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Editor

MRI-Arthroscopy Correlations

A Case-Based Atlas of the Knee, Shoulder, Elbow and Hip

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With 522 Figures

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To my wife Kristin, whom I love and admire more than anyone in this world
To my children, who keep me grounded, entertained, and provide a reason for my being
To my mentors, past and present, who have afforded me guidance, inspiration, and humility

Preface

The advent of magnetic resonance imaging scanning and the development of arthroscopic surgical techniques are the two principal events responsible for revolutionizing Sports Medicine to where it is today. The confluence of these two entities spans two specialties, Orthopedic Surgery and Radiology, and allows for increasingly accurate diagnosis of pathology and advanced treatment options to aid in optimizing patient outcomes and recovery.

This text, *MRI-Arthroscopy Correlations*, represents a microcosm of daily patient care. By aligning the MRI findings associated with the spectrum of problems seen in the most commonly treated joints in sports medicine with the diagnostic findings seen during arthroscopy of the same joint in the same patient, the reader is able to correlate this pathology and apply these findings to the clinic, the radiology reading room, or the operating suite. At our institution, we have found this type of interactive correlation to be an exceedingly effective tool for education and continued learning, an impetus for interdisciplinary research collaboration, and a critical part of our approach to optimum patient care. Furthermore, we have found this case-based correlation between MRI imaging and arthroscopic findings and treatment to be a well-received and effective method for teaching and discussion at meetings and instructional courses.

We have organized this book into four parts highlighting the four major joints in which MRI and arthroscopy are most commonly used in Sports Medicine: knee, shoulder, elbow, and hip. Each of the part editors, Dr. Mark D. Miller (knee), Dr. Felix H. "Buddy" Savoie III, Dr. Larry D. Field, Dr. Michael J. O'Brien (elbow), Dr. John J. Christoforetti (hip), and myself (shoulder), are nationally recognized experts, teachers, and pioneers in their respective areas of sports medicine and have covered the gamut of topics in each of their parts. Chapters are formatted to present an overview of the specific disease entity first, followed by selected cases chosen by the chapter authors that best illustrate common or noteworthy disease entities or pathology with an emphasis on the parallel MRI imaging and arthroscopic findings.

I want to thank Drs. Miller, Savoie, Field, O'Brien, and Christoforetti for their tremendous contributions to this book, and I also want to thank the many contributing authors for volunteering their time, expertise, and cases to make this book successful.

We hope you find this book interesting and educational and that it fosters similar collaboration in your practices and institutions.

Charlottesville, VA, USA — Stephen F. Brockmeier

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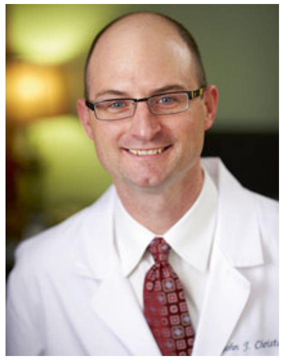
About the Editors

Dr. Stephen F. Brockmeier is a board-certified Orthopedic Surgeon with a sub-specialty certification in Sports Medicine. He joined the University of Virginia Department of Orthopaedic Surgery in 2010, where he is currently an Associate Professor and specializes in Sports Medicine and Shoulder Reconstructive Surgery. His primary areas of clinical and research interest are in arthroscopic and reconstructive surgery of the knee and shoulder with a specific focus on sports injuries of the upper extremity. He serves as a team physician for the University of Virginia Athletics as well as for James Madison University and is the fellowship director for the University of Virginia Sports Medicine Fellowship program.

Prior to joining the UVA faculty, Dr. Brockmeier completed undergraduate studies at the University of Virginia and medical school and Orthopedic residency training at Georgetown University, followed by a fellowship in sports medicine and shoulder surgery at the Hospital for Special Surgery in New York where he trained with Dr. Russell Warren, Dr. David Altchek, and many other leaders in the Sports Medicine field. He then spent 3 years in practice in Charlotte, North Carolina, specializing in sports medicine, arthroscopy, and shoulder surgery. While in Charlotte, he served as a team physician for the Charlotte Bobcats.

Dr. Brockmeier is actively involved on the national level in a number of societies including the American Orthopaedic Society for Sports Medicine (AOSSM), where he currently serves on the Council of Delegates and the Education Committee. He is a member of the American Shoulder and Elbow Society (ASES) and serves on the Editorial Board for *Techniques in Shoulder and Elbow* Surgery and *The Orthopaedic Journal of Sports Medicine*.



John J. Christoforetti is an Assistant Professor at Drexel University School of Medicine in clinical practice at the Allegheny Health Network in Pittsburgh, Pennsylvania, USA. He serves as a consultant for hip injury to the Pittsburgh Pirates, Pittsburgh Riverhounds, Robert Morris University, and the US Olympic Regional Medical Center. He is faculty-at-large for the American Hip Institute in Chicago, Illinois. Dr. Christoforetti specializes in arthroscopy of the hip, shoulder, and knee.

Dr. Christoforetti's educational process began as an undergraduate at the University of Notre Dame and continued at Georgetown University School of Medicine followed by orthopedic residency at Georgetown University Hospital. In 2004, he conducted basic scientific research at the National Institutes of Health cartilage and mesenchymal stem cell laboratory under the mentorship of Rocky Tuan, Ph.D. In 2006, he studied hip preservation surgery with Jeffrey Mast, M.D., and Michael Karch, M.D., through an AO North America Surgical Preceptorship in Mammoth Lakes, California. He completed his formal training with the Steadman-Hawkins Clinic faculty in the Carolinas with director Dr. Richard J Hawkins and in Vail, Colorado, with Dr. Marc J Philippon.

In 2008, Dr. Christoforetti and coauthors received the Aircast Award for Clinical Science from the American Orthopaedic Society for Sports Medicine for his pioneering radiographic survey of femoroacetabular impingement findings in professional baseball pitchers. He is currently a Master Instructor of Hip Arthroscopy for the Arthroscopy Association of North America and Editorial Board member for the Journal of Arthroscopic and Related Surgery. He is director of the Center for Athletic Hip Injury at the Allegheny Health Network and coordinates multidisciplinary evaluation of non-arthritic hip disorders. His research interests include clinical outcomes in joint preservation surgery, healthcare innovation, and basic biomechanical and applied investigations into the tissues and motion patterns of the human hip.

Larry D. Field is an orthopedic sports medicine surgeon specializing in shoulder and elbow surgery and serves as a program director for the ACGME accredited Sports Medicine and Arthroscopy Fellowship Program at the Mississippi Sports Medicine Center in Jackson, Mississippi. He completed his orthopedic surgical training at the University of Mississippi with additional fellowship training in Interlaken, Switzerland, with Dr. Bruno Noesberger and with Professor Ulrich Holz in Stuttgart, Germany. Dr. Field also completed a sports medicine fellowship training program at the Hospital for Special Surgery in New York. Dr. Field is active in clinical research related to shoulder and elbow disorders and has written and edited several books on these conditions. In addition, Dr. Field has published over 150 peer-reviewed scientific papers, review articles, and book chapters on shoulder and elbow related topics and lectures nationally and internationally regarding shoulder and elbow problems. Dr. Field is actively involved in a number of professional orthopedic organizations and societies including ISAKOS, AOSSM, ASES, AOA, AAOS, and AANA where he currently serves on the Board of Directors. Dr. Field also participates as an editorial board member for the *Journal of Shoulder and Elbow Surgery* and *Techniques in Shoulder and Elbow Surgery*.

Dr. Mark D. Miller is the Head of the Division of Sports Medicine and the S. Ward Casscells Professor of Orthopaedic Surgery at the University of Virginia. He is a Distinguished Graduate of the Air Force Academy and the Uniformed Services University F. Edward Hebert' School of Medicine. Dr. Miller is a highly decorated retired Colonel in the US Air Force and former team physician for the US Air Force Academy. He currently serves as team physician for James Madison University in Harrisonburg, Virginia. Dr. Miller has over 25 orthopedic textbooks that he has written and/or edited including the "best selling" Review of Orthopaedics (now in its 7th Edition) and is the author of over 200 peer-reviewed articles. He is the Founder/Director of the popular Miller Review Course and is a highly sought-after speaker.

Dr. Miller has been very active in several professional societies including the American Orthopaedic Society for Sports Medicine (AOSSM) and is the former chair for three different committees in that society. He was an American Orthopaedic Association North American Traveling Fellow and both a Traveling Fellow and a Godfather for the AOSSM Traveling Fellowship program. Dr. Miller has been named as a "Top Doctor" for numerous regional, national, and international programs. Although widely known for his expertise in knee surgery, Dr. Miller is also an accomplished shoulder surgeon and sports medicine specialist. He is married to his wife, Ann, and has four grown children and two grandchildren.

Dr. Michael J. O'Brien received his medical degree from the Tulane University School of Medicine in 2003. After completing his Orthopaedic Surgery residency at the University of Maryland and a Shoulder and Elbow Reconstruction fellowship at the Rothman Institute at Thomas Jefferson University in Philadelphia, he returned to New Orleans in 2009 to become Assistant Professor of Clinical Orthopaedics at Tulane. He is certified by the American Board of Orthopaedic Surgery and is an active member of the American Shoulder and Elbow Society (ASES), Arthroscopy Association of North America (AANA), Southern Orthopaedic Association (SOA), Louisiana Orthopaedic Association (LOA), and the American Academy of Orthopaedic Surgeons (AAOS). Dr. O'Brien serves on the AANA Research and Technology Committees, Tulane eCW Steering Committee, and Tulane Quality Directors Committee. He is the Louisiana Councilor to the SOA and is also Tulane's newest member of the Association of American Medical Colleges Council of Faculty and Academic Societies. He has over 25 articles and book chapters to his credit and lectures locally, nationally, and internationally. His interests include arthroscopy of the shoulder and elbow, rotator cuff disease, shoulder and elbow reconstruction including total shoulder replacements and total elbow replacements, sports medicine, ligament reconstruction of the knee, and fracture care in both adults and children. He practices at the Tulane Institute of Sports Medicine in uptown New Orleans, where he is a team physician for the New Orleans VooDoo of the Arena Football League, Loyola University New Orleans, and Tulane University.

Dr. Felix H. Savoie III is an internationally recognized expert in the areas of Shoulder and Elbow Surgery and Sports Medicine. He is ABOS certified in Orthopaedic Surgery and Sports Medicine. A 1982 graduate of the Louisiana State University School of Medicine in New Orleans, he completed his internship and residency at the University of Mississippi Medical Center in Jackson. After completing an AO fellowship in Switzerland and Hand and Microvascular Surgery and Arthroscopy fellowships in the United States, he returned to Jackson to enter private practice and as an Assistant Professor of Orthopaedic Surgery at the University of Mississippi. While he continues as a Clinical Associate Professor there, he came to the Tulane University School of Medicine in 2007 after Hurricane Katrina to take on the mantle of Professor of Clinical Orthopaedics, Chief of the Division of Sports Medicine, and Director of the Tulane Institute of Sports Medicine, and a year later was named Vice-Chairman of the Department of Orthopaedics.

He is currently Vice President of a the American Shoulder and Elbow Surgeons, a Past President and Trustee of the Arthroscopy Association of North America, a past member of the NCAA Committee on Competitive Safeguards and Medical Aspects of Sports, and a member of the Louisiana High School Sports Association Sports Medicine Advisory Committee. Dr. Savoie also serves on the Editorial and Review Boards of several peer-reviewed journals, and in various capacities in numerous international, national, regional, and local societies.

Dr. Savoie is the author of over 100 peer-reviewed journal articles and 72 book chapters and editor of six textbooks. He is in great demand as a speaker, presenting over 1,600 lectures throughout the United States and over 20 other countries. He has been a frequent contributor to VuMedi and Audio-Digest Orthopaedics, helping to expand medical instruction to the Internet, and has participated in several broadcasts of live surgical procedures around the world.

He is a strong advocate of research, with multiple ongoing projects. His interests lie in every facet of orthopedics, from work on the cellular level, to improvements in surgical instruments and techniques, and increasing safety on the field of play.

MR Imaging for the Orthopedic Surgeon

1

Mark W. Anderson

Introduction

Magnetic resonance imaging (MRI) is a powerful diagnostic tool that has become a mainstay in orthopedic imaging. Its ability to provide a detailed depiction of normal and pathologic tissue is unparalleled, and with recent improvements in both hardware and software, the diagnostic information made available to the clinician continues to improve. The goal of this chapter is to provide an overview of MRI for the orthopedic surgeon leading to a practical understanding of how it works and when it is most useful in the workup of an orthopedic patient by addressing these questions:

- What is MRI and how does it work?
- Why does the MR image look the way it does?
- What should normal musculoskeletal tissues look like on MR images?
- What do common types of musculoskeletal pathology look like on MR images?
- When is MRI most useful, and when should a different imaging modality be chosen?
- What is on the horizon for MR imaging?

Hopefully, this basic introduction will provide enough information for you to begin looking at MR images yourself, but if you would like a more detailed information, several general references are provided [1–5].

What Is MRI and How Does It Work?

At its core, MRI is unlike any other imaging modality. The machine looks something like a computed tomography (CT) scanner since the patient is placed on a gantry that is positioned within a tube-like bore of the machine, but unlike CT, no X-rays are used. The basic components of an MR unit are a large magnet and a source of radio waves. Hydrogen atoms are very abundant throughout the body, and since they contain an unpaired electron, they react like small bar magnets within a magnetic field. As such, when the body is placed within the scanner, hydrogen protons tend to line up parallel with the magnetic field. When energy is then pulsed into the body in the form of radio waves, some of the protons will absorb this energy and "flip" into a higher-energy state. When the pulse is turned off, these protons will relax back to a lower-energy state and release energy in the form of radio waves which are detected by the machine and then used to create the MR image (Fig. 1.1).

Most MR imaging units use a superconducting magnet that is made up of wires coiled around the open bore of the machine. These wires are supercooled with cryogens such as liquid helium to reduce electrical resistance and as such, the machine is *always* "on," and anyone working in the magnetic field must be careful to not bring any ferromagnetic objects into the scanning room since these can become lethal missiles if they are pulled into the magnet's bore.

The field strength of clinical MR machines range from 0.2 Tesla (T) to 3 T, with most operating at 1.5 or 3 T. Typically, the higher the field strength, the better the images, and although that is not always the case, lower-field-strength units are not able to produce very high-resolution images, even with an optimized technique. Because a certain percentage of patients are too claustrophobic to tolerate the rather small bore of a standard machine, some MR units are designed with a larger bore (known as an "open" magnet), and smaller "extremity" scanners are also available in which only the affected extremity is placed within the machine. A major drawback of this type of machine is that it cannot be used to image more central joints such as the shoulder or hip.

In addition to placing the patient within the large "body" coil that surrounds the bore of the machine, smaller "surface" coils that conform more closely to the size of the body part

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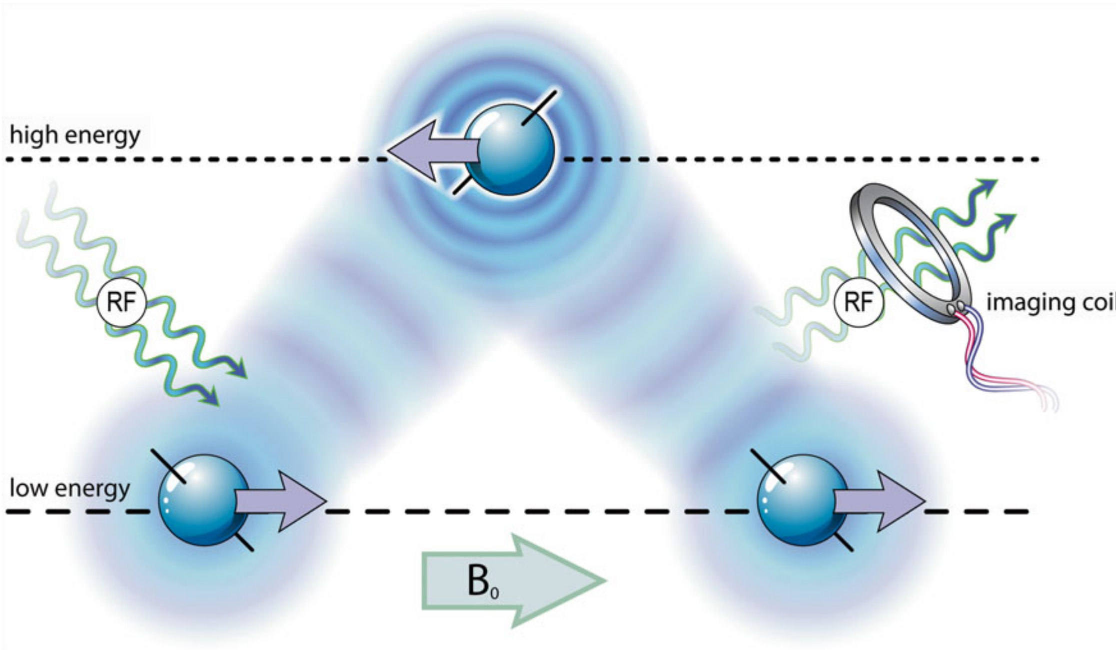

Fig. 1.1 Magnetic resonance. A hydrogen proton absorbs radiofrequency energy and flips into a higher-energy state. As the radiofrequency is turned off, the proton relaxes back to a lower-energy state and releases energy in the form of radio waves which are detected and used to create MR image (B_0 = direction of the main magnetic field)

Fig. 1.2 Surface coil. In preparation for an MRI of the wrist, the patient's hand is placed into the surface coil (*inset*) which is then placed into the bore of the magnet during scanning

being imaged are used for most MSK MR imaging examinations (Fig. 1.2). These are critical for producing high-resolution images since they can be positioned very close to the tissues of interest and maximize the amount of signal detected.

Because of the nature and configuration of the machine, two patient-related factors should be considered before ordering an MR imaging study. First, because of the large magnetic field involved, patients must be screened for certain implants such as a pacemaker or some types of intracranial aneurysm clips as well as for a history of metal fragments within the eyes. These may be affected by the magnetic field and cause potentially fatal injuries.

Also, because of the relatively small bore of many machines, some patients will be too claustrophobic to complete the examination. Possible solutions include performing the exam with a larger "open-bore" magnet or "extremity" scanner or by administering sedatives either before or during the study.

Why Does the Image Look the Way It Does?

T1 and T2

Protons are influenced by the local molecular environment of the tissue in which they reside. As a result, protons in one type of tissue will behave differently from protons within a different tissue, and these differences provide the basis for the superb soft tissue contrast observed on MR images. The manner in which protons within a given tissue react during an MR scan is described by two characteristics known as "T1" and "T2" that are unique to each type of tissue. By changing the way in which the parameters for a given scan are set up, the images produced may emphasize differences in these values resulting in what are called "T1-weighted" (T1W) or "T2-weighted" (T2W) images, respectively. By comparing the appearances of a tissue on T1W and T2W images, the type of tissue present can often be deduced based on its signal characteristics.

For example, the signal intensity of fluid is quite low on a T1-weighted (T1W) image and very bright on a T2-weighted (T2W) image (Fig. 1.3a, b). This is why each MR examination is composed of several imaging "sequences" that are obtained with different scanning parameters, and a basic understanding of the most common pulse sequences used in musculoskeletal (MSK) imaging is important.

Pulse Sequences

When performing an MR imaging study, several different "sequences" are obtained with each sequence displaying the tissues in a different way. The most common sequences used in MSK imaging are T1, T2, proton density, inversion recovery, and gradient echo. It is not critical to know the details of how each sequence is performed, but it is helpful to know what the normal appearances of various tissues are on each. (See the next section on Normal Musculoskeletal Tissues and Table 1.1.)

Gadolinium Contrast Agents

Gadolinium-based contrast agents are commonly used in MR imaging studies. This agent produces increased signal intensity on T1W images and can be administered intravenously (analogous to iodinated contrast with CT scanning) or as a dilute solution that is directly injected into a joint to perform an MR arthrogram. (The latter is considered an "off-label" use by the Food and Drug administration, but it is a routine procedure in most practices.)

Intravenous

Any tissue that contains increased vascularity will take up intravenous gadolinium and demonstrate bright enhancement on T1W images (Fig. 1.4a). Typical situations in which intravenous gadolinium is used include suspected infection in the soft tissue or bone, evaluation of a soft tissue mass, or in a postoperative tumor case.

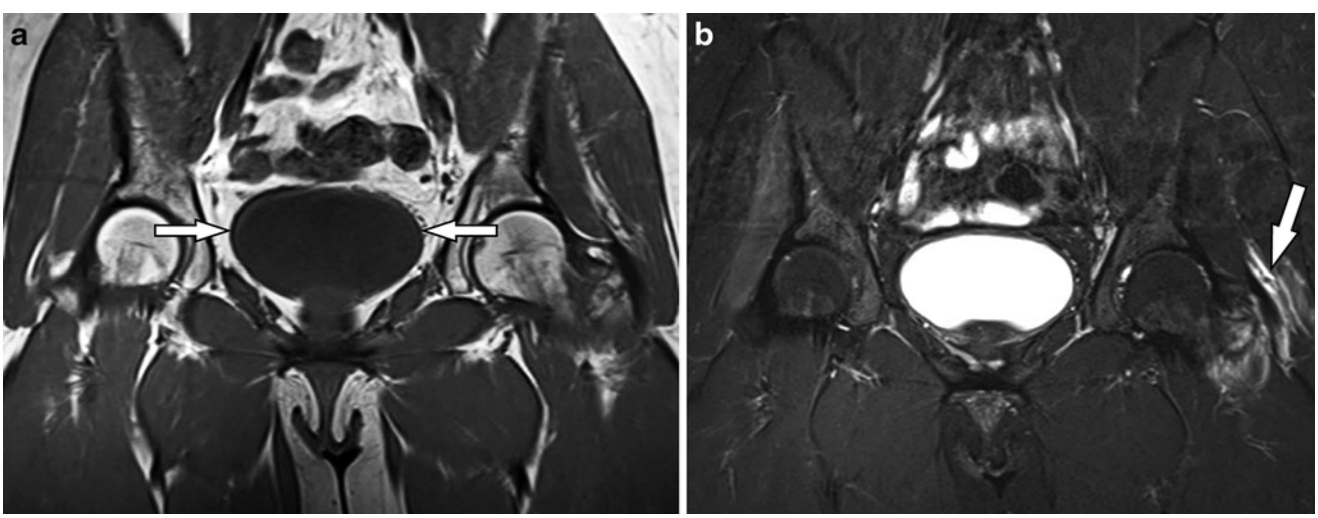

Fig. 1.3 (**a**, **b**) Fluid. (**a**) Coronal T1-weighted image demonstrates low-signal fluid within the bladder (*arrows*). (**b**) The corresponding coronal STIR (T2W) image reveals increased signal-intensity fluid within the bladder as well as tearing of the left gluteus medius/minimus tendons along the greater trochanter (*arrow*)