Magnetic resonance imaging in sports medicine – an overview

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As more Britons become health conscious and are involved in a variety of sporting events, sports-related injuries are a daily occurrence. Although evaluation of bony abnormalities resulting from acute and chronic sports injury by conventional radiography and bone scintigraphy has been satisfactory, the assessment of soft tissue and tendinous injury is more difficult and imprecise. Due to its superior contrast sensitivity and multiplanar imaging capability, magnetic resonance imaging has already shown great promise in delineating soft-tissue and tendinous abnormalities. In addition, marrow pathology is exquisitely displayed.

Keywords: Magnetic resonance imaging, sports injuries

In an age of finely tuned athletes and superior on-field performances, medicine has followed suit. Gone are the days when professional sportsmen and sportswomen ignored their injuries, or relied simply upon radiography to investigate chronic pain. Doctors now have access to sophisticated imaging equipment and athletes are reaping the benefits. Furthermore, increased health consciousness has motivated more of the general public to participate in sports with a concomitant rise in sports injuries.

In recent years, particularly in the USA, magnetic resonance imaging (MRI) has proved itself the premier imaging tool in the evaluation of sports injuries. The technique provides excellent inherent soft-tissue contrast allowing direct visualization of cartilage, muscle, tendons, and other soft tissues, in addition to bone marrow. Further advantages include its multiplanar imaging capability, the absence of ionising radiation, and no known harmful effects attributed to the technique.

The nuclear magnetic resonance phenomenon is a normal property of matter, initially discovered by the American Physicists Bloch and Purcell in the 1940s. The physics of magnetic resonance imaging is complex but it is helpful to understand some background to the subject for the interpretation of the images.

The nuclei of many substances within the body will show magnetic resonance, but the hydrogen nuclei are by far the most common in the human body, and will give the biggest signal. Hydrogen nuclei can be considered as acting like spinning bar magnets. Since the hydrogen in the body is mainly in the form of water and fat, the information obtained from MRI is principally concerned with the distribution of water and fat.

In an external magnetic field the magnetic moment of the spinning hydrogen nuclei will have a wobbling spin, known as precession. The frequency of precession is dependent on the strength of the magnetic field. Once the patient is placed in a strong magnetic field a pulse of electromagnetic energy at a particular radio frequency is passed through the patient imparting energy to the nuclei which are spinning at the same frequency. Only the nuclei that are resonating at the correct frequency will be affected. Magnetic gradients are applied in addition to the main field. These are applied in three planes, at right angles to one another, and they decide the position of the slice and encode any one position within the slice, such that each point or pixel has a different radio frequency or phase. When the radio frequency is switched off, a signal can be detected emanating from the resonating nuclei. This signal is detected as a complex wave form, but is converted by Fourier transformation into constituent frequencies with their respective phases and amplitudes. The position of the signal on the scan will be determined from the frequency and phase. The amplitude of the signal will determine the position on the grey scale with the higher signal being shown as a brighter area. Many factors affect the emitted signal and hence the final picture. These include:

1. *Proton density.* This is of considerable importance since in the absence of protons there can be no signal.
2. *Relaxation times.* These are constants related to the length of time for the signal to decay after stimulation by the radio frequency. The *T1* relaxation time is relaxation between the spinning protons and the main magnetic field and is also known as the spin lattice relaxation. The *T2* relaxation time represents relaxation between the neighbouring protons due to interference, this is known as the spin-spin relaxation time.

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3. *Chemical shift.* The hydrogen is bound differently in water and fat and these two forms have slightly different resonant frequencies resulting in overlapping image and edge artefacts.
4. *Flow.* Flowing fluid in the body, e.g. cerebrospinal fluid and blood can cause flow voids or enhancement, depending on the signal used.
5. *Susceptibility.* This is a measure of the paramagnetic effect of a material. Some substances, e.g. melanin and methaemoglobin, possess paramagnetic properties and these can alter the local magnetic environment, resulting in enhancement or decrease in signal. If the substance has high susceptibility, e.g. some metallic pigments in eye mascara, the magnetic field may be substantially distorted causing artefacts across the image. The most classical sequence used in MRI is known as spin echo, using 90° and 180° radio frequency pulses. Images are produced with T_1 , T_2 and proton density weighting. It is also possible to suppress the signal from fat using the short tau inversion recovery (STIR) sequence with some summation of T_1 and T_2 effects, giving rise to increased lesion detection.

Magnetic resonance imaging is a safe technique, but because of the strong magnetic field, care is needed with metallic implants, neurosurgical clips etc., to avoid migration or excessive tissue heating. Claustrophobia is a problem for about 1% of patients. The scan currently takes longer than a computed tomographic (CT) examination, although major progress in improving the acquisition times is underway. While MRI is not usually needed in the diagnosis of obvious acute injuries, its ability to delineate accurately the extent of certain injuries can be of value in determining which cases require surgical intervention and which may be handled with conservative methods.

Upper extremities

The shoulder is commonly injured in activities involving overhead movements, e.g. swimming, racquet sports and gymnastics. MRI is generally regarded as the most appropriate noninvasive technique for the evaluation of rotator cuff tears and impingement syndrome, which are the most common shoulder injuries¹. MRI determines the location and size of the tears, the degree of retraction of torn edges and the status of the remaining rotator cuff. The presence of subacromial fluid is a sensitive indicator of a tear with interruption of the tendon being a specific finding² (Figure 1).

MRI is limited, however, in detecting labral abnormalities when a joint effusion is absent and CT arthrography, although more invasive, remains the gold standard in this respect³.

The elbow, as the focus of stress in many sports, is prone to injury. MRI of elbow injuries has developed slowly but its application has good potential as new coil designs provide comfortable patient positioning.

Injuries to the hand and wrist occur frequently in a wide variety of sports. Standard radiographs, CT scans and arthrography are used to evaluate the

Figure 1. A T_2^* GE coronal image shows fluid within the subacromial-subdeltoid bursa and heterogeneous signal in the supraspinatus tendon indicative of a partial tear, confirmed at surgery

majority of wrist injuries, but there is a growing consensus that MRI is accurate in detecting tears of the triangular fibrocartilage⁴.

Lower extremities

Players in contact sports and activities characterized by rapid bursts of movement such as soccer, hockey, rugby and athletics are the most likely to be associated with injuries to the lower extremities. The knee is the most frequently injured joint in sport⁵. A chronic knee injury is one of the most typical reasons for premature retirement from athletics.

MRI has largely replaced arthrography, computed axial tomography and ultrasonography in examination of the knee because of its noninvasive high diagnostic accuracy⁶. While arthroscopy can be both diagnostic and therapeutic, the frequency of normal arthroscopy can be decreased substantially by the routine use of MRI^{7,8}.

Normal menisci appear as black, low signal structures, as does the posterior cruciate ligament. The anterior cruciate ligament is more vascular and is seen as a band of intermediate signal. So sensitive is magnetic resonance to local change in water content that after jogging, about 50% of people can be shown to have a higher signal in their menisci with small joint effusions⁹.

There is a well accepted grading system for meniscal abnormalities ranging from grade I and II increases in signal intensity within the substance of the meniscus, representing various stages of myxoid degeneration, to grade III changes which represent complete tears¹⁰.

MRI is particularly useful in determining the presence of tears of the posterior horn of the medial meniscus which can be difficult to see at arthroscopy (Figure 2). Cysts of both the menisci and popliteal region are easy to diagnose in addition (Figure 3).

Tears of the cruciate and collateral ligaments are well seen by MRI. In anterior cruciate ligament (ACL) tears a correlation of 94% with arthroscopy has been

Figure 2. A T2* GE sagittal image of the knee. The posterior horn of the medial meniscus should appear of uniform low signal intensity but there is a region of linear high signal intensity running through the meniscus extending to the inferior articular surface (long arrow). These findings indicate a meniscal tear, confirmed on arthroscopy. A joint effusion is also seen (arrow head)

reported¹¹, as compared with 78% for the anterior drawer test and 89% for Lachman's test.

Injuries of the patellar tendon are common, particularly in jumpers. Incomplete tendon rupture can be seen on MRI as irregular thinning, localized thickening and hyperintense areas within the tendon¹². Disruption of the continuity of the tendon indicates complete rupture (*Figure 4*). MRI is indicated in osteochondritis dissecans since it is particularly useful in defining the origin of the bone fragment and is able to demonstrate if the fragment remains attached to the underlying bone or cartilage¹³. MRI is also able to demonstrate whether the bone under the area of cartilage damage is viable or not.

Although MRI shows cortical bone as a signal void, it is exquisitely sensitive to abnormalities seen in the bone marrow. This makes MRI an effective modality for demonstrating occult fractures, stress fractures and bone contusions¹⁴. Minimally displaced impacted fractures may have no radiographic findings, yet be the cause of significant symptoms. Bone contusions, or bone 'bruises' are seen at the sites of a direct blow, often in the subchondral region of an epiphysis and are thought to represent microscopic compression fractures of trabecular bone. The presence or absence of a so called bone 'bruise', is now considered an extremely useful prognostic sign, with respect to the degree of severity of the internal derangement of the joint. It follows that MRI is now the most sensitive and specific technique for the

Figure 3. Meniscal cyst. a Sagittal T1 image – the cyst can be seen as a well circumscribed area of intermediate intensity adjacent to the posterior horn of the lateral meniscus (arrow). b Sagittal T2* image – the cyst demonstrates high signal intensity due to its fluid filled nature (arrow)

Figure 4. Sagittal GE T2* image. Acute rupture of the patellar tendon with oedema and haemorrhage shown as high signal area (straight arrow). A normal ACL is also seen (small arrows)

Figure 5. Coronal *T1* weighted image demonstrating bilateral avascular necrosis (AVN) of the femoral heads in a young weightlifter known to have used anabolic steroids. The right femoral head shows a characteristic 'geographic map' (arrow) indicating early AVN. The left femoral head shows a more advanced lesion with flattening and extensive marrow signal loss (arrow head)

diagnosis of avascular necrosis¹⁵. Numerous studies have shown that the earlier diagnosis of osteonecrosis of the femoral head is possible using MRI (Figure 5). This diagnosis is made more important in the sports world due to the acknowledged risks of steroid abuse.

The ankle rivals the knee as the most frequently injured joint in athletics. The anatomy of the ankle joint is well demonstrated by multiplanar MRI¹⁶. The majority of ankle injuries involve the soft tissues, particularly the lateral ligament complex. Injuries of the ankle tendons are relatively uncommon compared with ligament injuries. The Achilles tendon is an exception, being a common site of injury in older

athletes. Achilles tendon injuries account for 20% of all running injuries¹⁷.

In complete rupture there is discontinuity of the tendon with high signal material visible on *T2* weighted images, occupying the gap. MRI before an operation can provide information concerning the degree of shredding, the orientation of the torn fibres and the width of the gap that is useful to the surgeon¹⁸.

Partial tears can be seen on MRI as localized thinning or thickening of the tendon, with or without high signal areas on *T2* weighted images. The continuity of the tendon is preserved. Tendinitis of the Achilles tendon is seen in a wide range of athletes. Chronic tendinitis may cause substantial thickening of the tendon (Figure 6), with or without abnormal intratendinous signal intensity. The distinction from a partial tear is sometimes difficult, although the history is often helpful.

Certain types of sport trauma can occur anywhere in the body. Exertion related muscle pain is a frequent occurrence although its severity and significance may be difficult to assess clinically. MRI is highly sensitive to muscle oedema and haemorrhage and, therefore, is useful in evaluating myalgia, strains, contusions, delayed onset muscle soreness, chronic muscle-overuse-syndromes and contracture. Associated injuries to the adjacent tendons, fascia and bones may also be detected and their presence alter injury management¹⁹.

The STIR sequence is particularly sensitive to muscle pathology and often demonstrates possible tears undetectable by other sequences (Figure 7). MRI visualizes the sequelae of muscle injuries, such as fibrosis, myositis ossificans, fatty infiltration and compartment syndrome. MRI thus complements the clinical evaluation of muscle injuries. In addition, its safety allows serial monitoring of exertional muscle injuries and may provide insight into possible relationships among acute and chronic injuries.

Figure 6. Axial *T1* image of both ankles in a weekend jogger. The left Achilles tendon (small arrows) is slightly crescentic with rounded sides and a flattened anterior aspect. The abnormal right Achilles tendon (large arrow) is grossly widened consistent with chronic tendinitis

Figure 7. Coronal STIR image of a footballer with left thigh pain following a match. There is diffuse high signal in the rectus femoris muscle reflecting an acute strain

Spine

Injuries to the spine and spinal cord are a cause of serious morbidity in diving, gymnastics and motor sports in particular. The incidence of quadriplegia in trampolining was sufficiently high that the event was removed from national and international competitive gymnastics.

Radiographic evaluation of spinal trauma remains an important initial investigation. MRI will show associated bone marrow oedema in fracture evaluation and also document the degree of spinal cord compression and haemorrhage.

In the assessment of lumbar radiculopathy, MRI has an accuracy of 90% which is equal or superior to CT scanning after intrathecal contrast²⁰. A specific advantage of MRI is its ability to show the whole lumbar spine and thoracolumbar junction including the conus medullaris, thereby ensuring that unsuspected proximal lesions are not overlooked, unlike axial computed tomography. MRI is usually recommended in preference to computed tomography in the evaluation of spinal stenosis, thoracic disc disease and cervical disc disease and stenosis. Further advantages are offered by MRI in the assessment of various types of disc disease. In the degenerative disc there is an overall reduction in hydration of the annulus and nucleus pulposus to about 70%. As the magnetic resonance image is highly sensitive to the degree of hydration of different tissues, the degenerate disc can be seen in the absence of morphological abnormalities (Figure 8).

Summary

MRI is a relatively new and advanced imaging modality. Its role in studying the musculoskeletal

Figure 8. T2 weighted sagittal image of the lumbar spine in a patient with low-back pain. The CSF exhibits high signal with a so called 'myelographic' effect. The normal intervertebral discs also exhibit high signal indicating normal hydration. There is marked reduction in signal intensity in the L4/5 intervertebral disc reflecting a loss of hydration and indicating degenerative change. Significant posterior disc protrusion is also present at L4/5

system has grown rapidly in the past 5 years. Due to its ability to display the soft tissue components of the musculoskeletal system with a high level of contrast and specificity MRI has emerged as a preeminent tool in the evaluation of sports injuries. Not only accurate in assessing muscles, tendons, ligaments and cartilage, MRI plays a key role in evaluating bone trauma because of its sensitivity to trauma related marrow oedema. The use of MRI in sports medicine will continue to grow with advances in, and increased availability of, scanners in the UK.

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