The Role of Imaging in Sports Medicine

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Abstract
Imaging plays a vital role in the diagnosis and management of sporting injury. There are several factors unique to sports medicine that need to be taken into account when considering imaging of the injured athlete, such as sporting technique and the biomechanical stresses associated with any given activity. Close liaison between the referring physician and the reporting radiologist is vital not only for selecting the most appropriate imaging technique, but also for accurate interpretation of imaging findings. We discuss the current status of imaging in sports medicine, focusing on challenges to the referrer, challenges to the radiologist and the roles of the most commonly used modalities. Interventional techniques and recent advances are also discussed for each modality. Finally, there is recognition that imaging needs to be promoted in sports medicine research in order to help establish a firm evidence base for practice.

Keywords
Imaging, sports medicine, athletic injury, ultrasound, magnetic resonance imaging

Imaging plays a vital role in the diagnosis and management of sporting injuries. Early diagnosis can reduce rehabilitation time and long-term disability, so developments in imaging have had the knock-on effect of an improvement in the outcome of injury episodes. Combined with increased understanding of the biomechanical factors involved in athletic activity, advances in imaging have contributed to earlier and more accurate diagnosis, but in doing so have uncovered findings of undetermined saliency in a spectrum of ‘normal’ to ‘abnormal’ that pose a challenge to the interpreting radiologist. In this article, we discuss the developing role of imaging in the management of sports injuries and address specific challenges to the referring physician and the reporting radiologist in this field, illustrated with several pictorial examples.

Challenges to the Referrer
Good working relationships are vital to ensure as much information as possible is gleaned from imaging studies, starting with discussion with the radiologist about the clinical assessment. This should include details of the mechanism of injury, usual activity levels, previous injuries, sporting technique and salient positive and negative examination findings. Close liaison with a focus on the specific area of interest leads to appropriate imaging being performed, sometimes with multimodality assessment being required. The patient can then be reviewed with the results and re-imaged should there be further indication.

While injuries affect athletes at all levels, professionalisation has contributed significantly to changes in imaging strategies. Performance pressures have pushed for the earlier detection of injury in order to limit time away from activity and to avoid disability and deformity that may detract from career length, peak performance or activity enjoyment. This has prompted imaging to be performed at an early stage when clinical evaluation can be non-specific, and as a result has led to unsuspected sub-clinical findings being revealed that pose a direct question of relevance to the interpreting radiologist.

Challenges to the Radiologist
There are several factors unique to sports medicine that need to be taken into account when considering imaging of the injured athlete, such as sporting technique and the biomechanical stresses associated with any given activity. Close liaison between the referring physician and the reporting radiologist is vital not only for selecting the most appropriate imaging technique, but also for accurate interpretation of imaging findings. We discuss the current status of imaging in sports medicine, focusing on challenges to the referrer, challenges to the radiologist and the roles of the most commonly used modalities. Interventional techniques and recent advances are also discussed for each modality. Finally, there is recognition that imaging needs to be promoted in sports medicine research in order to help establish a firm evidence base for practice.

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in the presence of warning signs and symptoms;
• for objective documentation of disease, progression or resolution (such as in medicolegal situations); and
• for pre-operative planning.4,3

In many clinical scenarios, the most suitable image modality is yet to be determined. For example, the shoulder has historically been imaged with plain radiography, ultrasound (US), computed tomography (CT), CT arthrography, magnetic resonance imaging (MRI) and MR arthrography;7 with rotator cuff pathology being reliably demonstrated with both US and MRI. The precise choice of modality may also depend on local expertise, equipment, safety, financial constraints and patient tolerance; therefore, it is important to discuss options with the radiologist.

Challenges to the Radiologist
The greatest challenge to the reporting radiologist is to be able to correctly identify imaging features that are associated with pain, injury and disability, and thus related to relevant symptomatic pathology in a spectrum of imaging findings. It is important that subtle abnormalities that relate to an episode of injury are not overlooked, while asymptomatic pathology should be underplayed (but not ignored), especially if it does not require intervention. Increasing age can also present difficulties in interpreting findings that in a younger individual may be more confidently called pathology, such as with degenerative change in the menisci of the knee, which can be misinterpreted as a tear.3

The difficulty in defining the ‘normality’ of findings in the imaging of athletes has led to recurring debate in the medical literature. There appears to be a spectrum of appearances from completely normal that ranges through anatomical/congenital variants, physiological change to ‘normal for athletes’, sub-clinical pathology and relevant symptomatic and asymptomatic pathology. These are discussed with examples below.

Medicolegal situations in which there is the requirement for objective documentation of disease progression or resolution can also be encountered.2 There is very little discussion on this topic in the medical literature, yet it also poses a challenge to the radiologist, who must consider the consequences of an unsuspected finding that has not yet caused injury or detraction from performance.

Imaging Findings – What Is Normal?
Anatomical/Congenital Variants
Knowledge of underlying anomalies and variants that can predispose to injury or pain on performance provides important information for clinical management. For example, abnormal joint alignment and congenital joint dysplasia are known risk factors for injury and can lead to osteoarthritis.3 Tarsal coalition can present with hind-foot pain, multiple sprains and subtalar joint stiffness as a result of abnormal biomechanical stresses through the foot. While suspected coalition can be shown with plain radiography (see Figure 1A), further cross-sectional imaging with CT or MRI can be performed if the diagnosis is equivocal. In such cases appropriate imaging can lead to correct diagnosis and treatment with acceptable return to activity.10

Physiological Change
An MRI study of Olympic fencers has demonstrated that bone develops trabecular adaptations and an increased marrow volume in response to stress as a means of resisting increased load, providing an example of physiological adaptation in elite athletes11 – further discussion on adaptive bone stress is included below. Another example of physiological change seen with imaging is muscle imbalance that can develop with poor training technique or single-handness of an activity, which can subsequently lead to overuse injury.12

Figure 1: Plain Radiography in the Assessment of Ankle and Foot Pain

A: Lateral radiograph of the ankle showing calcaneonavicular tarsal coalition in a skeletally immature individual. Compare with B, in which there is no coalition. B: Lateral radiograph of the ankle of a footballer taken in the assessment of an acute injury, showing a bony spur on the superior aspect of the talar neck. These lesions are found in both symptomatic and asymptomatic athletes.

Table 1: Specialist Areas of Computed Tomography Application

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<th>Specialist Areas of Computed Tomography Application</th>
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<td>Leg length (use of the CT scout image only)</td>
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<td>Guidance for deep body injections</td>
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*Found in developmental hip dysplasia, it limits the external rotation required in ballet, for example.

‘Normal for Athletes’
Ankle ‘spurs’ are a common finding in athletes, being found on the superior aspect of the talus in up to 60% of football players (see Figure 1B). Such lesions are thought to be either osteophytes formed from repetitive microtrauma or enthesophyte development from recurrent capsular or ligamentous traction.2 However, anterior tibiotaral spurs have also been found in a significant proportion (45–59%) of asymptomatic athletes,4 and so may represent part of a spectrum that is ‘normal for athletes’ at one end with painful symptoms of anterior ankle impingement at the other.

Sub-clinical Pathology
MRI assessment of the shoulder in asymptomatic baseball pitchers has been shown to demonstrate labral abnormalities that have thus been assumed to be ‘non-clinical’.6 Impact and torsional loading of joints has been implicated in the development of osteoarthritis in athletes with undiagnosed joint injury, but not in those who have undertaken moderate habitual exercise, by middle age.7 Osteophytes and meniscal abnormalities have also been demonstrated in the knees of asymptomatic volunteers.8
Relevant Symptomatic Pathology
The aim is for the radiologist to correctly identify this, especially if it is a finding that could be considered sub-clinical if the athlete was asymptomatic. Importantly, recognised patterns of change related to a specific activity should not be dismissed as ‘normal for the athlete’ if they are symptomatic, as has been demonstrated with spondylolysis and spodylolisthesis in the spine in elite female gymnasts.  

Asymptomatic Pathology
Gross pathology of osteoarthritis, rotator cuff disease and intervertebral lumbar disc protrusions have all been demonstrated in asymptomatic individuals and may not be relevant to the injury episode at the time of imaging. The incidence of asymptomatic pathology has also been shown to increase with age, as in meniscal tears demonstrated on MRI of the knee, for example. This is important because lesions that are not symptomatic should not necessarily be treated clinically.

Plain Radiography
Apart from soft-tissue injuries, such as muscle tears and superficial tendinopathy (when US is more appropriate), first-line imaging for sports injuries is nearly always with plain radiography, which provides a lot of information for minimal radiation exposure. Omitting plain radiography in the initial assessment can also lead to errors in diagnosis. Plain radiography is cheap, quick and readily available and gives low radiation exposure. Disadvantages of this technique include the production of a flattened 2D image; although radiographs have been historically associated with poor soft-tissue information, recent techniques have improved this, for example, with the use of multiplanar reconstruction (MPR) technology.
advances in digital imaging have provided much improved soft-tissue detail and contrast.

Beyond the assessment of acute bony trauma, plain radiography is valuable in the assessment of prostheses, accessory ossicles, soft-tissue calcification, heterotopic ossification, bone stress (such as in osteitis pubis), tendon rupture and avulsion (see Figure 2), bony coalition (see Figure 1A), degenerative joint disease, tumours and suspected foreign body. The finding of a normal plain radiograph also adds value through the exclusion of such conditions.5

Computed Tomography
Although CT is the main source of iatrogenic radiation dose in the general population and therefore not an insignificant cancer risk,20 it is nonetheless valuable in the assessment of bony pathology and traumatic injuries to the head, spine and body. Specialist areas of CT application are listed in Table 1.

Strengths of CT include the fact that it is quick and readily available. Advances in computer algorithm processing and image reconstruction have reduced artefacts caused by metallic prostheses, while
unsuitable for MRI.

Bone stress reactions have been demonstrated on MRI in the ankles and feet of asymptomatic individuals, while they have also been shown on MRI in the ankles and feet of volunteers whose normal biomechanical forces were altered by the use of a unilateral orthosis. Sub-clinical bone stress injury has also been demonstrated on MRI in the feet of ballet dancers, in whom it correlated with ankle pain. Bone marrow oedema can in fact be demonstrated in a multiplicity of locations with the caveat that we still do not know what the norm is for certain athletic groups, and so its clinical significance on MRI within the spectrum of imaging findings in sporting injury is under continuous debate.

In terms of the clinical application of MRI, good technical understanding and clinical integration between physician and radiologist is integral in order for the right MR technique to be performed. For example, proton density fast spin-echo sequences are especially accurate for meniscal and cruciate pathology in the knee (see Figure 5), while fat suppression techniques such as short tau inversion recovery (STIR) and fat saturation imaging are excellent for identifying bone oedema (see Figure 4) and cartilage abnormalities.

Advances in gradient-echo MR sequences, such as steady-state free precession imaging, have allowed for faster and higher spatial resolution 3D volume acquisition with fewer of the artefacts that previously detracted from this technique. This can be used effectively in MR arthrographic assessment of shoulder instability. Direct MR arthrography has nearly completely replaced diagnostic arthroscopy in the management pathway of shoulder and knee disorders, while indirect MR arthrography, in which intravenous injection of contrast medium gradually perfuses into the joint space over time, may have some future application in the imaging of small joints such as the wrist and ankle.

A specific advantage of MRI over US is in its ability to image multiple pathologies at once, such as shoulder rotator cuff injury with a concomitant labral tear, which can thus reduce the possibility of failed shoulder surgery. However, MRI is a confined examination (more so than CT) and can induce claustrophobia, as well as placing a limit on the size of subject that can be examined. Recent advances have seen the introduction of less restrictive open MRI scanners, sometimes in the enterprising role of interactive and interventional MR imaging. In the former, joints can be imaged under direct stress or dynamically, while in the latter MR is used to guide injection (although this does require specialist MR-compatible equipment).
Ultrasonography

In recent years, US has been increasing in popularity in sports imaging. It is appropriate as the first-line imaging for muscle tears and superficial tendinopathy and also has an important role in the assessment of general tendon disorders. Other areas of US application include groin injuries, entheseal injuries, ligamentous disease, avulsion fractures, stress fractures, foreign bodies and synovitis. Small and superficial soft-tissue masses and ganglia are also well suited to US examination.

Like MRI, US has the advantage of being a non-ionising technique with excellent soft-tissue imaging characteristics. A unique feature of US is its capacity for realtime, dynamic imaging that can demonstrate features such as tendon glide, subluxation, soft-tissue impingement and hernia protrusion. Conversely, the dynamic nature of imaging means that its full value can only be appreciated by the ultrasonographer at the time of examination.

High-frequency transducers (9–17MHz) have improved spatial resolution significantly, while miniaturised, albeit less powerful, portable scanners are suitable for examining patients immediately after injury or even on the field of play. New ‘sweep’ technologies can provide extended panoramic views (see Figure 6) as well as 3D reconstructions, while the power Doppler mode allows for sensitive vascular assessment (see Figures 7E and 7F). Insurmountable obstacles to US include its inability to assess bone, marrow and cartilage disease. The lack of information in depth is another defining limitation.

Open MRI certainly allows imaging in positions not possible in conventional scanners.

Upright positional MRI has been used to demonstrate the effect of load-bearing on the lumbar spine, and may find further application in the evaluation of the load-bearing biomechanics of body positioning in sport. Other areas of research with MRI have involved the use of 7T scanning, for example in the assessment of trabecular bone microarchitecture in the knees of Olympic fencers, as described above.

The most frequently cited criticism of US is that inexperience can lead to loss of sensitivity in the detection of subtle abnormalities. Like MRI, good technical understanding and clinical integration is essential, however, the additional aspect of ‘driving’ the machine to produce optimum image quality also has to be considered, emphasising the importance of training and experience for safe and accurate examination. This is especially relevant as the increasing availability and practicality of US has led to its regular use by practitioners across a number of specialist fields outside radiology.

US has an important role in guiding intervention, such as for the injection of local anaesthetics and corticosteroids into joints, tendon sheaths and bursae. US-guided joint injection can be performed in preparation for MR or CT arthrography and also to guide aspiration of collections, cysts and ganglia. Recent advances in US research include realtime sonoelastography, which may offer further insight into mucoid degeneration in tendon disorders, and the use of contrast agents to demonstrate low-volume blood flow in tendon neovascularity.

Concentration

While the principles of imaging in general radiology also apply for imaging in sports medicine, there are factors unique to the imaging of athletic injuries that must be considered by those directly involved in their care. These include the biomechanical stresses of different activities, the technique of the individual athlete and the increasing motivation to return to activity earlier. Both the sports physician and radiologist require a good understanding of these factors in order to initiate appropriate imaging, accurately diagnose and treat athletic injury. Close liaison is vital to enable appropriate
and focused imaging and to help the radiologist in the challenge of interpreting relevant symptomatic findings in a spectrum through anatomical/congenital variants, physiological change to ‘normal for athletes’, sub-clinical pathology and relevant symptomatic and asymptomatic pathology.

Plain radiography remains an essential first-line tool for most injuries. CT, although best avoided in younger athletes because of the high radiation load, still has several targeted roles. MRI and US are non-ionising techniques with excellent soft-tissue imaging characteristics that are ideal for the imaging of sports injury, with choices between the two often dependent on cost, local expertise and equipment. Bone scintigraphy is now virtually redundant as MRI provides more information with far greater anatomical detail and without the risks associated with ionising radiation.

Interventional techniques in sports imaging are continually developing, with MR arthrography now having nearly replaced diagnostic arthroscopy of the shoulder and knee. The non-ionising aspect and broad reproducibility of MRI will also continue to make it an exciting research tool in sports imaging. Finally, imaging must be encouraged in the research activities of sports medicine in order to develop a greater understanding of changes in athletes that span from physiological to pathological, and hence create a solid platform for the practice of evidence-based medicine in the future.