Magnetic Resonance Imaging
Skeletal Applications

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ABSTRACT: It has been assumed that magnetic resonance imaging (MRI) would have limited utility in visualizing bones, due to the lack of hydrogen atoms in cortical bone. Nonetheless, that same lack makes it possible to clearly distinguish cortical bone from soft tissue and from marrow. Thus, roles are described for magnetic resonance imaging in depicting bone and soft tissue tumors, the spine (including the spinal cord and vertebral discs), and appendicular soft tissue, as well as the detection of avascular necrosis in the hip.

Introduction

The clinical significance of magnetic resonance imaging (MRI; also known as nuclear magnetic resonance) is rapidly becoming apparent in dealing with organ systems such as the brain, chest, heart, genitourinary system, and abdomen. Little, however, has been published involving the musculoskeletal system. It has been assumed that the lack of hydrogen atoms in bones makes the skeletal system particularly difficult to visualize. In fact, this may be beneficial in visualizing the skeleton because the marrow, which contains a considerable number of hydrogen atoms, contrasts well with the cortical bone. For instance, any marrow disorder or any process (such as metastatic disease) that primarily affects the marrow cavity will be well visualized by MRI. Soft tissue tumors certainly contain sufficient hydrogen atoms for effective MRI study, and early investigation reveals great promise in this area.

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Fig. 1: A spin echo image of a patient with metastatic disease to the T11 vertebral body. Note the low intensity image as compared with the adjacent vertebral bodies. Note also the extension of the tumor mass posteriorly into the spinal canal with compression of the spinal cord (arrow). (Case courtesy of Dr. Michael Brant-Zawadzki.)

This report shows our preliminary use of MRI of the musculoskeletal system, and suggests ways in which it can perhaps be used in the future to better evaluate some disease processes.

All subjects in this report were examined at the University of California, San Francisco, using a Diasonics MT/S
Fig. 2: An osteochondroma of the distal femur on the right side as compared with the normal left distal femur. Note that the cortical bone and medullary cavity of the stalk of the tumor are smoothly confluent with those of the distal femur. These are indicators of a benign process. No definite soft tissue involvement is noted. Note the differentiation between the quadriceps muscle and the quadriceps tendons, which is due to the low signal intensity of the tendons. Popliteal vein and artery (arrow) have a low MRI intensity as a result of the blood flow.

Fig. 3: A recurrent liposarcoma of the distal thigh on the right side is seen on this spin echo image. The tumor and postoperative fibrosis have a low intensity signal as compared with the normal left thigh. The popliteal vessels can again be seen as a very low intensity image deep to the tumor (arrow).

Imaging System. This system consists of a 0.5 Tesla superconducting magnet operated at a field strength of 0.35 Tesla. All images are acquired using a spin-echo technique, which yields images in which the intensity of a tissue is a complex function of the $T_1$, $T_2$, and hydrogen density of that tissue.

$T_1$ and $T_2$ are intrinsic factors of proton relaxation following perturbation by a radio frequency wave. Some tissues have longer or shorter $T_1$ and $T_2$ than other tissues, and these can be highlighted by different imaging parameters. The significance of a particular tissue having a long or short $T_1$ or $T_2$ is not fully known at this time.
Bone Tumors

Magnetic resonance imaging appears to have utility in imaging both primary and metastatic bone tumors. The appearance of giant cell tumors was described in an earlier report.6

The obvious advantage of MRI over conventional radiography and perhaps even over computed tomography (CT) is in evaluating the extent of the tumor in the marrow cavity. Since fatty marrow has a high intensity by MRI, it should be a sensitive indicator for tumor infiltration.
Tumor infiltration has been detected effectively with CT by comparing CT attenuation numbers in extremities, the area with tumor infiltration having a higher number because of obliteration of the marrow fat. This should also apply when using MRI with primary or metastatic tumors. Figure 1, a case of metastatic disease, shows how obliteration of the marrow radically changes the MRI intensity in a vertebral body.

Visualization of an osteochondroma with MRI (Fig. 2) showed little improvement over conventional radiography. However, because of the excellent soft tissue discrimination with MRI, one can speculate that an osteochondroma with malignant degeneration may be better appreciated than with CT or plain films.

**Soft Tissue Tumors**

Soft tissue tumors are often difficult to visualize with conventional radiography. Computed tomography greatly improved our ability to see the extent of most soft tissue masses. Magnetic resonance imaging shows promise not only of visualizing the extent of the tumor, but also of giving information concerning its histology.

Fatty tumors can be expected to have characteristically high MRI intensity (Fig. 3), just as CT shows fatty tissue to have very low attenuation numbers. Vascular tumors such as arteriovenous malformations can be expected to show low MRI intensity because of the blood flow (Fig. 4). Without contrast enhancement given intravenously, CT is unable to denote blood flow or vascularity.

Magnetic resonance imaging should provide elegant soft tissue discrimination between tumors and normal structures. Differentiation of the $T_1$ and $T_2$ of soft tissues will determine how well those soft tissues can be visually separated.

**Axial Skeleton**

At the present time the resolution of MRI is not competitive with that of CT; however, this should be a short-lived drawback since the technology is constantly improving. The need for high resolution for spine work is somewhat
limiting; nevertheless, our initial MRI studies of the spine show promise that MRI will be useful in studying the spine.

The normal anatomy of the lumbar spine (Fig. 5) is well demonstrated because of the high intensity on MRI of the epidural fat. The ligamentous and bony cortices have extremely low intensity, and therefore stand out in contrast to the discs and marrow elements of the vertebral bodies.

In the upper lumbar spine and in the thoracic spine, the cord can be visualized because of the low-intensity signal from the surrounding cerebrospinal fluid (Fig. 6).

A possibly useful factor in spine work is that direct sagittal imaging can be performed, eliminating the need to do reconstructions with consequent distortions, as in CT.

A few abnormal lumbar discs have shown a decrease in MRI intensity as compared with the normal disc, especially in the region of the nucleus pulposus (Fig. 7). This may enable us to sample the $T_1$ or $T_2$ of an abnormal disc and compare it with a normal one to determine if nuclear degeneration has occurred.

Routine disc protrusions can be visualized either directly (Fig. 8) or by noting the obliteration or asymmetry of the epidural fat.

**Appendicular Skeleton**

We have studied several patients' hips to determine if MRI has a role in diagnosing early aseptic necrosis. Preliminary results show that a hip with aseptic necrosis will have a decreased MRI intensity as compared with a normal one (Fig. 9). In one of our cases this finding on MRI was striking, whereas the plain film findings were quite subtle (Fig. 10). This may prove to be a very sensitive method that
Fig. 9A: A plain film of the hip shows advanced avascular necrosis with subchondral sclerosis and flattening of the femoral head.

Fig. 9B: An axial spin echo image at the level of the femoral heads shows a decreased MRI signal intensity on the left side as compared with the right.

Fig. 10A: A frog leg anteroposterior pelvic radiograph shows subtle articular surface irregularity and sclerosis in the left hip as compared with the right. This is consistent with early avascular necrosis.

Fig. 10B: An axial spin echo image through the same patient's femoral heads shows subtle decreased MRI signal intensity in the left femoral head as compared with the right.

will have to be compared with radionuclide bone scanning.

The ability to differentiate between muscles and ligaments (and tendons) on MRI allows excellent anatomic delineation of joint soft tissue; such as in the knee (Fig. 11) and foot (Fig. 12). With MRI, ligaments and tendons are not as bright (less intense) as muscle and can therefore be differentiated. Computed tomographic images will not separate these tissues because their density is so similar. Although we have not been able to image the menisci of the knee, the anterior and posterior cruciates have been visualized. Since the cruciates are poorly seen by arthrography and incompletely seen with arthroscopy, this may have significant clinical implications for orthopedic surgeons.

Conclusion

Considerable work remains to be done in finding the place of MRI in skeletal radiology; however, preliminary investigation shows promise in a number of aspects that should augment or supplant conventional radiography and computed tomography.
Fig. 11: Sagittal spin echo images through the knee of a normal volunteer show nice definition of the quadriceps and patellar tendons with their characteristic low intensity. The anterior cruciate ligament is also well defined (arrow).

References


Fig. 12: An axial spin echo image through the normal feet of a volunteer shows excellent discrimination between the tendons and surrounding soft tissues. The tendons all have a very low signal intensity. The Achilles tendon (arrow) is nicely demonstrated.