

HOW DOES IMAGING MOST IMPACT ATHLETE CARE

A SPORTS MEDICINE PHYSICIAN PERSPECTIVE

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Imaging has become a fundamental tool in sports medicine, playing a pivotal role in diagnosing and managing injuries, monitoring recovery, and guiding the safe return of athletes to activity. As participation in sports continues to grow globally, the demand for rapid, accurate, and efficient injury assessment has intensified. This increasing demand highlights the critical role of imaging in facilitating timely interventions and supporting the overall health and performance of athletes. The evolving landscape of sports medicine now requires a multidisciplinary approach, where sports medicine physicians, athletic trainers, and physiotherapists often serve as first responders in post-injury scenarios. These professionals must not only rely on clinical examination but also possess the ability to utilize imaging tools effectively to confirm diagnoses, assess injury severity, and develop comprehensive treatment plans. In this context, imaging technologies act as a bridge between initial clinical impressions and definitive treatment

strategies, enabling optimized care and outcomes for athletes.

Imaging contributes to athlete care in several fundamental ways. It allows clinicians to establish precise diagnoses that may be challenging to confirm through physical examination alone. Injuries involving soft tissue, cartilage, or subtle stress fractures often necessitate the use of imaging to uncover the underlying pathology. It provides detailed information about the extent and nature of injuries, which is critical for tailoring individualized treatment plans. Imaging is also invaluable for monitoring an athlete's recovery, offering objective evidence of healing and assists in determining readiness to return to activity. Decisions about when it is safe to resume training or competition is critical to reducing the risk of re-injury. Additionally, imaging supports image-guided procedures, such as injections or aspirations, and plays a vital role in preoperative planning by ensuring surgeons have an accurate understanding of the injury's scope.

Historically, the role of imaging in sports medicine was limited to basic modalities such as X-rays, which were primarily used to assess fractures and dislocations. While X-rays remain a valuable diagnostic tool, they offer limited information about soft tissue injuries and subtle changes in bone structure. Advances in technology have revolutionized this landscape, introducing imaging modalities including MRI, CT scans, and ultrasound, which provide highly detailed views of musculoskeletal structures. Ultrasound (US), with its portability and dynamic imaging capabilities, has become a critical tool for real-time assessment during training sessions or competitions. These advances have transformed imaging from a diagnostic tool to an integral part of injury prevention, rehabilitation, and performance optimization.

In elite sports, the stakes are particularly high, and imaging plays an important role in the complex decision of determining whether an athlete can safely return to competition. Major sporting events have



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increasingly incorporated on-site imaging facilities to enable immediate assessments and interventions. Portable imaging tools such as laptop ultrasound devices have further enhanced the ability of sports medicine professionals to make real-time decisions on the sidelines, addressing injuries promptly and effectively. While elite athletes benefit significantly from advanced imaging, the principles of imaging-guided care have also extended to community and recreational sports. As more individuals engage in physical activity to maintain health and well-being, the demand for accessible and effective injury management has grown. Imaging

supports this need by enabling clinicians to deliver evidence-based care, improving the accuracy of diagnoses, and tailoring treatments to individual needs. The value of imaging in sports medicine is amplified when integrated with thorough clinical evaluation. History-taking and physical examination remain cornerstones of medical practice, providing context and guiding the selection of appropriate imaging modalities. Imaging should complement, rather than replace, clinical judgment. This integration ensures that imaging adds value by confirming diagnoses, ruling out serious conditions, and refining treatment strategies.

The indications for imaging in sports medicine are diverse. These include uncertain diagnoses, the presence of clinical red flags, or the need to evaluate injury progression. Imaging is also crucial for monitoring treatment outcomes, particularly in cases where healing progress must be documented objectively. Beyond clinical care, imaging may be required for administrative purposes, such as insurance claims or eligibility determinations for athletes returning to competition. By addressing these needs, imaging enhances the precision and efficiency of athlete care across all levels of participation.

However, the reliance on imaging must be judicious. Overuse of imaging can lead to unnecessary procedures, increased healthcare costs, and heightened patient anxiety. Exposure to ionizing radiation, particularly with CT scans and nuclear medicine scans and repeated X-rays, poses additional risks that must be considered carefully. Moreover, the potential for misinterpretation of imaging findings, especially by clinicians without specialized training, can result in inappropriate management decisions. For instance, incidental findings on imaging that are unrelated to the patient's symptoms may lead to overtreatment or unwarranted interventions. This underscores the importance of ensuring that imaging is used in conjunction with clinical expertise and not as a substitute for comprehensive evaluation. Additionally, having the imaging results reviewed by a second expert, typically a radiologist, is important. A study in the United States found that radiologists' reports were more frequently reviewed than the images themselves, highlighting a reliance on their interpretations.

OVERVIEW OF IMAGING MODALITIES IN SPORTS MEDICINE

X-Ray

X-ray imaging is a fundamental diagnostic tool, especially in the initial evaluation of acute sports injuries. It is widely used to identify fractures, dislocations, and other abnormalities of the bone. X-rays are cost-effective, widely available, and deliver quick results, making them the preferred first step in diagnosing suspected bone injuries. They are particularly useful for identifying fractures with significant displacement and ruling out major bony injuries. However, despite advancements in imaging

technology, X-rays have limited sensitivity for subtle bone injuries and are unable to detect soft tissue damage, such as ligament or tendon injuries. Avci et al. reported that XR imaging was found to have 89% sensitivity, 95% specificity, 92% positive predictive value, and 92% negative predictive value in identifying knee fractures¹.

Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging (MRI) has emerged as the gold standard for assessing the morphology and pathology of musculoskeletal structures. Its ability to produce high-contrast, high-resolution images of soft tissues, bones, and joints without exposing patients to ionizing radiation makes it indispensable for evaluating both acute and chronic injuries, such as those involving muscles, tendons, ligaments, and cartilage. Additionally, MRI's non-ionizing nature ensures its safety for repeated scans, further enhancing its value in the ongoing management of musculoskeletal conditions.

MRI offers unparalleled soft tissue contrast and flexible imaging protocols, which are critical for accurate diagnosis and treatment planning. It is especially effective in differentiating between various types of soft tissue injuries, identifying subtle abnormalities, and monitoring the progression or healing of injuries. However, despite these advantages, MRI is associated with certain limitations, including high costs, lengthy examination times, and relatively limited use in image-guided

procedures compared to other modalities, such as ultrasound.

MRI for Muscle Injuries

MRI is particularly advantageous for visualizing soft tissue injuries allowing detailed evaluation of muscle morphology and injuries². It is highly effective for detecting and delineating the extent of traumatic lesions, especially in deep muscle compartments that may be challenging to assess with ultrasound (US) which could potentially cause false-negatives. To comprehensively evaluate muscle injuries, multiplanar acquisitions (axial, coronal, and sagittal) of the affected muscles are essential. MRI protocols for muscle injuries prioritize fat-suppressed, fluid-sensitive pulse sequences. These sequences, such as short tau inversion recovery (STIR), T2-weighted, and proton density-weighted imaging, are essential for detecting pathological features such as edema, hematomas, and fluid collections. Fat suppression improves contrast by eliminating signal interference from adipose tissue, thereby enhancing visualization of muscle abnormalities. In contrast, T1-weighted imaging, while less sensitive to edema, plays a complementary role in characterizing chronic changes, including muscle atrophy, fatty infiltration, and scar tissue³. This dual approach ensures that both acute and chronic muscle changes are adequately captured.

Muscle injuries frequently involve the myotendinous junction (MTJ), which is a common site of strain due to its

biomechanical role as the weakest link in the muscle-tendon complex and is reported to have a long recovery. On MRI, injuries to the MTJ are characterized by edema and hemorrhage that extend along adjacent muscle fibers and fascicles. This extension creates a distinctive "feathery" appearance on fluid-sensitive sequences, which is considered a hallmark of MTJ injuries on fat-suppressed T2-weighted and STIR sequences. In addition, central tendon injuries are more likely to recur and require longer recovery period compared to other muscle injuries. Classifying muscle injuries is crucial for developing effective treatment strategies, and many of these classifications cannot be accurately made without the use of MRI. Additionally, MRI has been shown to be valuable in predicting recovery timelines and identifying risk factors for recurrent injuries, both of which are essential for determining an athlete's readiness to return to play. It is also worth noting that some previous reports have indicated that many MRI findings may persist in athletes during follow-up after completing rehabilitation, despite full clinical and functional recovery.

MRI for Bone and Cartilage Injuries

MRI demonstrates the highest combination of specificity and sensitivity for diagnosing bone stress injuries, solidifying its role as the preferred imaging technique for evaluating these injuries in symptomatic individuals. On MRI, bone stress injuries are characterized by periosteal or bone marrow edema, appearing as hyperintense signals

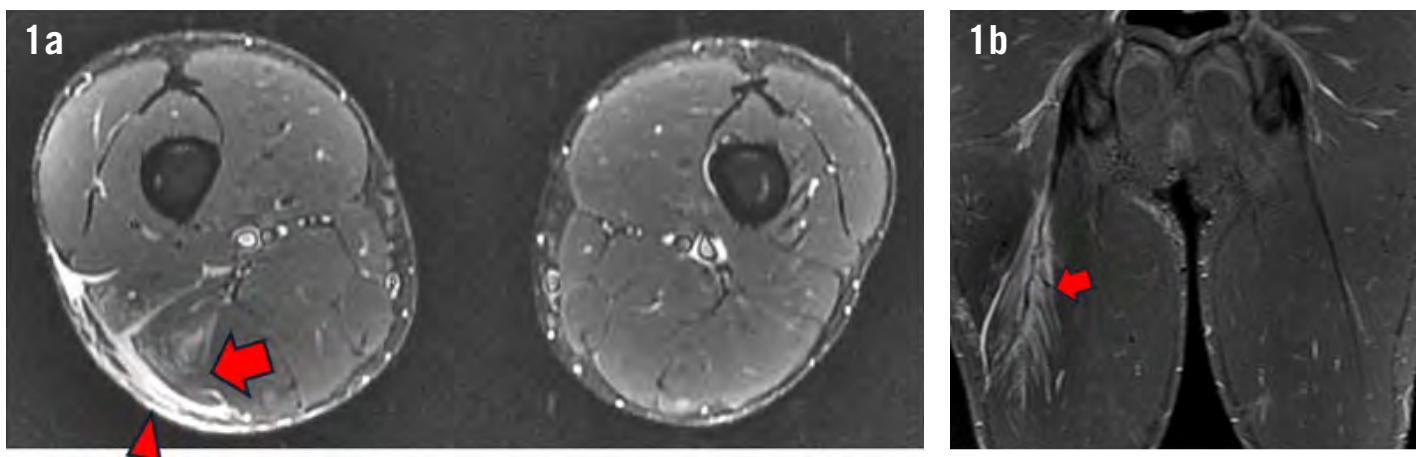


Figure 1a: Myofascial tear with edema (increased signal) at the posterolateral and distal aspect of the long head of the biceps femoris muscle in axial T2-weighted fat-saturated image (arrow). Also note the extensive peri-fascial edema (arrowhead).

Figure 1b: T2-weighted fat-saturated MRI indicating intra-muscular tendon injury with a "feathery" appearance in muscle belly and a redundant wavy pattern to the central tendon (arrow).

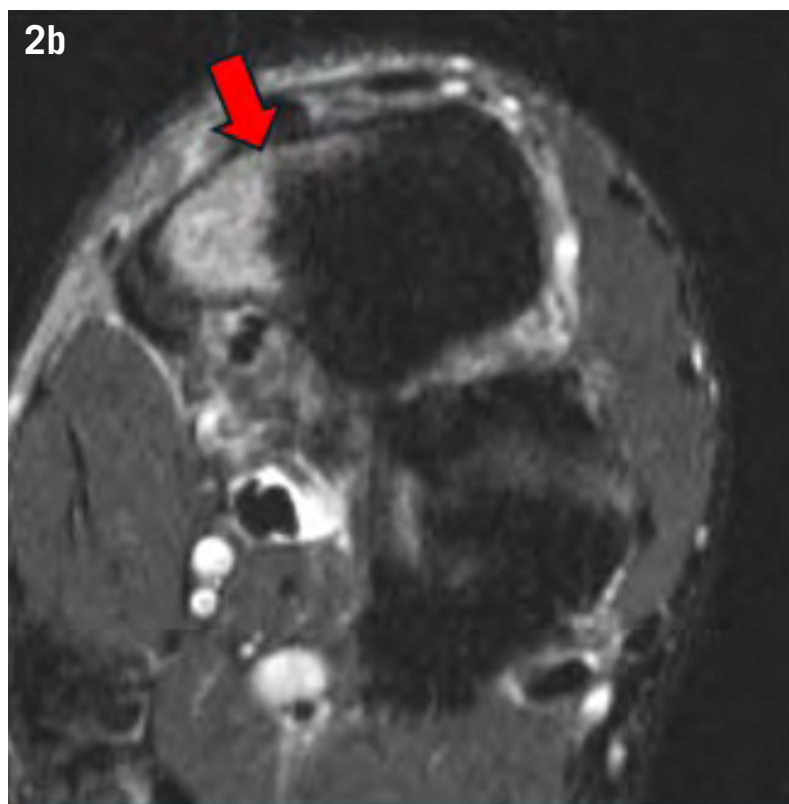


Figure 2a: Axial CT image showing a stress fracture line involving the cortex of the proximal tarsal navicular bone (arrow).

Figure 2b: T2-weighted fat-suppressed MR image showing bone marrow edema in the navicular bone, also secondary to a stress injury (arrow).

on T2-weighted and short-tau inversion recovery (STIR) sequences and hypointense signals on T1-weighted sequences. In addition to its utility for bone stress injuries, MRI is particularly effective in detecting apophysitis, which is often accompanied by bone marrow and soft tissue edema⁴. However, differentiating apophysitis from avulsion fractures can be complex, requiring a detailed patient history to aid in diagnosis. Furthermore, MRI excels in identifying early-stage posterior element bone stress injuries, where CT may fail to detect abnormalities if the cortical bone appears intact. Previous research demonstrated that MRI achieves sensitivity and specificity rates exceeding 90%, highlighting its reliability in such cases. Similar to its role in evaluating muscle injuries, MRI is invaluable for classifying bone stress injuries. According to a systematic review, MRI-based grading of these injuries provides significant prognostic information regarding return-to-play outcomes. This capability emphasizes MRI's importance in both diagnostic accuracy and the development of tailored treatment and return to play.

Quantitative Musculoskeletal Techniques

The followings are qualitative imaging with more physiological and anatomic information.

T2 mapping

T2 mapping is a techniques that measures the T2 relaxation time of tissues, which reflects water content and tissue integrity. This method holds significant value in evaluating hyaline cartilage, allowing for the detection of early degeneration and the identification of irreversibly damaged cartilage⁵. Beyond cartilage, it is widely used to analyze muscle composition, facilitating the measurement of edema and inflammation and provides detailed insights into the physiological and biochemical properties of muscles by capturing changes induced by exercise.

Ultrasound

In recent years, the use of ultrasound in evaluating musculoskeletal conditions has surged, largely due to its cost-effectiveness and real-time imaging capabilities. Unlike static imaging techniques such

as X-rays and MRI, ultrasound enables dynamic assessment of soft tissues during movement, making it particularly valuable in sports medicine. Its portability, affordability, and non-invasive nature further enhance its clinical utility. Additionally, ultrasound has become an essential tool for guiding interventional procedures, helping to accurately position needles while visualizing surrounding anatomical structures to reduce the risk of injury⁶. However, the accuracy of ultrasound is highly dependent on operator expertise, and its utility diminishes when imaging deeper structures, especially in individuals with a higher body mass index.

Ultrasound for muscle injuries

One of its key strengths lies in its ability to clearly visualize muscle fibers and their associated aponeuroses, with high sensitivity for detecting injuries to these structures⁷. Unlike MRI, which struggles to differentiate individual muscle fibers, US, with its higher spatial resolution, excels at distinguishing between muscle fiber disruptions and muscle edema. This

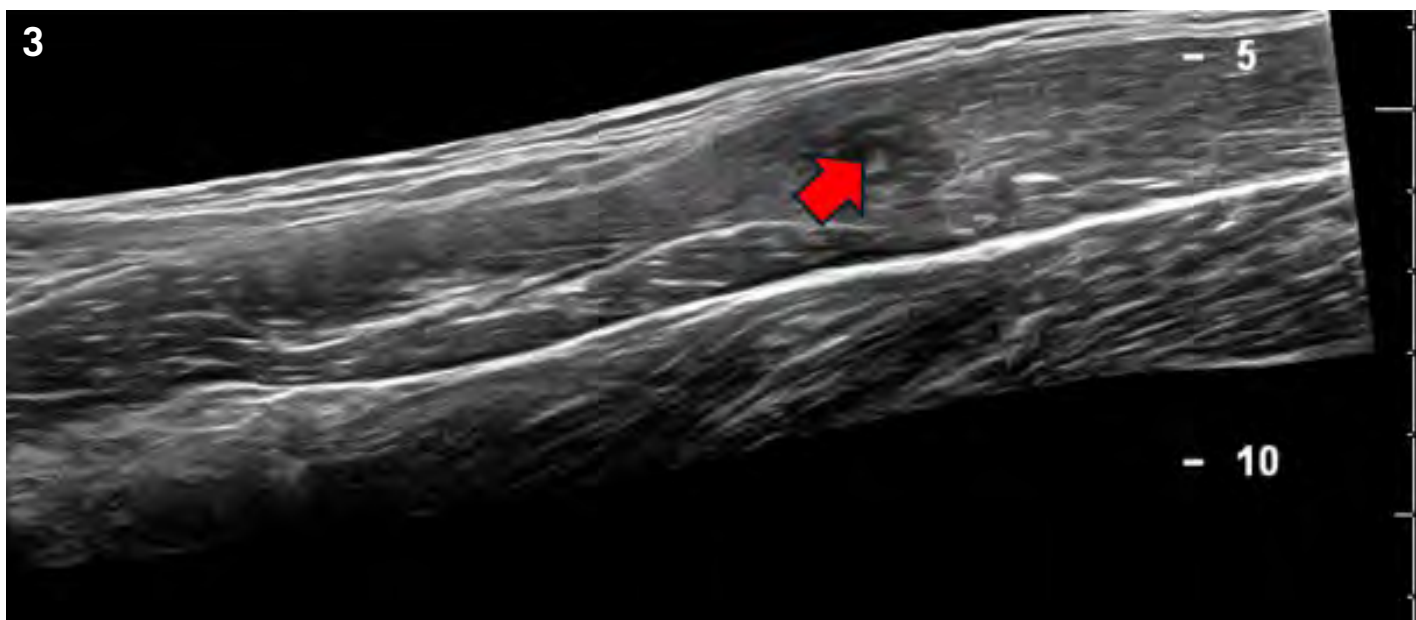


Figure 3: Extended field of view ultrasound image of a rectus femoris tear showing a degloving type bull's-eye sign (arrow), characterized by a hypoechoic area (fluid collection) surrounded by a hyperechoic rim.

capability makes US particularly useful in acute settings where rapid diagnosis is critical.

However, the effectiveness of US diminishes with increasing tissue depth, limiting its utility in evaluating deep-seated injuries such as piriformis muscle tears, where MRI offers superior performance. While US demonstrates comparable sensitivity to MRI for detecting acute muscle injuries, it may fail to identify subtle, ongoing pathological changes indicative of incomplete healing. For this reason, MRI is often recommended for follow-up imaging to provide a more comprehensive assessment of muscle recovery and guide treatment decisions.

Recent studies have indicated that ultrasonographic measurements of tendon dimensions demonstrate high reliability, both in relative and absolute terms, ensuring consistent and reproducible results across various clinical settings. This enhances its utility in longitudinal assessments and comparative analyses of tendon pathologies. Additionally, the advent of shear wave elastography has significantly advanced the evaluation of the mechanical properties of muscles and tendons. This technique provides a quantitative measure of tissue stiffness, represented as an elastogram, offering deeper insights into

tissue biomechanics. Such assessments are particularly valuable in diagnosing subtle changes in tissue integrity, monitoring rehabilitation progress, and evaluating the efficacy of therapeutic interventions.

Computed Tomography (CT)

Computed Tomography (CT) is a cross-sectional imaging technique used in sports medicine particularly for evaluating suspected bone injuries and in cases where MRI is contraindicated. While CT provides inferior soft tissue contrast compared to MRI, it provides visualizing fracture lines and calcifications. Recent advances, such as metal artifact reduction software, have further enhanced its diagnostic capabilities in postoperative imaging by minimizing distortions caused by metallic implants. Dual-energy CT, a notable advancement, uses two energy spectra to differentiate between tissues, allowing for the detection of bone marrow edema and potentially replacing MRI in specific scenarios⁸. For example, it can detect occult fractures and is also widely used to detect monosodium urate crystal deposition in soft tissues and joints, facilitating the assessment of gout. Despite these advantages, CT is limited by higher radiation exposure and less effective soft tissue visualization compared to MRI.

Dual-Energy X-Ray Absorptiometry (DXA): Bone Density and Stress Fractures

Dual-energy X-ray absorptiometry (DXA) is widely recognized for its role in assessing bone mineral density and body composition in athletes. In sports medicine, DXA serves as a tool for evaluating athletes at risk of repetitive stress injuries and conditions related to Relative Energy Deficiency in Sport (RED-S). While initial diagnoses for conditions such as scoliosis are often based on standard X-rays, DXA scans can incidentally detect scoliosis during assessments of bone mineral density and body composition in athletes⁹. Furthermore, DXA offers insights into bone structural geometry, which may aid in predicting the risk of stress injuries¹⁰. An advantage of DXA is its use of minimal radiation, making it a safer option for repeated assessments. However, further evidence is required to validate its broader applications in monitoring skeletal health and detecting musculoskeletal abnormalities.

SUMMARY

Imaging has become an essential tool in sports medicine, providing clinicians with the necessary insights to make accurate diagnoses, develop individualized treatment plans, monitor recovery, and guide athletes



Imaging has become an essential tool in sports medicine, providing clinicians with the necessary insights to make accurate diagnoses, develop individualized treatment plans, monitor recovery and guide athletes back to competition safely.



back to competition safely. From its origins in simple X-rays to the advanced technologies available today, imaging has expanded the scope of sports medicine, improving outcomes for athletes across all levels. While its role is critical, it must be balanced with clinical evaluation and expertise to ensure that its use is both effective and appropriate. As the demand for injury prevention, management, and optimization of athletic performance continues to grow, imaging will remain at the forefront of sports medicine, contributing to the overall health and well-being of athletes worldwide.

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