MAGNETIC RESONANCE IMAGING OF THE MUSCULO-SKELETAL SYSTEM

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INTRODUCTION

The harnessing of the nuclear magnetic resonance phenomenon (NMR) to investigate intact biological systems was initiated by Damadian (1971), and Lauterbur (1973). An NMR system measures the characteristic absorption and re-emission of quanta of energy by nuclei in the atoms of the body tissues. To obtain a magnetic resonance image, (MRI), the nuclei concerned must be abundant and behave suitably in a magnetic field. To date the hydrogen atom has been successfully chosen to produce high quality images as it is found in all tissues and its single proton nucleus interacts strongly with applied magnetic fields. The NMR signal is obtained after the nuclei being studied have been excited by radio frequency magnetic fields generated by transmitter coils wrapped around the patient or region of interest (surface coil). The detected signal is then spatially localised to provide an image on a grey scale basis. Following the absorption of radio frequency energy, the interactions of the nuclei on return to an equilibrium state involve two simultaneous relaxation processes called "spin spin" relaxation and "spin lattice" relaxation. The time constants

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characterising these two processes are T2 and T1 respectively.

IMAGE CONTRAST

MRI imaging is therefore a process of mapping in space the density distributions and the relaxation times of hydrogen nuclei in the body. Image contrast and the differentiation of structures depends on detecting differences in the hydrogen concentrations or differences in T1 or T2. Ten per cent of the body mass is composed of hydrogen and about 2/3 is contained in water molecules. About 1/4 of body hydrogen is contained in fats whilst about less than 1/2 of this is in proteins. Most of the proton signal comes from water and most of MRI imaging is concerned with the properties of aqueous solutions in the body, (see Table A). The relaxation times of nuclei in structures as different as lipids, proteins and water molecules are different. The differences in T1 relaxation times between soft tissues of different composition allows the major anatomical distinctions to be made. T2 relaxation times vary from tissue to tissue and T2 weighted images do not portray the same contrast as T1 or proton density images.

Pathological conditions alter the relaxation times and tissue characteristics, making it possible to identify and describe the presence and extent of diseased states.

CONTRAST MEDIA

The contents of fat and water account for much of the normal variation of NMR properties and the MRI image. Intravenously administered contrast agents with para-magnetic properties provide further differentiation in tissue characterisation as the relaxation times are drastically altered.

APPLICATIONS OF MUSCULO-SKELETAL MR IMAGING

Five applications account for most musculo-skeletal MR examinations;

(A) the non-invasive imaging of the spine and disc disease
(B) the early detection of osteonecrosis
(C) the evaluation of musculo-skeletal tumours
(D) the assessment of focal and diffuse marrow replacing processes
(E) the depiction of articular and peri-articular structures

Although there are other sporadic applications, it is appropriate to focus on these categories because of their increasing importance in Orthopaedic diagnostic imaging. The musculo-skeletal system has become the most important non-neurologic application of MR imaging.

SPINE AND DISC DISEASE

Computerised Axial Tomography (CT) of the lumbar spine is the preferred method of investigating intervertebral disc prolapse and as in other specialised institutions, it has replaced radi-radiculography as the investigation of choice at Oswestry. MRI's superior soft tissue resolution and the ability to directly image larger regions of the spine in the sagittal and coronal images,

Figure 1: Sagittal T1 (Left) and T2 (Right) weighted Images of the Lumbar Spine. Normal hydrated nucleus pulposus of all discs except L5/S1 degenerate level with a small prolapse (Arrow).

Figure 2: T1 sagittal Lumbar Spine Images. Large L5/S1 Disc Extrusion displacing Epidural fat (Arrow).

allows significant advantages over CT. Degenerative disc disease is heralded on MRI by decrease in the water content of the nucleus with a consequent reduction in signal, best seen on the T2 weighted image, (figure 1). Nuclear herniations are well demonstrated, their exact impact on the nerve roots assessed, and the differentiation between protrusion, extrusion and sequestration made by MRI (figure 2). As with CT, MRI will pick out the lateral disc herniations which are missed by radiculography. MRI has the potential of becoming the method of choice for investigating cervical disc disease, (figure 3). Myelography with or without CT, outlines the spinal cord as a silhouette. MRI delineates the cord characteristics and intrinsic biochemical status non-invasively as a separate structure clearly identified from the surrounding CSF, best seen on T1 weighted images. MRI is indeed the gold standard for imaging the spinal cord to define the presence of cord compression, medullary and extramedullary tumours, and the presence and extent of syringomyelia. Axial and sub-axial instability is a common feature of cervical spine involvement in rheumatoid arthritis. Vertical subluxation of the odontoid peg through thefora menmagnum, cord compression, and soft tissue neural encroachment by pannus disease is evident on MRI. In spinal injury compression by fracture fragments on the cord is easily assessed and trauma to the cord highlighted by altered signal, is also evident (figure 3). Intra-spinal tumours are well assessed by MRI. The subarticular and foraminal forms of spinal stenosis can be assessed quite easily by magnetic resonance imaging by virtue of the loss of epidural and peri-neural fat on the T1 weighted images. The evaluation of the post-operative lumbar spine is difficult both clinically and radiologically. MRI provides valuable information regarding disc recurrence, new disc protrusions, epidural fibrosis, and bony over-growth causing nerve root compression. Furthermore, with the advent of para-magnetic contrast material, (GD-DTPA), it also differentiates recurrent disc from post-operative epidural fibrosis.

OSTEONECROSIS

Osteonecrosis of the femoral head is a major medical problem which frequently leads to severe hip joint deformity and dysfunction. An early diagnosis is extremely desirable so as to institute both conservative and surgical measure to allow healing, prevent fracture, collapse, and destruction of the joint as well as plan surgical intervention. The sensitivity of MRI for osteonecrosis of the femoral head is substantially higher than that of scintigraphy or CT and similar findings have been shown for osteonecrosis elsewhere in the skeleton. The basic MR image on a T1 weighted sequence of simple avascular necrosis is a relatively well defined region of decreased signal intensity (black) within the (bright) medullary bone. (Figure 4) It is fair to say, however, that it takes about 8 weeks for this reactive zone to develop but this may still be at a stage where symptoms are absent. It should prove very helpful in screening patients at risk. An unexplained hot spot in the peripheral skeleton on a scintigram in an established case of a primary visceral malignancy may represent a medullary infarct, rather than a metastatic lesion. MRI allows such a differentiation to be made. In an established case of osteonecrosis, a

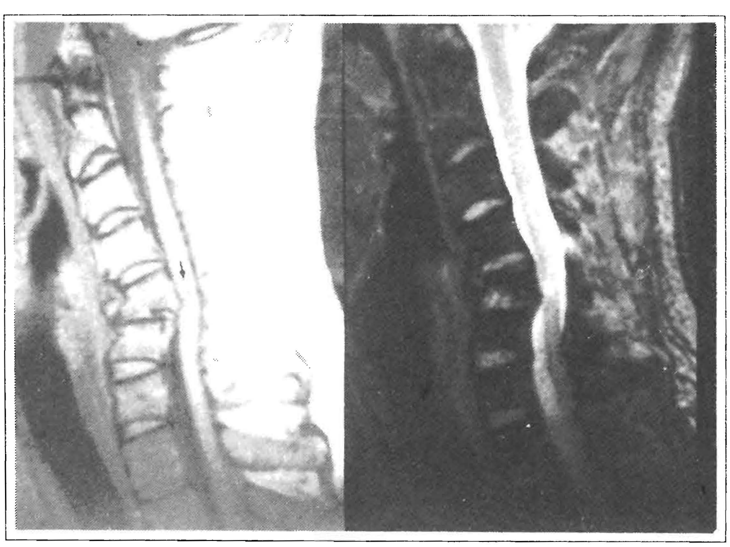

Figure 3: Burst Fracture of C5 Vertebra with chronic spinal cord injury. Intra-medullary low signal area on T1 (Arrow) and corresponding high signal on T2 typical of cystic change.

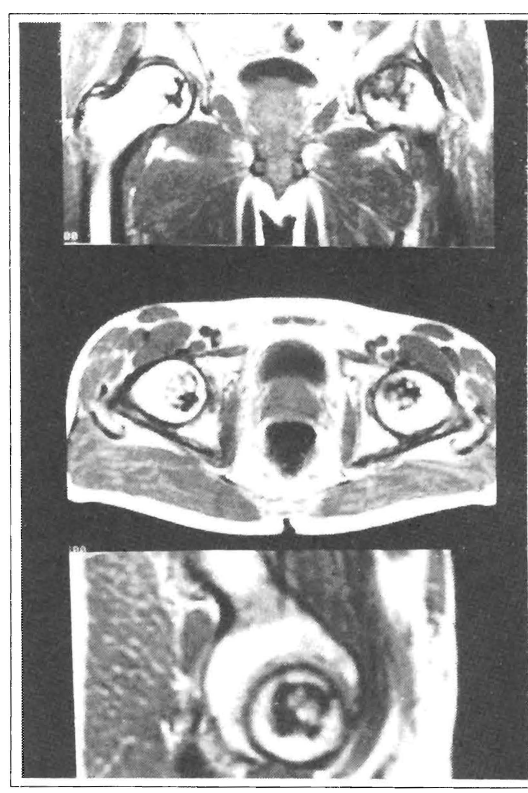

Figure 4: Alcohol Induced Avascular Necrosis of the Femoral Heads. (From Top) Coronal, Axial and Sagittal T1 Images.

trans-trochanteric rotational osteotomy to rotate an unaffected portion of the femoral head to the weight bearing position can be performed. MRI provides the basic information as to the feasibility of this procedure prior to collapse and surgical intervention by defining the extent of necrosis in the sagittal, axial, and coronal planes.

MUSCULO-SKELETAL TUMOURS

With the advent of endo-prosthetic replacement and sophisticated oncological advances, pre-operative evaluation of musculo- skeletal tumours is increasing in importance. Tumour management has changed substantially in the past decade with surgical emphasis shifting from radical amputation to limb salvage and regional resection techniques. MRI has three tasks - detection, staging, and characterisation. It also plays a significant role in the follow-up period in the evaluation of possible local recurrences.

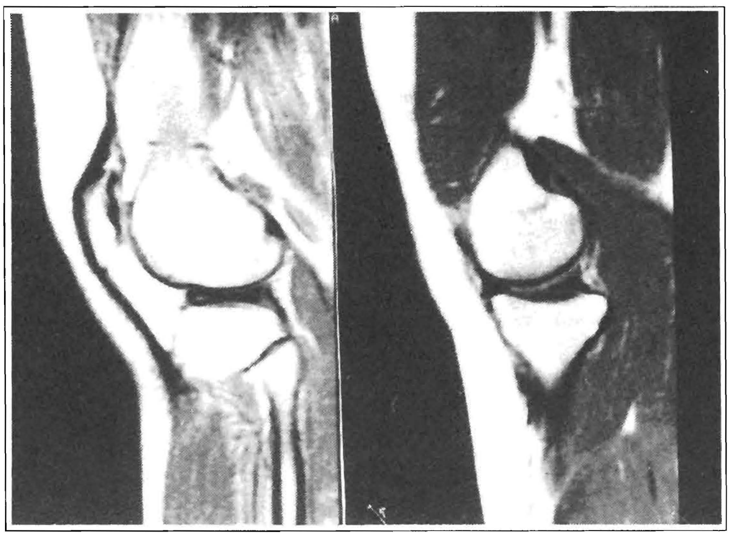

Figure 5: Parasagittal T1 Images through Lateral Meniscus (Left) and normal Medial Meniscus (Right). Intra-meniscal tear of the anterior horn of the Lateral Meniscus.

% WATER CONTENT OF ADULT HUMAN TISSUES

C.N.S. - Grey Matter	84.3
- White Matter	70.6
Cortical Bone	12.2
Skeletal Muscle	79.2
Skin	69.4

Table A

MRI GREY SCALE WITH INCREASING BRIGHTNESS

FAT
MARROW-CANCELLOUS BONE
NUCLEUS PULPOSUS
SPINAL CORD
MUSCLE
FLUID - FILLED CAVITIES
LIGAMENTS, TENDONS
FAST FLOW BLOOD VESSELS
CORTICAL BONE
AIR

MRI provides a more reliable assessment of marrow involvement in primary bone tumours such as osteo-sarcomas and Ewing's sarcoma when compared with CT and scintigraphy. Encasement as opposed to displacement of these anatomical planes can be confirmed and joint involvement established. Most tumours have similar tissue characterisation with low T1 and high T2 signal appearances, making it difficult to provide a tissue diagnosis, Some lesions can however be quite specific on MRI, benign lesions tend to have well defined margins and relatively homogeneous internal structure as opposed to malignant ones. The limitations of MRI are important, especially as tumour matrix calcification and ossification can be undetectable and details of cortical destruction are best assessed by CT. CT is still the method of choice in staging distant spread of disease to the lungs.

MARROW REPLACEMENT DISORDERS

An intense uniform homogeneous signal is seen in normal bone marrow with MRI. Age related changes take place from the paediatric to the geriatric age group as the distribution of red and fat marrow alters in the skeleton. Marrow based disorders such as, osteomyelitis and certain anaemias, e.g., B-Thalassemia are well suited for MRI assessment. Other primarily bone marrow disorders such as Gaucher's disease and myelofibrosis can be assessed, and the extent of myeloproliferative malignancies, including lymphomas and multiple myelomas are better assessed by MRI, bearing in mind that the scintigram in multiple myeloma is more often than not, normal. Following treatment, previously active metastatic lesions on a radionuclide scintigram can return to normal despite the presence of quiescent tumour. MRI has th ecapability of detecting residual quiescent tumour in the presence of a normal scintigram.

ARTICULAR AND PERI-ARTICULAR DISORDERS

Ligaments, tendons, fibro-cartilage and hyaline cartilage can be visualised by conventional arthrography with or without CT. MRI using specially designed surface coils increases the resolution and image quality while reducing quite significantly the scanning time. The knee joint has received considerable attention because of the high prevalence of post-traumatic dysfunction, its large size, and the presence of menisci and cruciate ligaments which play an important role in chronic knee dysfunction. The fibrocartilaginous menisci can be well depicted with T1 images, (figure 5) while T2 images best delineate the articular surfaces. MRI of meniscal tears is comparable to that of arthrography and arthroscopy in the detection of significant tears. Furthermore,intrameniscal degeneration ranging from myxoid change to frank intra-substance tears are identified on MRI while remaining totally occult to arthrography and arthroscopy. Peri-articular masses that may have communications with the joint, e.g., cysts or ganglia, are also easily evaluated. Extra-articular injuries include muscle tears, tendon tears, and ligamentous injuries. With all these injuries, bleeding is common and it is worth noting that a consistent relationship between haematoma, age, and appearance does not exist. Recent tears in muscle bellies are easily seen on T2 weighted images. Acute tears, especially in major tendons need early diagnosis and prompt treatment.

CONCLUSION

MRI is likely to be one of the safest methods of extracting information from the human body. High contrast high resolution images depend on tissue relaxation times which reflect fundamental differences in tissue properties. The versatility to obtain a wide spectrum of information combined with the ability to image in any plane with no apparent hazard, makes the technique an exciting advance for radiology and confirms that this is the "Golden Age of Radiology". Newer developments in magnetic design and sophistication as well as further technological advances, with soft ware up-dates and alternative acquisition sequences will definitely increase the applications of MRI to musculo-skeletal disease. The high cost of MRI has to be seen in the context of considerable savings to patient and Institution. It is prudent to apply this imaging modality early and decisively in the problem areas and musculo-skeletal applications described above. In this way, redundant diagnostic tests are eliminated, appropriate therapy instituted early, unnecessary surgical intervention and hospitalisation avoided, and time off work reduced - all these have financial implications.

SUGGESTED FURTHER READING:

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