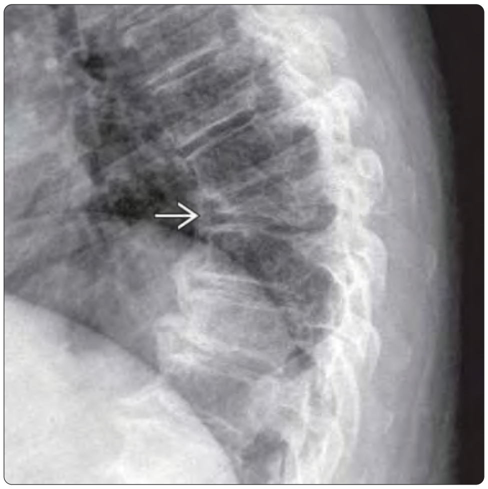
SELECTED REFERENCES

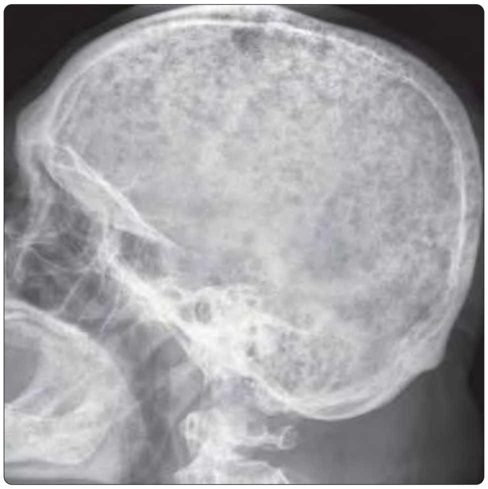
1. Chakarun CJ et al: Giant cell tumor of bone: review, mimics, and new developments in treatment. Radiographics. 33(1):197-211, 2013
2. Hechmati G et al: Cost of skeletal-related events in European patients with solid tumours and bone metastases: data from a prospective multinational observational study. J Med Econ. 16(5):691-700, 2013
3. Steensma M et al: Trends in the surgical treatment of pathologic proximal femur fractures among musculoskeletal tumor society members. Clin Orthop Relat Res. 471(6):2000-6, 2013
4. Chan SS et al: Subtrochanteric femoral fractures in patients receiving long-term alendronate therapy: imaging features. AJR Am J Roentgenol. 194(6):1581-6, 2010
5. Kurup AN et al: Ablation of skeletal metastases: current status. J Vasc Interv Radiol. 21(8 Suppl):S242-50, 2010
6. Shenoy R et al: Tumours of the hand presenting as pathological fractures. Acta Orthop Belg. 73(2):192-5, 2007
7. Erly WK et al: The utility of in-phase/opposed-phase imaging in differentiating malignancy from acute benign compression fractures of the spine. AJNR Am J Neuroradiol. 27(6):1183-8, 2006
8. James SL et al: Atraumatic avulsion of the lesser trochanter as an indicator of tumour infiltration. Eur Radiol. 16(2):512-4, 2006
9. Papagelopoulos PJ et al: Advances and challenges in diagnosis and management of skeletal metastases. Orthopedics. 29(7):609-20; quiz 621-2, 2006
10. Fayad LM et al: Distinction of long bone stress fractures from pathologic fractures on cross-sectional imaging: how successful are we? AJR Am J Roentgenol. 185(4):915-24, 2005
11. Weber KL et al: An approach to the management of the patient with metastatic bone disease. Instr Course Lect. 53:663-76, 2004
12. Bacci G: Pathologic fracture in osteosarcoma. J Bone Joint Surg Am. 85-A(9):1848; author reply 1848-9, 2003
13. Frassica FJ et al: Evaluation and treatment of metastases to the humerus. Clin Orthop Relat Res. (415 Suppl):S212-8, 2003
14. Spuentrup E et al: Diffusion-weighted MR imaging for differentiation of benign fracture edema and tumor infiltration of the vertebral body. AJR Am J Roentgenol. 176(2):351-8, 2001
15. Wai EK et al: Pathologic fractures of the proximal femur secondary to benign bone tumors. Clin Orthop Relat Res. (393):279-86, 2001
16. Dijstra S et al: Impending and actual pathological fractures in patients with bone metastases of the long bones. A retrospective study of 233 surgically treated fractures. Eur J Surg. 160(10):535-42, 1994
17. Bertin KC et al: Isolated fracture of the lesser trochanter in adults: an initial manifestation of metastatic malignant disease. J Bone Joint Surg Am. 66(5):770-3, 1984

(Left) *PA radiograph shows a comminuted fracture through an expansile lucent lesion with cortical thinning in the terminal phalanx of a finger in an adult. The patient suffered mild trauma. This lesion is an enchondroma, the most common such lesion of the bones of the hand.* **(Right)** *AP radiograph of the ankle shows an expansile bubbly lucent lesion extending from the metaphysis to the epiphysis with a pathologic fracture at its proximal margin. This was a giant cell tumor with secondary aneurysmal bone cyst.*



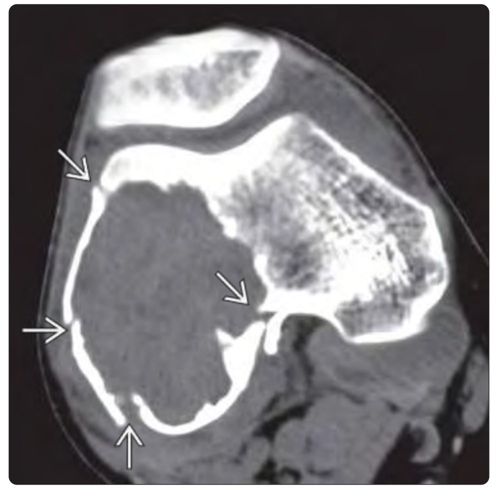
(Left) *AP radiograph from a child demonstrates a pathologic fracture through a large expansile lesion in the proximal humerus after low-grade trauma. This was a unicameral bone cyst, the most common such lesion of long bones in children.* **(Right)** *AP view of the right femur in a patient on bisphosphonates for 7 years shows focal thickening of the lateral cortex with a transverse line, characteristic of an insufficiency fracture. This finding requires urgent communication.*



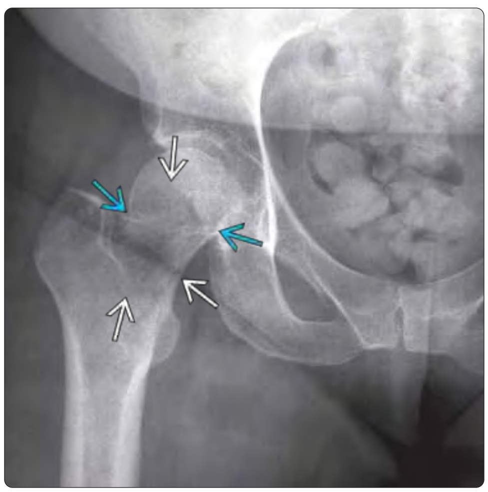


(Left) *Coned-down lateral view of the thoracic spine reveals a pathologic severe wedge fracture of T8 with diffuse mottling of the vertebrae compatible with multiple myeloma.* **(Right)** *Lateral radiograph of the skull in the same patient shows innumerable punched-out lucent lesions, confirming the diagnosis of multiple myeloma. Often radiographs of other body parts may help define a multifocal or systemic diagnosis.*

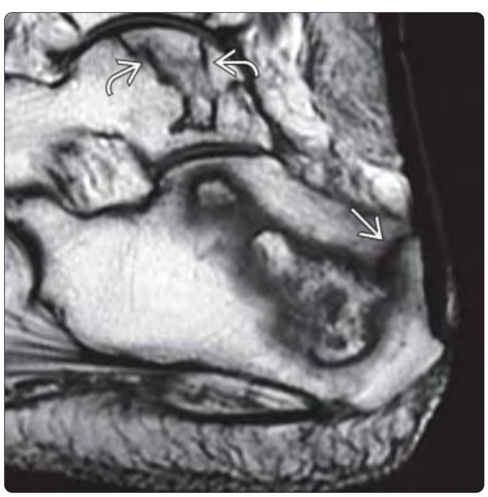
(Left) *AP radiograph shows a pathologic fracture* ➔ *through a well-defined lucent lesion in the lateral femoral condyle. The lesion extends to the articular surface* ➔ *of the femur. No matrix is seen in the lesion.* **(Right)** *Axial noncontrast CT shows expansion of the lateral femoral condylar cortex by the mass, with multiple cortical fractures* ➔*. Density of the lesion is similar to skeletal muscle. This was a biopsy-proven giant cell tumor.*

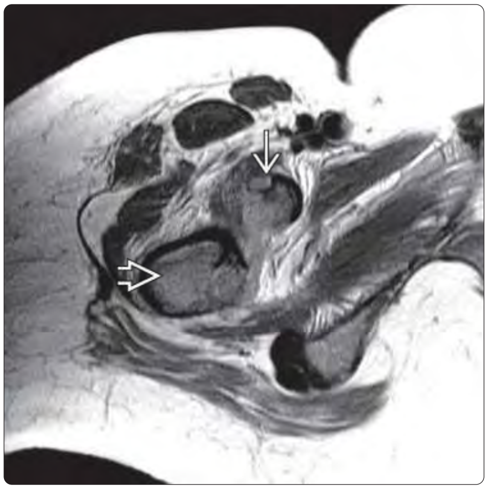


(Left) *AP view of the hip reveals a laterally impacted femoral neck fracture* ➔*, though the patient is not overall osteoporotic. There is subtle lucency and a permeative appearance* ➔ *of the femoral neck, compatible with her widely metastatic high-grade sarcoma.* **(Right)** *Coronal STIR MR in the same patient from 3 weeks prior to the fracture demonstrates numerous metastatic deposits* ➔ *including the soon-to-be culprit in the right femoral neck.*

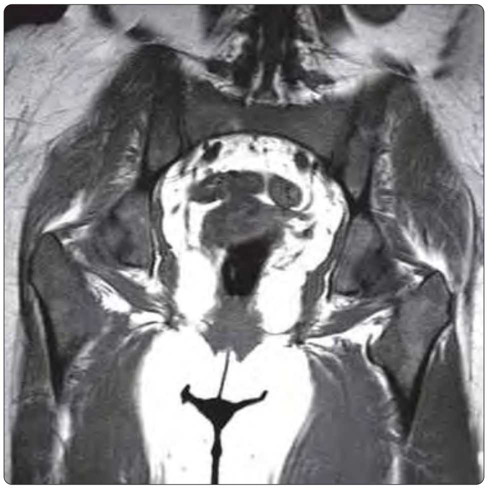


(Left) *Sagittal T1WI MR shows a fracture* ➔ *in the calcaneus extending into a well-defined but irregularly shaped focus of fat signal surrounded by serpentine low signal. This is a pathologic fracture through a bone infarct. Another infarct is seen in the talar dome* ➔ *in this patient with lupus.* **(Right)** *Lateral radiograph shows a spiral fracture* ➔ *through a lucent lesion with chondroid matrix (rings and arcs) and endosteal scalloping. This enchondroma enabled a fracture from a low-energy twisting injury.*

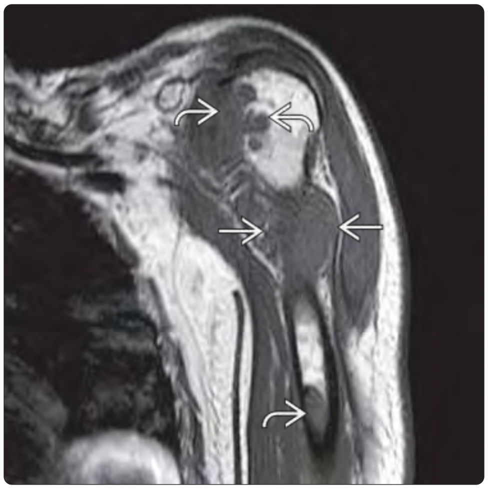




(Left) *AP radiograph from a 66-year-old woman with a history of breast cancer shows avulsion of the lesser trochanter of the femur . The avulsed edges of bone are irregular and poorly defined. Lesser trochanter avulsion in an adult should lead to a high level of suspicion for underlying pathologic lesion.* **(Right)** *Axial T1WI MR from the same patient shows the displaced lesser trochanter . Both the trochanter and the femur demonstrate abnormally low marrow signal intensity.*



(Left) *Coronal T1WI MR of the whole pelvis from the same patient shows diffusely low signal intensity throughout the marrow of the pelvis and proximal femora, consistent with diffuse osseous metastatic disease.* **(Right)** *AP radiograph shows an oblique fracture of the proximal humerus through an ill-defined lucent lesion . Surgical clips in the axilla indicate prior mastectomy for breast cancer. Biopsy proved this to be a breast cancer metastasis.*



(Left) *Coronal T1WI MR from a different patient shows an expansile mass at the site of fracture, confirming its pathologic nature. Several other destructive osseous lesions are seen in the humerus .* **(Right)** *AP and PA views from a whole-body bone scan of the same patient show multiple focal areas of increased uptake in the humerus and additional lesions in the thoracic spine . Absent kidney indicates prior nephrectomy for renal cell carcinoma.*

KEY FACTS

TERMINOLOGY

- Salter-Harris (SH) fracture, Salter fracture
- Fracture affecting physis in skeletally immature patient

IMAGING

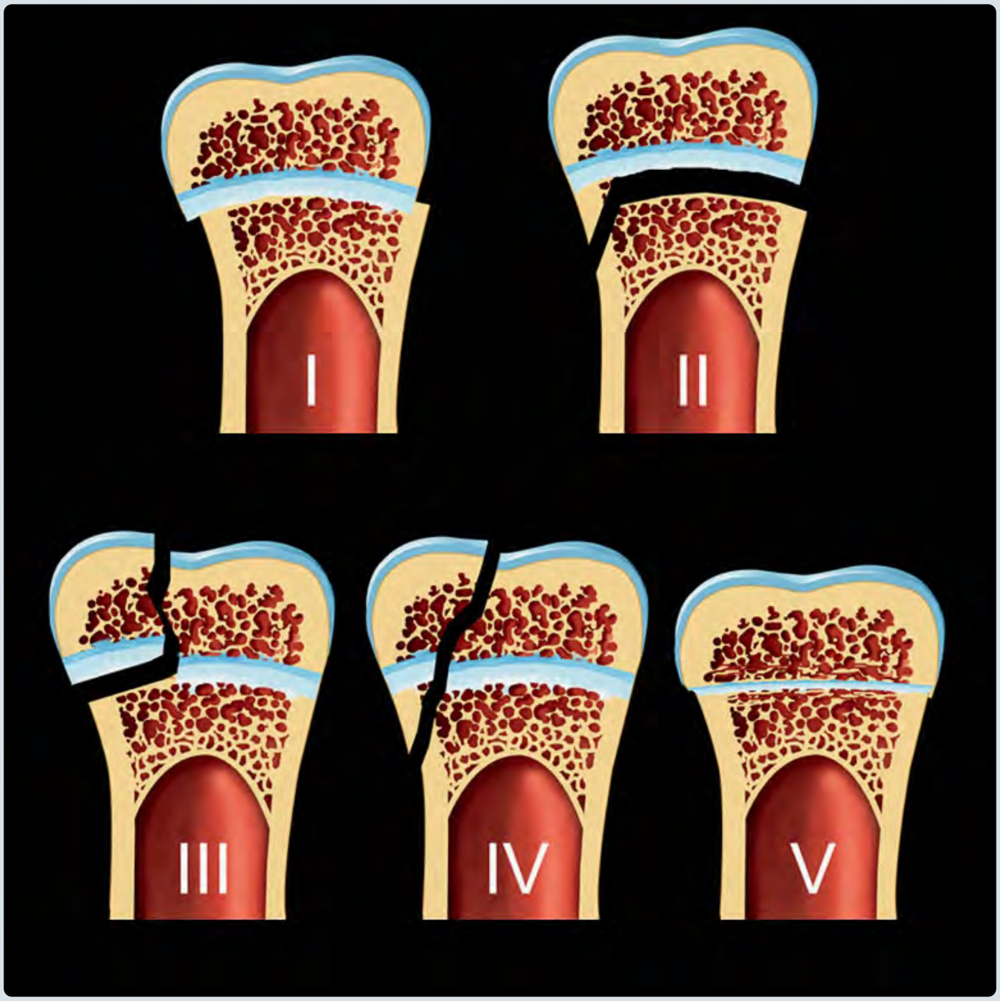
- Fracture extends into, across, or through physis
- Linear fracture in metaphysis ± epiphysis
- MR
  - ↑ T2 signal in physis
  - ± chondral injury
  - Soft tissue swelling
  - Joint effusion
  - Detection of premature posttraumatic physeal closure
- Opposite-side comparison radiographs may help confirm subtle SH type I fracture

PATHOLOGY

- Classification
  - Type I: Involves only physis
  - Type II: Involves physis and metaphysis
  - Type III: Involves physis and epiphysis
  - Type IV: Involves physis, metaphysis, and epiphysis
  - Type V: Crush fracture involving all or part of physis (rare)
- Joint capsule and ligamentous structures are stronger than physis in children
  - Physeal fractures in children are mechanical equivalent of ligamentous injuries in adults

CLINICAL ISSUES

- Average age: F = 11 years, M = 12 years
- 18% of childhood fractures involve physeal injury
- Prognosis worse in lower extremities regardless of SH classification
- Most substantial complications occur at knee and ankle
  - Premature epiphyseal closure
  - Limb shortening or angulation
  - Joint incongruity



Graphic representation of the Salter-Harris classification of injuries involving the growth plate (physis) of long bones in children shows the 5 most common types of injury. Type I injury involves a transverse shearing injury through the physis ± displacement or widening. Type II injury involves a metaphyseal fracture extending into the physis. Type III injury involves an epiphyseal fracture (often involving the articular surface) extending into the physis. Type IV injury involves a fracture of the metaphysis crossing the physis into the epiphysis. Type V, the rarest and most severe type, involves a crush injury to the physis, which destroys the layer of growing cells and halts growth.

TERMINOLOGY

Abbreviations

- Salter-Harris (SH) fracture

Synonyms

- Salter fracture

Definitions

- Fracture affecting physis in skeletally immature patient

IMAGING

General Features

- Location
  - Upper extremity
    - Distal radius: 28%
    - Fingers: 26%
    - Distal humerus: 7%
    - Proximal radius: 5%
    - Distal ulna: 5%
    - Metacarpals: 4%
    - Proximal humerus: 2%
    - Clavicle: 1%
    - Proximal ulna: 1%
  - Lower extremity
    - Distal tibia: 9%
    - Toes: 7%
    - Distal fibula: 3%
    - Metatarsals: 1%
    - Proximal tibia: 1%
    - Distal femur: 1%
- Morphology
  - Fracture extends into, across, or through physis

Radiographic Findings

- Radiography
  - Type I-IV
    - Adjacent soft tissue swelling
    - Joint effusion
  - Type I
    - Widening of part or all of physis ± displacement
    - May appear normal on radiograph; focal soft tissue swelling may be only hint of injury
  - Type II: Lucent fracture line(s) extending through metaphysis and into physis
  - Type III: Lucent fracture line(s) extending through epiphysis and into physis
  - Type IV: Lucent fracture line(s) extending through metaphysis, across physis, and into epiphysis
  - Type V: Narrowing of physis
  - Posttreatment
    - Persistent physeal widening > 3 mm post reduction → periosteal entrapment in fracture likely

CT Findings

- Used to evaluate anatomic extent and degree of displacement of the more complex SH injuries
  - Most commonly used with triplane fractures of distal tibia (SH IV)
- Used to evaluate focal bony bridging across physis during healing process (most common in SH IV or V)

MR Findings

- ↑ T2 signal in physis
  - Comparison to other physes in FOV can be helpful
- Linear fracture in metaphysis ± epiphysis
  - Usually ↓ signal on T1 and T2
  - Surrounded by marrow edema
- ± chondral injury
- Soft tissue swelling
- Joint effusion
- Detection of premature posttraumatic physeal closure
  - Quantification of closure as percentage of total area of physis
- Pitfall: Focal periphyseal edema zone
  - Characteristic bone marrow edema pattern; centered about central closing physis at knee
  - Seen in adolescents
  - Thought to be related to early stages of physeal closure
  - ± association with pain
  - Should not be mistaken for an abnormality; requires no further work-up

Ultrasonographic Findings

- Evaluation of physeal birth injuries presenting as "pseudodislocation" in long bones with unformed ossification centers
  - Proximal and distal humerus, proximal femur most common

Nuclear Medicine Findings

- Bone scan
  - Focal increased radiotracer uptake
  - Pinhole collimation → increased spatial resolution for small parts

Imaging Recommendations

- Protocol advice
  - Opposite-side comparison radiographs may help confirm subtle SH type I fracture

PATHOLOGY

General Features

- Etiology
  - Structure of normal epiphysis
    - Germinal zone closest to epiphyseal ossification center: Small active chondrocytes emerge from resting chondrocytes
    - Proliferative zone: Flattened chondrocytes arranged in columns
    - Hypertrophic zone: Swollen chondrocytes arranged in columns
    - Provisional calcification zone: Chondrocytes die, cartilage matrix calcifies, osteoclasts form osteoid
    - Perichondral ring: Layer of cartilaginous tissue contiguous with adjacent periosteum of metaphysis and epiphysis
    - Surface of metaphyseal and epiphyseal interface with physis is irregular or corrugated
      - Consists of small bony projections, undulations, knobs and ridges (mammillary processes)
    - Metaphysis and epiphysis receive most arterial supply from separate sources

        - Fracture through physis does not interfere with blood supply of either epiphysis or metaphysis
        - Exception: Femoral capital and radial head epiphyses, which are intraarticular
    - Joint capsule and ligamentous structures are stronger than physis in children
        - Physeal fractures in children are mechanical equivalent of ligamentous injuries in adults
    - Structure of physeal fracture
        - Damage due to shear, grinding, compression force
        - Fracture plane undulates within proliferative, hypertrophic, and provisional calcification zones
        - Fibrin appears within cleavage, cartilaginous cells continue to grow, epiphyseal plate thickens as cellular columns lengthen
        - Fibrin gone and normal growth pattern restored in ~ 21 days

Staging, Grading, & Classification

- Type I: Involves only physis
- Type II: Involves physis and metaphysis
- Type III: Involves physis and epiphysis
- Type IV: Involves physis, metaphysis, and epiphysis
- Type V: Crush fracture involving all or part of physis (rare)
    - Usually 1st recognized when cone epiphyses or partial epiphyseal arrest becomes apparent later
- Types VI-IX, as described by Ogden (rare)
    - Type VI: Perichondral ring injury
    - Type VII: Intraepiphyseal fracture not involving physis
    - Type VIII: Metaphyseal fracture not involving physis directly but → ischemic growth disturbance
    - Type IX: Periosteal injury → disturbed diaphyseal growth

CLINICAL ISSUES

Presentation

- Most common signs/symptoms
    - Pain, swelling, point tenderness, limited range of motion, inability to bear weight

Demographics

- Age
    - Average
        - F: 11 years
        - M: 12 years
    - Ages 16 and 17: Physeal fractures more common in males; physes have closed in females
- Gender
    - M > F
- Epidemiology
    - 18% of childhood fractures involve physeal injury
    - Relative incidence of SH fractures
        - Type I: 8.5%
        - Type II: 73% (most common)
        - Type III: 6.5%
        - Type IV: 12%
        - Type V: < 1% (rarest)
    - Exceptions to general relative incidence
        - Distal humerus: Almost all fractures are type IV
        - Distal tibia: Types II, III, and IV equally common

Natural History & Prognosis

- Most uncomplicated types I-III fractures do well with conservative or surgical therapy
- Prognosis worse in lower extremities regardless of SH classification
- Complications
    - Overall complication rate: ~ 14%
    - Most substantial complications occur at knee and ankle
    - Premature epiphyseal closure
        - Limb shortening (early fusion across entire physis) or angulation (early fusion across small portion of physis, continued growth in remaining portions)
        - Premature epiphyseal closure in lower tibial fractures
            - 27% overall rate
            - 21% in triplane (SH IV) fractures, rare in Tillaux (SH III) fractures
    - Joint incongruity
    - Persistently trapped periosteum
        - May prevent healing

Treatment

- Casting for low SH categories
- Open reduction and internal fixation often required with higher categories

DIAGNOSTIC CHECKLIST

Consider

- Follow knee and ankle fractures for at least 1 year or until skeletal maturity for early detection of premature closure of epiphyses

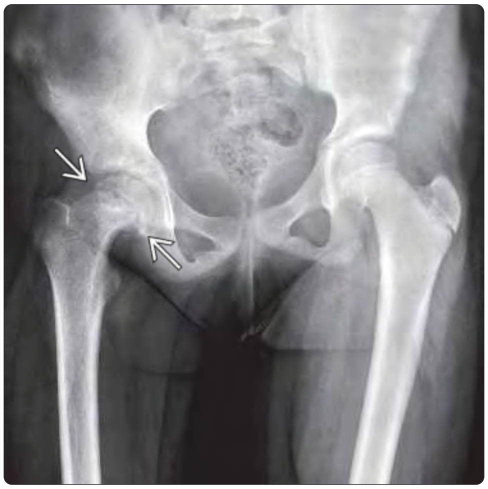
Image Interpretation Pearls

- Subtle type I injury may require comparison to contralateral extremity for diagnosis

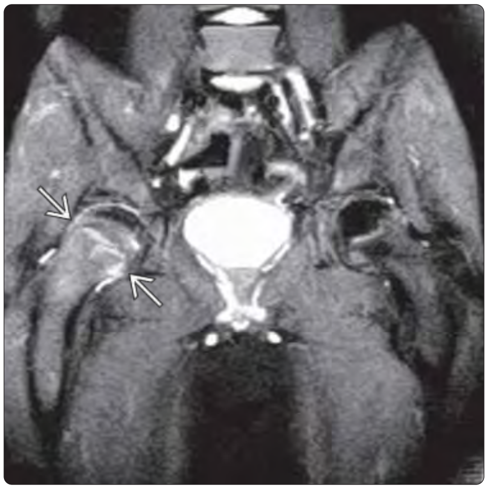
SELECTED REFERENCES

1. Zbojniewicz AM et al: Focal Periphyseal Edema (FOPE) zone on MRI of the adolescent knee: a potentially painful manifestation of physiologic physeal fusion? AJR Am J Roentgenol. 197(4):998-1004, 2011
2. Basener CJ et al: Growth disturbance after distal femoral growth plate fractures in children: a meta-analysis. J Orthop Trauma. 23(9):663-7, 2009
3. Leary JT et al: Physeal fractures of the distal tibia: predictive factors of premature physeal closure and growth arrest. J Pediatr Orthop. 29(4):356-61, 2009
4. Mubarak SJ et al: Classification of proximal tibial fractures in children. J Child Orthop. 3(3):191-7, 2009
5. Shi DP et al: Epiphyseal and physeal injury: comparison of conventional radiography and magnetic resonance imaging. Clin Imaging. 33(5):379-83, 2009
6. Cottalorda J et al: Salter-Harris Type III and IV medial malleolar fractures: growth arrest: is it a fate? A retrospective study of 48 cases with open reduction. J Pediatr Orthop. 28(6):652-5, 2008
7. Arkader A et al: Predicting the outcome of physeal fractures of the distal femur. J Pediatr Orthop. 27(6):703-8, 2007
8. Schnetzler KA et al: The pediatric triplane ankle fracture. J Am Acad Orthop Surg. 15(12):738-47, 2007
9. Ilharreborde B et al: Long-term prognosis of Salter-Harris type 2 injuries of the distal femoral physis. J Pediatr Orthop B. 15(6):433-8, 2006
10. Rohmiller MT et al: Salter-Harris I and II fractures of the distal tibia: does mechanism of injury relate to premature physeal closure? J Pediatr Orthop. 26(3):322-8, 2006

(Left) *Lateral radiograph of the fingers demonstrates subtle dorsal widening of the physis of the distal phalanx of the 4th finger compared to the other digits, with overlying soft tissue swelling. This is a Salter I injury.* **(Right)** *Oblique radiograph of the ankle in a child with lateral ankle pain after a fall demonstrates lateral widening of the distal fibular physis consistent with a Salter I injury. The fibular physis should be no wider than the lateral aspect of the tibial physis.*



(Left) *Coronal T2WI FS MR of the elbow demonstrates elevated signal in the physis of the medial humeral epicondyle in a little league baseball pitcher with medial elbow pain. This represents little leaguer's elbow and can lead to displacement of the epiphysis. Note the closed lateral epicondylar epiphysis.* **(Right)** *AP radiograph shows slipped capital femoral epiphysis of the right hip, a Salter I injury. The left hip is normal.*

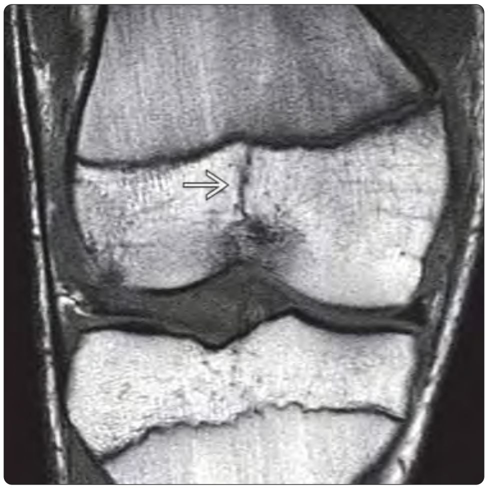


(Left) *Coronal T2WI FS MR demonstrates elevated signal in the proximal right femoral physis with surrounding marrow edema consistent with a Salter I injury. There was no radiographic evidence of slipped capital femoral epiphysis in this patient. Patient was treated surgically based on the MR findings.* **(Right)** *AP radiograph demonstrates fractures of the metaphyses extending into the growth plates of the proximal phalanges of the 3rd and 4th fingers consistent with Salter II fractures.*

(Left) *Coronal reformatted bone CT shows a nondisplaced metaphyseal fracture → of the distal lateral femur entering the physis, consistent with a Salter II fracture. The fracture was not visible on routine radiographs. MR is more commonly used in this clinical setting due to its lack of ionizing radiation.* **(Right)** *AP radiograph shows marked displacement of fractures of the distal radius and ulna. Involvement of the radial growth plate is difficult to assess on this view.*

(Left) *Lateral radiograph from the same patient confirms extension of the radial fracture through the physis → and shows a triangular metaphyseal fragment → attached to the displaced epiphysis, consistent with a Salter II injury.* **(Right)** *AP radiograph shows a displaced fracture of the distal lateral tibial epiphysis → extending through the growth plate but not into the metaphysis. This is a juvenile Tillaux fracture, a type of Salter III injury.*

(Left) *Lateral radiograph from the same patient shows anterior displacement of the epiphyseal fracture fragment →. This fracture is typical in 12-15 year olds due to partial closure of medial distal tibial physis and patency of the lateral physis, restricting fracture propagation to the lateral tibia.* **(Right)** *Coronal reformatted bone CT from the same patient shows the closed medial tibial physis → and patency of the lateral physis →. The vertical fracture → enters the articular surface.*




(Left) *Coronal T1WI MR shows a nondisplaced vertical fracture of the distal femoral epiphysis* → *extending into the intercondylar notch consistent with a Salter III injury. This was not visible on radiographs.* **(Right)** *Coronal T2WI FS MR shows a displaced Salter III fracture of the distal femur extending vertically through the roof of the intercondylar notch* → *and medially through the physis* →*. A large lipohemarthrosis* → *is present.*


(Left) *AP radiograph shows subtle linear lucency in the distal radial metaphysis* → *and another in the distal radial epiphysis* → *more medially. This suggests a Salter IV injury. The width of the growth plate is normal.* **(Right)** *Coronal reformatted bone CT from the same patient confirms the fracture lines in the radial metaphysis* → *and epiphysis* →*. Confirmation of involvement of the radial articular surface is important for treatment and prognosis.*


(Left) *Coronal T1WI MR in a 13 year old with painful knee clicking shows a distinctive pattern of bone marrow edema* → *within the medial epiphysis and metaphysis centered around the physis. This is referred to as the focal periphyseal edema zone and is considered normal in this age group.* **(Right)** *Sagittal T2 FS MR in the same patient shows an abnormal pattern of bone marrow edema* → *within the medial epiphysis and metaphysis. (Courtesy T. Laor, MD.)*

KEY FACTS

TERMINOLOGY

- Nonaccidental trauma, trauma X, battered child syndrome, shaken baby syndrome

IMAGING

- Lower extremity fracture in infant prior to walking age
- Metaphyseal corner fracture
  - Most common in proximal humerus, distal femur, and proximal and distal tibia
  - Triangular bone fragment at edge of metaphysis close to growth plate
- Bucket-handle fracture
  - Similar to corner fracture but involves more of metaphyseal circumference
- Subperiosteal new bone formation
  - Appears 5-14 days after trauma
- Finger/thumb fracture: Pinched/levered/twisted
- Skeletal survey
  - Healing fractures of differing ages
  - Metaphyseal corner, posterior rib, finger/thumb, scapular, sternal fractures; thoracolumbar compression fractures; spinous process avulsion fractures

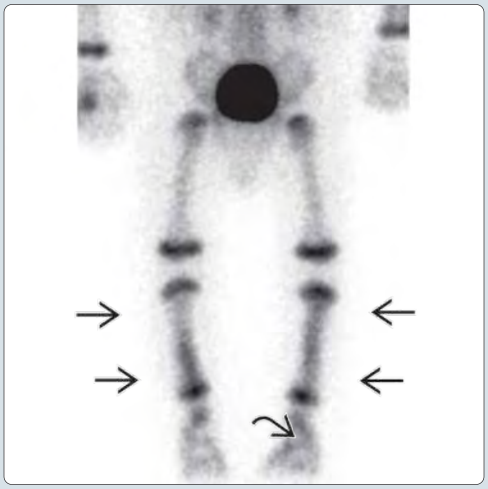
TOP DIFFERENTIAL DIAGNOSES

- Rickets
- Leukemia
- Osteogenesis imperfecta

CLINICAL ISSUES

- Discordance between stated history and injury on imaging (history of minimal or no trauma)
- Most < 1 year
- Almost all < 6 years
- Recognition of abuse is key
- Notification to local child protection agency mandated

(Left) *AP radiograph shows a metaphyseal corner fracture ⮕ of the proximal humerus in a small child. This is a hallmark finding suggesting child abuse, as fractures in this location rarely are due to accidental trauma. Corner fractures strongly suggest a violent twisting injury due to abuse by another individual.* **(Right)** *AP radiograph shows a bucket-handle fracture of the distal radius. A circumferential fragment ➡ has separated from the metaphysis. A small corner fracture ➡ is also present.*



(Left) *Anteroposterior radiograph from a young child who would not walk shows a buckle fracture of the 1st metatarsal ⮕.* **(Right)** *Anteroposterior projection from a radionuclide bone scan in the same patient discloses varying increased uptake in both tibial diaphyses ⮕ and in the foot ⮕. The presence of multiple fractures, particularly with varying degrees of activity (and therefore likely of different ages), is highly suggestive of child abuse.*