MAGNETIC RESONANCE IMAGING IN ORTHOPAEDIC SURGERY

A GLIMPSE INTO THE FUTURE

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Magnetic resonance images (MRI) were obtained of 10 healthy volunteers and 70 patients suffering from various orthopaedic disorders. Selected images of soft tissue, joint, bone and spinal abnormalities are presented and their interpretation is described.

Although we have been using MRI for only a very short time, it is already possible to see its advantages: it provides good images of soft-tissues, detailed pictures of bone marrow, and excellent visualisation of the spine and spinal cord. The decision-making process in surgical procedures will in the future be influenced by this technique.

The purpose of this presentation is to describe some nuclear magnetic resonance (NMR) images of orthopaedic pathology as well as typical normal anatomical appearances and thereby derive conclusions as to possible future applications of NMR imaging in the diagnosis and follow-up of orthopaedic disorders. The interpretation of various NMR modes is still at an early stage and we do not claim final authority for our assessments of the anatomical and pathological meaning of the images described. Rather, we wish to indicate future prospects in the use of this remarkable, harmless, non-invasive repeatable method, capable of portraying an image in any plane.

MATERIAL AND METHODS

Ten normal, healthy volunteers and 70 patients with various orthopaedic problems underwent magnetic resonance imaging (MRI) examinations at the Elscint MRI Centre, Herzlia, Israel. Written informed consent was obtained from all patients. Fifty-six of the patients had a confirmed diagnosis on the basis of clinical, radiological, and pathological studies.

The principles underlying the technique of NMR

imaging have been described by Andrew (1983), and Crooks *et al.* (1984). The Elscint S-5000 magnetic resonance imager has a cryogenic super-conducting magnet operating at 0.5 tesla. Various radiofrequency pulse sequences were performed initially: these included saturation recovery, inversion recovery and spin-echo

Table I. First spin-echo grey scale, using a long T_R sequence (1200–2000 ms)

HIGHEST INTENSITY SIGNAL
(whitest)

LOWEST INTENSITY SIGNAL
(blackest)

Fat
Marrow
Fluid (static)
Muscle
Ligaments, tendons and fluid flow
Cortical bone
Gases

sequences. It appeared, however, that the best results for most orthopaedic problems were obtained by applying spin-echo sequences with echo delay times (T_E parameter) of 28 and 56 ms after application of the 90° pulse. Radiofrequency pulse sequence intervals (T_R parameter) were varied between 450 and 2000 ms. Each of the patients underwent a total of four series of examinations: short and long T_R series, in the axial plane and in the coronal or sagittal plane; the slice thickness was 5 or 7 mm. The images can best be described by using a grey scale (Table I) which changes with the different techniques.

The studies of the spine or pelvis were obtained using a body coil with an aperture size of 60 cm. The upper cervical spine and legs were studied using a head coil with an aperture of 30 cm.

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Fig. 1

Fig. 2

Fig. 3

Figure 1—Sagittal spin-echo image of a normal knee ($T_R = 1200$ ms; $T_i = 28$ ms). Figure 2—Sagittal spin-echo image of lower limb, revealing a soft-tissue mass in the thigh ($T_R = 461$ ms; $T_i = 28$ ms). Figure 3—Osteogenic sarcoma of the femur ($T_R = 1850$ ms; $T_i = 28$ ms).

RESULTS

The following have been chosen as demonstration cases of the imaging to be expected from the MRI method in orthopaedics.

Limbs

Case 1: *The normal anatomy of the knee in the sagittal plane* (Fig. 1). The brightest, whitest appearance is that of the fatty tissues—the subcutaneous fat, the infrapatellar fat pad, the fat pad in the floor of the suprapatellar pouch, and the fat of the popliteal fossa. The darkest, blackest appearance is that of the compact cortical bone. Still very light but definitely less so than fat is the bone marrow. The thin grey line of the growth plate separates the marrow of the epiphysis and the metaphysis. The articular cartilage covering the cortical bone of the condyle is seen as a line similar in brightness to the marrow. The dense fibrous tissue such as the patellar tendon and suprapatellar aponeurosis are close to cortical bone on the “grey scale”. The dark streak in the popliteal fossa is a blood vessel which appears rather black-grey because of the blood flow within. The muscles are varying shades of grey and the light grey streak traversing the fossa is the sciatic nerve.

Case 2: *A malignant neurilemmoma* (Fig. 2). An oval mass in the proximal apex of the popliteal fossa is clearly connected proximally and distally with the sciatic nerve. The border of this malignant neurilemmoma is very clearly defined (arrow) and the darker outline suggests that a pseudocapsule may be present. Clearly there is no infiltration of the surrounding tissue.

Case 3: *Osteogenic sarcoma of the femur* (Fig. 3). The normal uniform pattern of the marrow is grossly disturbed by a diffuse area of stippled, darker, reduced reso-

nance and proximal and distal black “holes”, suggesting osteogenesis inside the marrow cavity. The cortex is breached posteriorly and light and dark lines running parallel to the cortex of the shaft suggest a periosteal reaction. The marrow pattern towards the midshaft area is undisturbed.

Case 4: *Fibrous dysplasia of bone* (Fig. 4). The normal marrow signal is disturbed by an oval area of darkness in the subtrochanteric area whose sharp border contrasts vividly with the surrounding undisturbed marrow brightness (arrow). The black cortex is intact.

Fig. 4

Fibrous dysplasia of the upper femur ($T_R = 500$ ms; $T_i = 28$ ms).

Fig. 5a

Fig. 5b

Fibrohistiocytic sarcoma of the thigh: (a) coronal view; (b) axial section ($T_R = 2000$ ms; $T_E = 28$ ms).

Case 5: Malignant fibrous histiocytoma of the thigh (Figs 5a and 5b). In Figure 5a (the coronal plane) the massive tumour is vividly visualised as two grey masses; the proximal extension is limited by the black line of the inguinal ligament. Much of the tumour is outlined sharply by a black line of reduced resonance, suggesting a fibrous pseudocapsule. The horizontal plane view (Fig. 5b) shows the mass lying immediately under the subcutaneous fat but definitely not attached to the black cortex of the femur, some muscle layer (grey) intervening.

Case 6: Osteoarthritis and osteonecrosis of the knee (Fig. 6). The smooth fluffy appearance of the marrow of the upper tibia is disturbed (arrow) by darker spots close to the subchondral bone. An island of whiteness within a

Fig. 6

Osteonecrosis and osteoarthritis: coronal section of the left knee ($T_R = 2000$ ms; $T_E = 28$ ms).

dark deficiency at the articular surface of the medial femoral condyle indicates an area of osteonecrosis. Extensions of marrow into spiky osteophytes are seen at the medial and lateral tibial articular margins.

Case 7: Infection of bone (Figs 7a and 7b). A horizontal slice at the level of the lower end of the femoral shaft shows the more intense whiteness in the marrow cavity of the right femur, indicating an inflammatory exudate which is also visible diffusely in and amongst the soft tissues of the thigh (Fig. 7a). A similar appearance is seen in Figure 7b, a horizontal view of the upper third of the leg. In addition to the intense whiteness of the infected bone marrow, two black areas are observed: these views were taken two months after the removal of an infected total knee prosthesis. The white areas in the marrow cavity represent the infected spaces where the prosthesis had lain, and the black areas are retained pieces of cement. The limb was in plaster at the time of the examination (the plaster is simply not visualised at all and causes no difficulty with MRI).

Fig. 7a

Fig. 7b

Osteomyelitis of (a) the right lower femur and (b) the right upper tibia ($T_R = 1800$ ms; $T_E = 28$ ms).

Fig. 8

Soft-tissue inflammation in the mid-thigh ($T_R = 2000$ ms; $T_E = 28$ ms).

Case 8: Infection of soft tissues (Fig. 8). This is an example of soft-tissue inflammation of the medial side of the mid-thigh. The whole area of grey normal muscle compartments clearly visualised in the left thigh contrasts with the almost structureless white mass in the right inflamed thigh.

Spine

Case 9: Fracture of C5 (Figs 9a and 9b). This sagittal section shows the remarkable picture of the spinal cord which can be obtained without any contrast medium (Fig. 9a). The dark area around the cord represents the

Fig. 9a

Fig. 9b

Sagittal section of the cervical spine showing fracture of the C5 vertebra: (a) low magnification; (b) high magnification ($T_R = 1500$ ms; $T_E = 28$ ms).

Fig. 10

Spondylosis of cervical spine ($T_R = 1000$ ms; $T_E = 28$ ms).

Fig. 11

Herniation of lumbar disc: sagittal view ($T_R = 1500$ ms; $T_E = 28$ ms).

cord membranes, the cerebrospinal fluid, and the cortical bone of the vertebral canal. A compression fracture of the body of the fifth cervical vertebra is seen as dark irregular patches disturbing the regular pattern of the marrow. The enlargement (Fig. 9b) of the fracture area shows that there is no encroachment on the cord. The nucleus pulposus shows as a distinct bright centre within the darkness of the annulus and the cortical end-plates of the vertebral bodies. This light spindle-shaped image is almost absent in the disc below the fracture, indicating that the anatomy of the disc is disturbed. As would be expected, the retropharyngeal space is widened at and below the fracture site.

Case 10: Cervical spondylosis (Fig. 10). The disc spaces are narrowed. The bright image of the nucleus pulposus has been lost. Once again the spinal cord is clearly visualised, but the space around it is much narrower than normal. Dense fibrous tissue bulges are observed in front of and behind the narrowed discs between C4/5/6/7, indenting the spinal cord (arrow).

DISCUSSION

The use of nuclear magnetic resonance scanning in medicine was reported by Zeitler and Schittenhelm in 1981. Its capability in anatomical imaging had been demonstrated by Hinshaw *et al.* (1978). Since then some preliminary reports of its capabilities and limitations in the diagnosis of spinal disorders (Han *et al.* 1983; Chafetz *et al.* 1983; Modic *et al.* 1983), bone marrow disease (Cohen *et al.* 1984) and the musculoskeletal system in general (Moon *et al.* 1983) have appeared in the radiological literature.

The NMR scanner is capable of producing images in any plane, and repeated examinations are apparently devoid of any deleterious effect (Budinger 1981; Alfidi *et al.* 1982).

Details of bone structure cannot be visualised—only gross changes of shape—since bone itself has a very low echo density and appears an amorphous black on the images. At the time of writing, the NMR image is therefore inferior to the CT scan and plain radiographs in giv-

Fig. 12

Herniation of lumbar disc: axial view ($T_R = 1500$ ms; $T_F = 28$ ms).

Case 11: Herniation of the lumbosacral disc (Fig. 11). A sagittal section of the lumbosacral spine shows that the bright image of the healthy nucleus is absent. The disc appears grey and is outlined by the thin black lines of the cortical plates of the vertebral bodies. The white line bordering the vertebral discs and bodies posteriorly is the extradural fat. The cauda equina is a lighter grey than its coverings and the cerebrospinal fluid around it, and the distinction between them is not clear-cut.

Case 12: Herniation of a lumbar disc (Fig. 12). A horizontal section through the lumbosacral disc shows the dark grey disc protrusion (arrow) encroaching on the extradural fat. The psoas muscles are seen as round dark grey discs on either side and the black iliac vessels lie medially; they are black because of the rapid flow within.

ing precise information on the normal or pathological anatomy of bone. On the other hand, the anatomical imaging of the soft tissues is superior, owing to the clear-cut contrast between the various soft-tissue structures, and the extent of a soft-tissue lesion is very clearly defined (Figs 2 and 5); in future we may also be able to draw conclusions concerning the nature of such a lesion by its resonance characteristics. The tissue in which very early changes can be specifically detected by this method is bone marrow. Disease of the marrow can be followed up (Cohen *et al.* 1984) and spread of pathology along the marrow cavity assessed (Fig. 3); this may well aid decision-making when surgery is planned.

In the realm of spinal diseases the imaging of the cord is unparalleled (Figs 9, 10, 11). The method is specific for the diagnosis of syringomyelia (Modic *et al.* 1983).

The infringement of a space-occupying lesion upon the cord is readily visualised (Figs 10 and 11).

The distinct contrast between the white nucleus pulposus and the dark annulus in the healthy disc delineates the nucleus pulposus more precisely than does any other method (Fig. 9). In the degenerate damaged disc this contrast wanes or disappears (Figs 10 and 11). MRI is also effective in revealing disc herniae (Figs 10, 11, 12), and may in future replace invasive diagnostic methods.

Since the signal intensity of fluids is related to flow,

MRI may well turn out to be a useful non-invasive auxiliary examination for the assessment of flow in blood vessels of the limbs.

MRI is still a very expensive, lengthy examination, often uncomfortably tedious and noisy for the patient (a CT scan may take only minutes, the MRI examination will take half to one hour). Even so, this safe, non-invasive radiation-free method will surely find an important place in the diagnosis and follow-up of orthopaedic disorders.

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