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Musculoskeletal MRI In The Emergency Department: Using The Evidence To Maximize Resource Utilization

March 2009
Volume 11, Number 3

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CME Objectives

Upon completion of this article, you should be able to:
1. Cite the basic principles of MR technology, including its limitations.
2. Identify and interpret common biases in studies of diagnostic imaging.
3. Determine the risks of gadolinium including induction of nephrogenic systemic fibrosis.
4. Identify and employ the diagnostic features of MRI for high-risk musculoskeletal injuries, including suspected scaphoid fracture, hip fracture, nontraumatic spinal conditions, and deep tissue infections.

Date of original release: March 1, 2009
Date of most recent review: February 10, 2009
Termination date: March 1, 2012
Medium: Print and Online
Method of participation: Print or online answer form and evaluation
Prior to beginning this activity, see "Physician CME Information" on the back page.

It's 2 am on a busy Saturday night. An 85-year-old female with a history of thoracic spine laminectomy 10 days prior presents with increasing back pain. She has no neurological complaints and has no noted fever, but her triage temperature is 38.5°C (101.3°F). Her neurological examination is normal and her wound is not markedly erythematous. Her white blood cell count is 21,000 with an elevated sedimentation rate. You are concerned about possible epidural abscess or vertebral osteomyelitis. Your neurosurgeon asks you to withhold antibiotics until a definitive diagnosis is made. You order a thoracic spine MRI; however, the radiologist does not want to mobilize the needed resources in the absence of a neurological deficit; he tries to reassure you that the study will be prioritized first thing in the morning. You consider your options, wanting to provide the best care possible for your patient. You love a fight but wonder if a CT would be acceptable or if the MRI is an essential test. You also wonder if a few hours will really make a difference.

In Room 2, the nurse puts a 70-year-old female brought by EMS after a fall at home. The patient lives alone and walks with a cane. She states that she tripped on a rug and fell on her left hip. She has pain with left hip range of motion but does not have the external rotation or foreshortening of the limb that is classic for femoral neck fracture. Her x-rays are non-diagnostic, showing degenerative joint disease in the hip and osteoporosis. The patient wants to go home but continues to have pain with weight-bearing. You wonder whether the x-rays have missed a non-displaced fracture. If the patient returns to weight-

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bearing, will a complete femoral neck fracture result? Orthopedics recommends an MRI, which is not readily available overnight. You ponder the choices: perform alternative imaging such as CT and admit the patient for further workup or hold the patient until morning in the ED.

In Room 3, the nurse tells you that there is a 30-year-old male who fell onto his outstretched hand. You review his plain films which do not demonstrate a fracture. However, he is showing tenderness with direct palpation of his anatomic snuffbox and with axial loading of the thumb. You explain to the patient the possibility of an occult scaphoid fracture and tell him that he will need to be immobilized in a thumb spica splint for 1 to 2 weeks, with orthopedic follow-up. The patient looks crestfallen as he explains that he is a violinist in a quartet leaving for a tour of China the next morning. Without him, the tour will be cancelled, at a cost of thousands of dollars. He asks if there is a way to definitively evaluate his injury. You wonder whether immediate MRI or CT might be of value.

Musculoskeletal magnetic resonance imaging (MRI) can be a valuable tool for the diagnosis of a variety of conditions and holds the potential to avoid diagnostic delay that may result in serious morbidity. Unfortunately, MRI remains expensive and is not routinely available at all hours in all emergency departments (ED). In cases where MRI may be diagnostic, the clinician is often confronted with the decision to transfer the patient to another facility or hold the patient pending MRI availability. Even in tertiary care centers, MRI may not be available after normal business hours, except in the direst of emergencies.

In this issue of *Emergency Medicine Practice*, an overview of the technical features of MRI will be presented in order to provide a framework for understanding its limits and potential benefits. Frequently asked questions will be addressed, including the role of contrast in MRI, contraindications to contrast, and contraindications to MRI. Some of the common methodological flaws that limit the internal and external validity of specific studies will be reviewed. A focused discussion will be provided on the diagnostic accuracy of MRI for spinal epidural abscess, occult hip fractures, and occult fractures of the wrist. In this age of ED and hospital overcrowding, the author hopes that this review will stimulate a critical analysis of the use of technologies and assist clinical decision-making regarding appropriate use and timing of imaging in order to maximize operational efficiency and good patient outcomes.

Critical Appraisal Of The Literature

Evidence of the diagnostic sensitivity and specificity of MRI for emergency musculoskeletal conditions is limited, and even less evidence exists for the effect of emergency MRI on clinical outcomes. Rigorous methodology would require that MRI be prospectively compared with a high quality gold standard, but few studies achieve this. A few artifacts common on MRI should lead us to question whether all MRI abnormalities represent real pathology. According to a meta-analysis of 19 studies, in one soft tissue application of MRI (screening for breast cancer with magnetic resonance [MR] mammography), MRI is known to have excellent sensitivity but poor specificity – with 1 false positive test for every 2 true positives.[1] It should not be assumed that a positive MRI in other settings automatically indicates the presence of disease. In the case of lumbar spine pathology, studies have shown a 25% rate of abnormal MRI in asymptomatic subjects.[2] In asymptomatic patients undergoing wrist MRI, signal intensity in ligaments may be elevated, simulating pathology.[3-5]

Several limitations and sources of bias occur in studies evaluating diagnostic tests. [6] **(See Table 1.)** Selection bias creates a non-representative sample of study participants. Examples include studies of the frequency of "occult" fractures in a population of patients with a potential injury. If all patients with negative x-rays undergo further definitive imaging, an accurate population-based estimate of occult injury can be derived. If only patients with a high clinical suspicion of injury undergo definitive imaging, an inaccurately high estimate of occult injuries will likely occur, as the population tested will be "enriched" with patients with injuries due to selection bias. Even if all patients with negative x-rays are referred for definitive imaging, selection bias may occur due to losses to follow-up. For example, if some patients have resolution of pain and choose not to follow-up for imaging while patients with continued pain do follow-up, self-selection leads to a biased sample, likely with an overestimate of injury prevalence.

Biases associated with application of a gold standard are also a common problem in studies of diagnostic imaging. In order to assess the accuracy of a diagnostic test appropriately, a gold standard that reliably identifies the presence or absence of disease must be available. A limitation, though not necessarily a bias, in studies of diagnostic modalities is the availability of a diagnostic "gold" or reference standard. In some cases, it is unclear what the best gold standard should be, especially for diseases that rely on diagnostic imaging for diagnosis, where no confirmation is possible by laboratory, microbiological, pathological, or surgical means. An example is the case of a non-displaced fracture, where an imaging modality may be the best available diagnostic reference standard. When a new modality is being tested against this standard, it is unclear how to treat discrepancies between the results of the new modality and the reference standard. If the new test is (in truth) better than the reference standard, it may detect disease not detected by the reference test, or it may yield a negative result in cases where the reference test appears positive. If the reference standard is considered the final arbiter of the true diagnosis, these discrepant results must be treated as false positive and negative results in favor of the reference standard. Research authors often fall prey to the temptation to disregard the reference standard in these instances and to assume that results of the new test are correct. This use of the new test under consideration as its own gold standard is called incorporation bias, and it results in overestimation of test sensitivity and specificity. In effect, it guarantees the appearance of 100% sensitivity and specificity, since the test under consideration may never be considered to be wrong. Studies of MRI often suffer from this bias, since no confirmatory test is the obvious gold standard for many musculoskeletal MRI diagnoses.

A more subtle form of incorporation bias occurs in studies where the final clinical diagnosis is used as the gold standard. While this may appear to be the most reasonable independent reference standard, especially when 2 imaging tests are being considered, this ignores the fact that the final diagnosis is often heavily influenced by the results of imaging when clinicians are not blinded to the results of imaging tests. For example, if the results of computed tomography (CT) and MRI are compared with the final "clinical" diagnosis made by an orthopedist, MRI may more consistently match the clinical diagnosis if the orthopedist knows the results of both imaging tests but trusts MRI – rightly or wrongly – to make the diagnosis.

Verification bias occurs when not all subjects receive definitive confirmation of the diagnosis using the same gold standard. A specific type of verification bias, called workup bias, occurs when the results of a test are accepted in some patients but not in others, usually based on the initial test. An example would be patients undergoing gold standard testing (eg, biopsy or surgery) when the diagnostic test is positive but not when the test is negative. In effect, the negative test results are assumed to be correct, while positive test results are examined against the gold standard. In these cases, the reported sensitivity of the test may be inaccurate, since negative cases may in fact be false negatives. Moreover, specificity should not be reported given the absence of a confirmed negative control group.

An additional limitation of MRI studies is that every manufacturer uses different descriptors for the features that can be manipulated on their machines.[7] This may mean that a positive research study result may be difficult to duplicate using a different manufacturer's machine. In addition, MRI allows a wide selection of pulse sequences and imaging planes, and the positive results of a research study may not be reproduced unless the same pulse sequences and imaging planes are used. Moreover, a research study with a negative result may simply have failed to use the best sequence or imaging planes to demonstrate the pathology. Some of these subtleties may be difficult for non-radiologists to assess.

Emergency Department Utilization Of MRI

MRI availability and utilization from the emergency department is increasing. A retrospective review of ED utilization at a single academic tertiary care center from 2000 to 2005 found a 390% increase – mostly

Table 1. Biases And Limitations In Studies Evaluating Diagnostic Tests

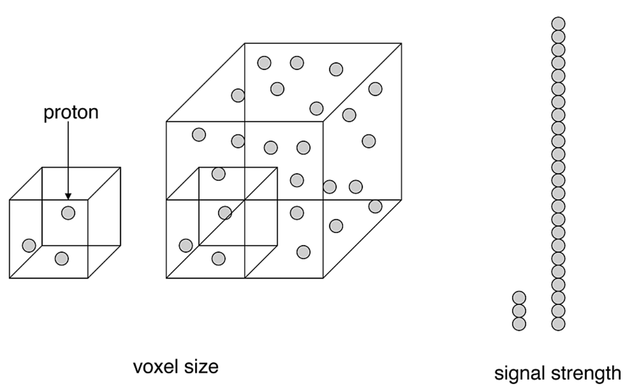
Limitations/Bias	Description/Example	Result
Selection bias	A non-consecutive sample of patients undergoes testing.	The non-representative sample makes the extrapolation of results to other populations unreliable.
Lack of gold standard (see verification bias)	No gold standard is available for the condition under consideration.	Results and conclusions of the study cannot be rigorously evaluated for validity
Incorporation bias	The test under evaluation is used as the gold standard, or the final diagnosis relies in part on this test result.	Results of study are biased in favor of the apparent accuracy of the diagnostic test.
Verification bias/workup bias	Not all subjects receive consistent confirmatory testing against a gold standard.	If negative tests are not confirmed against a gold standard, false negative tests will not be recognized. If positive tests are not confirmed against a gold standard, false positive tests will not be recognized. This may result in incorrect sensitivity and specificity calculations.
Lack of blinding	Results of other testing or patient characteristics are available to the researchers, potentially affecting their interpretation of the diagnostic test under consideration.	Results are biased by the physicians' or researchers' preconceptions about the accuracy of the diagnostic test.
Manufacturer-specific variations in MRI protocols and sequences	Manufacturers may differ in the technical features of the equipment, which can be manipulated to obtain images.	Results cannot be readily reproduced outside of the research environment or using different equipment.

due to MRI and MRA examinations of the head. Spinal MRI constituted 29% of total examinations, while lower extremity MRI was performed only 23 times during the study period, constituting 1% of total examinations.[8] Whether this increase in ED utilization results in better patient outcomes is unclear. A study from the Mayo Clinic found that 11% of patients with negative x-rays of the hip underwent hip MRI as part of their ED evaluation.[9] No data exists on the rate of ED musculoskeletal MRI use nationally. A recent practice survey of radiologists in the United States suggested that MRI scanners are physically present in only 3% of EDs.[10]

Basic Principles Of MRI

Understanding that MRI is not simply a "radiation-free CT" is important in recognizing why some pathological processes may be better imaged with MRI. MRI uses complex computer algorithms to generate images based on the radio signal generated by protons (hydrogen ions) when they are manipulated by an applied magnetic field. **(See Figure 1.)** Unlike CT and x-ray, MRI does not use ionizing radiation. Like CT, MRI allows multiplanar two-dimensional (2D) images and three-dimensional (3D) images to be constructed from 2D acquired slices. Gradient echo MRI pulse sequences allow acquisition of a true 3D volume of data that can be reconstructed in any plane. **(See Figure 2b.)** In contrast, modern multislice CT relies on the addition of many fine axial slices to construct a 3D data volume that can then be reconstructed in any plane or displayed in three dimensions. **(See Figure 2a.)** Consequently, some MRI sequences are not subject to reconstruction artifacts that may occur when CT reconstructions are created.[11]

Figure 1. MRI Process



In MRI, the signal strength from each voxel is proportional to the number of protons resonating within the tissue volume. Increasing the volume of each voxel reduces resolution but increases signal strength. Doubling the side length of the voxel increases the number of protons (signal strength) by 2^3 or 8-fold. (Image is courtesy of Joshua Broder, MD.)

CT can overcome this effect by using thin and overlapping slices but at the expense of significant radiation exposure for the patient. Nonetheless, thin-slice CT allows creation of volumes of data that, for clinical purposes, appear to have true 3D characteristics.

What Creates A Prominent Signal On CT And On MRI?

On CT, grayscale brightness is proportional to the degree of x-ray attenuation by a tissue, which is essentially proportional to physical density. **(See Figure 3a).** A physically dense tissue such as bone attenuates x-ray to a greater extent than does a less dense tissue such as blood or fat. Denser tissues are assigned brighter/whiter colors on CT, relative to less dense tissues, which are assigned darker gray shades.

On MRI, the brightness of a tissue is not proportional to physical density but rather to proton richness and the characteristics of the applied magnetic field. **(See Figure 3b).**Tissues rich in protons have strong signal characteristics; tissues relatively devoid of protons have poor signal characteristics. Calcified bone has a paucity of protons and appears black on all MRI sequences. Many different MRI algorithms exist, and the resulting images have specific color schemes – in some algorithms, water-rich tissues appears white, while in others they appear black. Similarly, fat may appear bright or dark, depending on the MRI protocol. **(See Figures 4a and 4b.)** High-quality MR images have good signal to noise ratios and high resolution. Unfortunately, these parameters are at odds with one another. An MRI image is composed of 3D pixels (also called "volume elements" or "voxels"). The smaller the

Figures 2a and 2b. CT And MR Imaging Processes

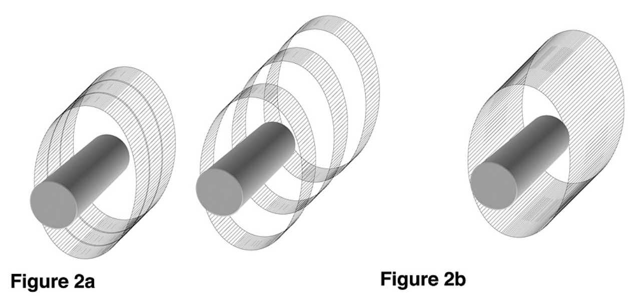


Figure 2a. CT involves acquistion of multiple 2D slices of variable "thickness" through the body part (solid cylinder). If the slices are thin and closely spaced or overlapping (left), the resulting 3D volume of data can be reconstructed in any plane with little artifact. Widely spaced slices (right) do not produce good multiplanar reconstructions due to missing image data between slices. Figure 2b. MRI can acquire a series of 2D images, like CT, or a true 3D volume (using gradient echo sequences), which allows multiplanar reconstructions with no artifact. (Image is courtesy of Joshua Broder, MD.)

volume of tissue represented by each voxel, the higher the resolution. However, since the strength of the signal from each voxel is proportional to the number of resonating protons within the tissue volume, a smaller tissue volume with a smaller number of protons produces a lower signal. Musculoskeletal MRI applications address this issue in part by moving the MRI coil closer to the extremity, achieving better signal strength.[7, 11]

What Are MRI Sequences, And How Do They Assist In Demonstrating Pathology?

As previously described, soft tissue appearance on CT depends on physical density and x-ray attenuation. MRI appearance of soft tissues depends not only on proton density of the tissue (protons per unit volume) but also on the resonance qualities of those protons, which varies by tissue type. Protons within fat resonate with different properties from protons in body fluids, hence the term, magnetic *resonance*. The signal given off by protons in various tissues also varies with the properties of the applied magnetic field, called the pulse sequence. This process of adjusting the applied magnetic field is called "weighting" the image, and it results in the various image types available from MRI.

Many different sequences have been developed. Each sequence has strengths and weaknesses, so multiple sequences are usually used to evaluate different tissue types for pathology. The emergency physician would not be called on to select the sequence, but informing the radiologist of the differential diagnosis or indication for the study can help the radiologist and MRI technician select appropriate sequences and imaging planes to maximize diagnostic accuracy. All sequences are not usually performed in a single patient, because each sequence takes time to perform, and the duration of the MRI examination would become prohibitive.[7]

Common protocols include 3 "spin echo sequences: " T1-weighted images (useful for visualizing fat-containing tissues), T2-weighted images (useful for identifying fluid, which is common in many pathological processes), and proton density images (which provide excellent anatomic detail without the degree of contrast for pathological processes). "Fast spin echo" techniques allow more rapid image acquisition, which is beneficial for many reasons. These reasons include reduction in patient movement during the examination (which is critical because motion artifact renders MRI images un-interpretable), additional time for more pulse sequences to be acquired, and faster throughput. Fast spin echo T2 images have replaced most spin echo T2 images due to their speed advantage, although this technique causes blurring at tissue margins that can hide pathology such as meniscal tears.

An additional technique with value for musculoskeletal applications is fat saturation, in which an administered magnetic pulse suppresses the signal from fat, resulting in a dark appearance of fat on the

Figures 3a and 3b. CT And MRI Grayscale Brightness

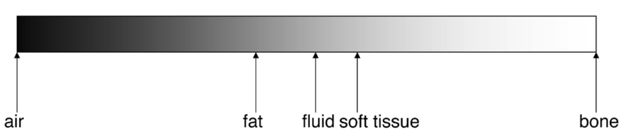


Figure 3a. On CT, a fixed relationship exist between tissue appearances. The less dense the material, the less it attenuates the CT x-ray beam, and the darker the color assigned to it. Although the gray-scale can be shifted to accentuate various tissues, the relative colors of various tissues remain the same. Air is always less dense than bone and appears blackest, while bone is always the densest native tissue and appears whitest.

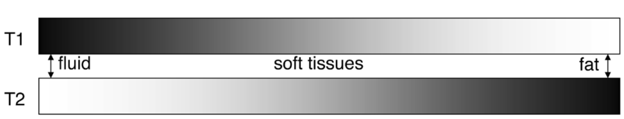
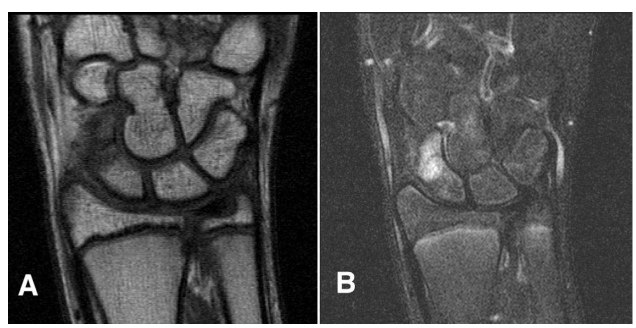


Figure 3b. On MRI, the relative color of various tissues is NOT fixed, since the color is dependent on the signal strength of the tissue, and that strength is dependent on proton density, the resonance of protons within that tissue, and the characteristics of the applied magnetic field. A mnemonic for remembering the appearance of fluid (water, or $H_{2}0$) is that $H_{2}0$ is bright on T2. Because many pathological processes result in increased fluid within a tissue (edema or hemorrhage), pathological processes are often bright on T2-weighted images. T1 = T1 weighted. T2 = T2-weighted. (Image is courtesy of Joshua Broder, MD.)

Figures 4a and 4b. Common MRI Pulse Sequence Examples Of T1-weighted And T2-weighted Images



T1-weighted images (A) highlight fat including marrow, while leaving fluid dark. T2-weighted images (B) show fluid as a bright signal, while fat is dark. On all sequences, bone appears black due to its paucity of protons. Additional sequences are sometimes used to highlight pathology. Fast spin echo T2 shows both fat and fluid as bright, but when fat saturation is added, fat becomes dark on these images. Proton density images have less tissue contrast (all tissues appear a shade of gray) but offer excellent anatomic detail. Gradient echo images allow true 3D volume imaging but have susceptibility artifact (see text), which makes them poor for patients with metallic prosthetic devices. (Image is courtesy of Joshua Broder, MD.)

image. This is particularly useful on fast T2 images where both fat and fluid appear bright unless fat suppression is used. An example of this technique in emergency applications would be to combine fast T2 with fat saturation to examine bone for fracture. Edema within bone marrow would appear white using this technique, while the surrounding marrow fat would become dark in appearance. Without fat suppression, edema would be difficult to discern from fat. Another sequence that causes fat suppression is short-term inversion recovery (STIR), which is often used interchangeably with fast-T2 with fat saturation.

Gradient echo is a separate family of pulse sequences with several advantages for musculoskeletal MRI. Gradient echo T2 images (also called T2*, pronounced "T2 star") have fast acquisition times and highlight fluid. They offer the additional advantage of showing cartilage, ligaments, and fibrocartilaginous structures in good detail, at the expense of other soft tissue contrast. Gradient echo techniques also allow true 3D or "volume" imaging, rather than 2D slice acquisition, as previously described. Volume imaging requires longer image acquisition times.

"Susceptibility effects" refer to artifact (loss of signal or black appearance) created on some pulse sequences at the interface of 2 different tissue types with widely different magnetic properties. This can be used to diagnostic advantage or can create diagnostic confusion, depending on the scenario. Increased susceptibility effects from hemoglobin breakdown products make gradient echo T2 (T2*) sequences excellent for detection of hemorrhage. At the same time, T2* performs very poorly when evaluating patients with metallic hardware, since susceptibility effects around hardware create a loss of signal that hides adjacent soft tissues. Minimal susceptibility effect artifacts are found with fast spin T2 sequences, making them ideal for imaging patients with metallic hardware.[7]

Unlike CT, where the color scale is assigned quantitatively based on the x-ray beam attenuation of the tissue, with MRI the gray scale is scaled relative to the brightest voxel (the voxel with the strongest signal). Since the signal strength is dependent not only on the tissue type but on the applied magnetic field, there is not a fixed relationship between tissue types in terms of the brightness of their appearance in MRI. **(See Figures 3a and 3b, page 5).** **Table 2** lists common sequences used in musculoskeletal MRI.

Normal Appearance Of Tissues On MRI

As described previously, the normal appearance of various tissues on MRI depends on the pulse sequence as well as tissue characteristics. Cortical bone is black on all MRI sequences, since hydrogen ions in mineralized bone do not resonate sufficiently to

Table 2. Common Musculoskeletal MRI Sequences

Sequence	Strength	Weakness
Spin Echo		
T1	• Anatomic detail • Fat, subacute hemorrhage • Meniscal pathology • Gadolinium enhancement with fat saturation • Marrow pathology	• Poor detection of soft tissue edema and other T2-sensitive pathologies • Not as sensitive as STIR or fast spin echo T2 with fat saturation for marrow pathology
Proton Density	• Anatomic detail • Meniscal pathology	• Poor detection of fluid and marrow pathology • Long imaging times
T2	• Detection of fluid, common to many pathological processes	• Long imaging times
Fast Spin Echo		
Proton Density	• Anatomic detail	• Blurring artifact can hide meniscal injury
T2	• T2 contrast obtained with shorter imaging times • Excellent for marrow pathology when combined with fat saturation • Useful when metal hardware is present (decreased "susceptibility effects")	• Poor detection of marrow pathology unless combined with fat saturation (fat is bright on this sequence, as is fluid – so fat saturation is needed to reduce the signal from fat)
Gradient Echo		
T2* (T2 star)	• Ligaments • Tendons • Loose bodies and subtle hemorrhage • 3D imaging	• Poor detection of marrow pathology at high field strengths • Significant metallic hardware artifact due to susceptibility effects
STIR		
	• Marrow and soft tissue pathology	• Should not be used with gadolinium, as gadolinium signal is suppressed

produce signal. Air (composed of 79% nitrogen and 21% oxygen) is also black on all sequences since it has no protons to resonate and produce signal. This may create confusion for emergency physicians, who may be more accustomed to bone and air occupying opposite ends of the color scale on CT due to their widely different physical densities and x-ray attenuation. Fat and hematopoietic marrow within bone produce signals and their appearances depend on the pulse sequence. Hematopoietic marrow is hyperintense (brighter) than skeletal muscle on all sequences. Fat in marrow may be bright (T1) or dark (T2, fast T2 with fat suppression, or STIR). **Table 3** lists the appearance of various tissue types on MRI sequences.

Why Is MRI Recommended For Some Fractures (Scaphoid And Hip) While CT Is Considered The Gold-Standard For Fractures Of The Cervical Spine?

The recommendation against CT for detection of some fractures is based on outdated results from studies using older generation CT scanners. Modern multi-detector CT has excellent spatial resolution and ability to detect cortical fractures.[12] Early generation CT was relatively insensitive for non-displaced fractures, particularly fractures in the axial plane of the CT slices. **(See Figure 5.)** Because CT slice thickness was relatively thick (5 mm or more) and gaps between slices existed, a narrow fracture plane could be missed on early generation CT. Modern multi-detector CT allows slice thickness as low as 0.625 mm, contiguous or even overlapping slices, and multiplanar reconstruction. These features reduce the probability that even a thin fracture plain will be missed.

MRI is relatively poor at directly detecting fractures because it relies on the signal generated by protons as they interact with an imposed magnetic field. Tissues with high water or fat content are rich in protons and have strong signal characteristics on MRI. Calcified cortical and trabecular bone has a paucity of protons and has little signal on MRI, though bone marrow is proton-rich and generates a strong signal. On MRI, it is marrow edema in the presence of fracture that provides the diagnostic signal.

MRI and Contrast

When Is Contrast Needed In MRI And What Agents Are Used?

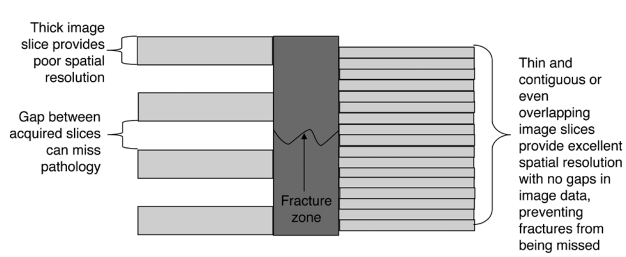
Gadolinium-DTPA is a paramagnetic compound that demonstrates increased signal on T1-weighted images. It can be given intravenously or used intra-articularly to produce an arthrogram. When given intravenously, gadolinium causes enhancement that is proportional to the blood flow in soft tissue, much like iodinated contrast for CT. For most trauma-related emergency musculoskeletal MRI, gadolinium contrast is not needed. Gadolinium is useful for discriminating solid masses from cystic masses and in identifying viable tumor tissue from non-enhancing necrotic tissue prior to biopsy.

An emergency indication for gadolinium is

Table 3. Tissue Appearances On MRI Sequences

Tissue	Appearance	Best sequence
Air	Black on all sequences	Not applicable
Bone	Black on all sequences	STIR Fast T2 with fat saturation T1
Articular cartilage	Variable	STIR Fast T2 with fat saturation GRE (gradient recall echo) with fat saturation
Meniscus	Dark on all sequences	GRE T2* T1 Spin echo proton density
Labrum	Dark on all sequences	T1 with intra-articular gadolinium GRE T2*
Tendons/ ligaments	Usually dark on all sequences, except ACL which has striated appearance	GRE T2* STIR Fast T2, +/- fat saturation
Muscle	Intermediate intensity on all sequences	STIR T1
Fat	Variable	T1
Synovium	Invisible unless pathologically thickened	T1 fat-saturated with IV gadolinium

Figure 5. Modern Multi-Slice Helical CT Versus Older Single-Slice Non-Helical CT



Differences in spatial resolution of modern multi-slice helical CT and older single-slice non-helical CT. At center, schematic of a bone with a narrow fracture zone. At left, older generation CT scanners acquired single slices of image data, with the patient table moving in steps through the CT gantry between acquisition of image slices. A narrow fracture zone might, by chance, fall between two adjacent slices and fail to be detected. Modern multi-slice helical scanners can acquire much thinner and overlapping slices, resulting in no missing image data. Even a thin fracture zone is unlikely to be missed using this technique, accounting for improving sensitivity of CT for fracture with newer scanners. (Image is courtesy of Joshua Broder, MD.)

suspected soft tissue infection, where gadolinium can differentiate true abscess from soft tissue edema and phlegmon. Marrow enhancement after gadolinium is not specific for osteomyelitis, since reactive hyperemia may appear similar. A second emergency indication for gadolinium is the evaluation of spine lesions, particularly tumors, demyelinating diseases, and intradural/extramedullary lesions such as metastatic disease. In post-operative spinal surgery patients, gadolinium can differentiate disc material (non-enhancing) from scar tissue (enhancing). Gadolinium is not needed for the evaluation of acute traumatic spinal cord injuries.

MR arthrograms with gadolinium will rarely be used in the emergency department, as they are typically used for preoperative diagnosis and planning, not for emergency diagnosis.[7]

What Are The Contraindications For Gadolinium Contrast? What Is Nephrogenic Systematic Fibrosis, And How Great Is The Risk?

Emergency physicians are well-acquainted with the contraindications for iodinated contrast materials such as those used for CT but may be less familiar with the dangers of gadolinium. Nephrogenic systemic fibrosis (NSF) is a potentially fatal condition first linked to gadolinium use in 2006.[13] Patients at risk for this condition are those with renal insufficiency, the very population in whom MRI is sometimes used because of concerns about contrast-induced nephropathy from iodinated contrast used in CT scanning. Unlike contrast nephropathy from iodinated contrast, which is of no concern in patients already dialyzed for chronic renal failure, gadolinium-associated NSF is a very rare but potentially grave risk in dialysis patients receiving large doses of contrast. The condition results in tissue fibrosis, sometimes localized, but in other cases involving multiple internal organs and progressing to death. In a retrospective study of patients undergoing gadolinium-enhanced MRI at 2 large medical centers over a 10-year period, 0 of 74,124 patients developed biopsy-proven NSF after receiving a standard dose of gadolinium (0.1 mmol/kg).[14] Fifteen of 8997 (0.17%) developed NSF after receiving a high dose of gadolinium (between 0.2 and 0.4 mmol/kg), and all of the affected patients had an estimated glomerular filtration rate (GFR) lower than 30 mL/minute (normal GFR is 120 mL/min). The risk of developing NSF from high-dose gadolinium was far greater in patients with acute or acutely worsening renal insufficiency in this study. Patients already dialyzed at baseline or dialyzed within 2 days of receiving high-dose gadolinium had a decreased incidence of NSF, and no patients dialyzed on the same day as receiving high-dose gadolinium developed NSF. Hyperphosphatemia was associated with increased risk of NSF. Overall, the risk of NSF appears very low in patients receiving standard doses of gadolinium, regardless of renal function. The risk remains small in those receiving high dose gadolinium, except in those patients in acute renal failure with estimated GFR less than 30 mL/min. As a rule, gadolinium should be avoided if possible in patients with acute renal failure (increase of 0.5 mg/dl or greater in a 24-hour period) due to this risk. Creatinine clearance, a surrogate measurement for GFR, is a more accurate means of recognizing renal dysfunction than measured serum creatinine. Creatinine clearance is calculated by a simple formula (see the following formula) and takes into account patient age and weight, 2 variables that influence the severity of renal dysfunction associated with a measured creatinine level. For example, in an 85-year-old female weighing 65 kg, a creatinine of 1.0 is a markedly abnormal value.

Estimated Creatinine Clearance Using Cockcroft-Gault Formula

Creatinine clearance is a more accurate measure of renal dysfunction and risk of gadolinium-related nephrogenic systemic sclerosis than is measured serum creatinine.

$$eC_{cr} = \frac{(140-\text{Age}) \times \text{Mass (in kilograms)} \times [0.85 \text{ if female, } 1.0 \text{ if male}]}{72 \times \text{measured serum creatinine (in mg/dl)}}$$

When standard doses of gadolinium are administered, the risk of gadolinium-induced NSF is lower than the risk of death from iodinated contrast agents used in CT. However, the American College of Radiology (ACR) recommends informed consent before administration of gadolinium-based contrast for patients with moderate to end-stage kidney disease.[15] Hemodialysis patients should receive the lowest possible dose of gadolinium and should receive dialysis as soon after contrast administration as is practical. The ACR recommends hemodialysis within 2 hours after administration of gadolinium contrast for patients with renal failure,[15] though this practice is not well-supported by research data. Peritoneal dialysis is relatively ineffective at removing gadolinium, and these patients may be at particularly high risk from gadolinium.[15] This is an important consideration because dialysis patients may be at risk for conditions such as epidural abscess, which may be best diagnosed by MRI.[16]

Is Gadolinium Safe In Pregnancy?

Gadolinium crosses the placenta, enters the fetal circulation, is filtered by the fetal kidney, and is excreted into the amniotic fluid. The effects of gadolinium on the developing fetus are unknown. Consequently, the ACR recommends that gadolinium-based contrast agents not be used routinely in pregnancy. Gadolinium-based contrast may be used in pregnancy on a case-by-case basis with consideration of the risk-benefit ratio, which should be documented in the patient's chart. Because the fetal risk of gadolinium is unknown, the decision to administer gadolinium should be made based on overwhelming potential benefit to the patient or fetus.[15]

Is Allergy To Gadolinium Contrast A Concern?

Allergic reactions to gadolinium-based contrast may occur and are more common in patients with prior gadolinium contrast reactions. Asthma is a risk factor for gadolinium contrast reaction. Patients with other allergies are at increased risk (2-4 fold) compared with those without allergies. Prior reaction to iodinated contrast doubles the risk of a contrast reaction to gadolinium – with the absolute risk being about 6.3%.[15]

MRI Safety Concerns

Is MRI Contraindicated For Patients With Pacemakers And AICDs?

MRI has long been thought to be absolutely contraindicated in patients with ferromagnetic material within the body, including pacemakers and other electronic devices. However, there are now over 230 published prospective cases of patients with pacemakers safely having undergone low-field MRI.[17] In *in vitro* studies of pacemakers and automatic implantable cardioverter defibrillators (AICDs) subjected to 1.5 to 3.0 tesla MRI, no significant changes in temperature occurred and no permanent damage to devices resulted.[16-19] The ACR calls pacemakers and defibrillators a "relative contraindication" to MRI and states that MRI of patients with these devices should not be routine but may be considered on a case-by-case basis. Possible deleterious effects could include programming changes to the device, inhibition of pacing, rapid pacing, induction of ventricular fibrillation, heating of the device or leads, battery depletion, and device damage requiring replacement.[15]

Is MRI Contraindicated When Intracranial Aneurysm Clips Are Present?

Intracranial aneurysm clips can result in serious injury or death when subjected to a magnetic field, due to deflection of the clip. Titanium clips are considered safe for MRI. Non-titanium clips manufactured in 1995 or later are considered safe if the product labeling asserts MRI compatibility. Older clips require careful consideration by a radiologist and may require proof of testing for ferromagnetic properties. It should NOT be assumed that a patient with an aneurysm clip who has safely undergone prior MRI can do so again – variations in magnetic field characteristics and clip orientation in the field may result in different biological effects in subsequent MRI. Case reports of significant injuries have been reported, including blindness.[15]

Other Safety Considerations For MRI

Magnetic effects on tattoos including first-degree burns and burning sensation have been reported, although these appear rare and more likely to interfere with completion of MRI than to cause significant harm.[19-22] MRI examinations also result in significant sound volumes, and hearing protection is recommended by the ACR.[15] As previously described, patients with devices such as pacemakers may be safely imaged, but the ACR recommends limiting field strength and other imaging parameters because of the danger of induced voltages. Because induced current from the magnetic field can occur in conducting loops, even when these loops are not connected to a device or power supply, care should be taken to remove any unnecessary wiring from the patient – it is not sufficient to disconnect wiring from a power source. Lead heating can occur rapidly, potentially resulting in significant tissue injury. The FDA has received reports of permanent neurological injury in patients with implanted neurostimulators, resulting from heating of lead tips. Thermal insulation should be placed between the patient and any leads whenever possible. Patients may themselves form large conducting loops and they should be instructed not to cross their arms and legs within the scanner. Non-ferromagnetic skin staples are not an absolute contraindication to MRI but may heat during the examination. Patients should be warned to report burning sensations immediately. Applying an ice pack to the staple line may reduce this risk by acting as a heat sink.[15] Similar precautions should be used for large tattoos. MRI field strength is an important determinant of thermal heating of leads. Devices should not be imaged in a field of a different strength from that approved by the manufacturer due to risks of thermal heating. Some drug-delivery patches contain metal foil that can heat in the magnetic field – these should be removed when possible.[15] Intrauterine devices including copper IUDs appear safe, with no deflection, torque, heating, or artifact observed *in vitro*.[23]

MRI For Epidural Abscess And Other Non-Traumatic Spinal Cord Lesions

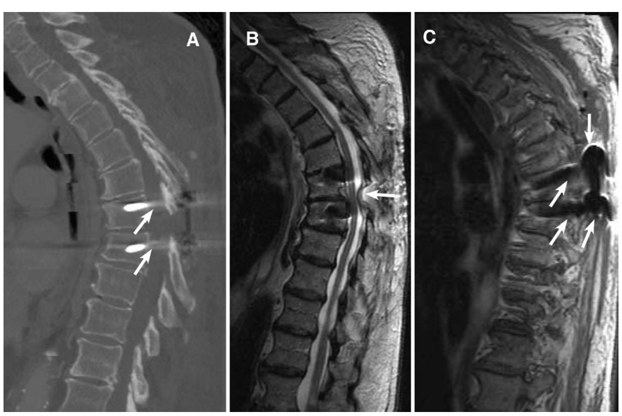
Probably the single most important emergency application of musculoskeletal MRI is in the evaluation of neurological deficits localizing to the spinal cord, where MRI is usually considered the gold standard diagnostic imaging test. In the case of spinal epidural abscess, delays in diagnosis can have devastating neurological consequences, so early MRI is of particular importance. In a retrospective case-control study of 63 patients with spinal epidural abscess, delay in diagnosis (defined as multiple emergency department visits or admission without a diagnosis and greater than 24 hours until definitive imaging) was common, occurring in 75% of cases. Persistent motor weakness occurred in 45% of patients with diagnostic delay, compared with 13% of those with more rapid diagnosis (odds ratio 5.65, 95% CI, 1.15-27.71, $p<0.05$).[24] The classic triad of fever, spine pain, and neurological abnormalities was present in only 13% of patients, demonstrating that a low threshold for imaging must be applied to avoid misdiagnosis. A well-conducted review of the literature from the New England Journal of Medicine concluded that the single most important predictor of neurological outcome is the patient's neurological status prior to surgery. Therefore, a vigilant effort to diagnose the patient prior to the progression of neurological signs and symptoms is imperative.[25] More studies are needed to identify patients at risk for spinal epidural abscess, in order to provide prospective clinical criteria for emergency physicians to guide MRI. MRI examinations demonstrating spinal cord compromise are shown in **Figures 6 and 7**.

Prospective trials comparing CT and MRI with a gold standard for diagnosis (clinical follow-up or surgical findings and cultures) do not exist mostly due to the rarity of epidural spinal abscess, which occurs in only about 1 in 10,000 hospital admissions.[25] The ACR publishes Appropriateness Criteria for imaging studies in various clinical scenarios. These are evidence-based guidelines but in the case of spinal abscess they represent expert consensus based on case series, rather than high-level evidence from prospective trials. The ACR criteria rank MRI of the spine without and with contrast as most appropriate (9 on a 9 point scale) in the infectious disease patient and as a 7 in the patient with painful myelopathy. CT gains a slightly lower rating in the ACR criteria, ranging from 3 to 7 depending on the exact scenario.[26] Unfortunately, these guidelines are meant for the patient with myelopathy (existing neurological deficit related to the spinal cord), while the emergency physician should aim to diagnose spinal epidural abscess prior to the onset of neurological signs when possible, to prevent poor neurological outcomes.

Strong evidence for CT of the spine for detection of epidural spinal abscess is extremely limited. A 1985 retrospective review of 19 patients with spinal infection found that CT demonstrated bone, paraspinal, and epidural involvement not seen on x-ray or nuclear medicine studies.[27] A 1983 retrospective review of 20 patients reported similar results – with CT myelography being performed in 45% of patients.[28] CT myelography is an invasive study in which contrast material is injected directly into the intrathecal space to outline the spinal cord and other nerve structures prior to CT imaging. These studies predate wide clinical use of MRI and provide no rigorous data on sensitivity or specificity of CT with or without myelography. Subsequent case reports and small case series shed little additional light on this topic.

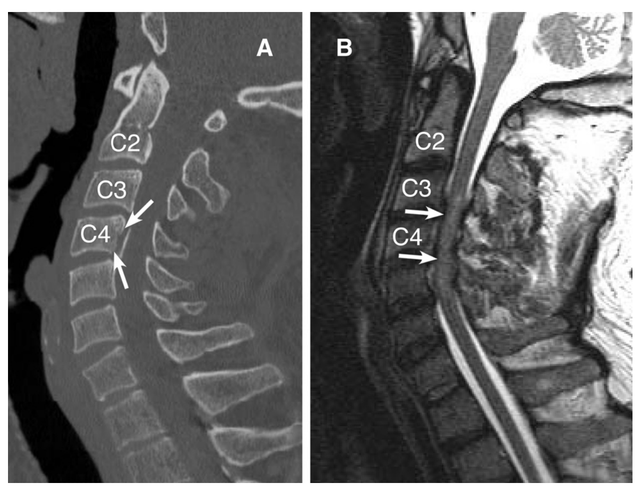
Evidence for MRI in suspected epidural abscess

Figure 6. MRI Of Thoracic Spine



MRI of thoracic spine in a patient with back pain, fever, and leukocytosis 3 weeks after thoracic spine surgery. This study was performed with gadolinium contrast, which is valuable for detecting suspected infectious or inflammatory conditions of the spine. (A) thoracic CT performed prior to MRI was nondiagnostic–metallic streak artifact from orthopedic hardware is visible (arrows). (B) T2-weighted sagittal image shows soft tissue mass (abscess) obliterating the CSF space at the T7-T8 level (arrow). (C) T1-weighted image is non-diagnostic due to susceptibility artifact (black region, arrows) from spinal hardware. This artifact is less prominent on T2-weighted images. (Image is courtesy of Joshua Broder, MD.)

Figure 7. MRI Of Cervical Spine



MRI of cervical spine in a patient with quadriplegia and a C4 fracture demonstrated on CT after a motor vehicle collision. CT (A) better demonstrates the fracture (arrows), while MRI (B) clearly demonstrates spinal canal narrowing with cord compression at the levels of C4 and C5. This MRI was performed without contrast, which is not needed for evaluation of acute spinal cord trauma. On this T2-weighted sagittal image, CSF appears white, as does hemorrhage within the cord. (Image is courtesy of Joshua Broder, MD.)

is similarly limited. No prospective studies to evaluate the sensitivity of MRI in this setting exist. Small studies have evaluated the correlation between MRI findings and outcome. A study of 18 patients with spinal epidural abscess found that abscess length, enhancement pattern, and severity of canal narrowing predicted clinical outcome.[29] More recent studies examining follow-up MRI in patients with known epidural abscess showed little correlation of imaging findings with clinical response to treatment.[30] A 1988 retrospective study of 24 patients with spinal infections including epidural abscess compared CT to MRI and found CT myelography to be superior to MRI.[31] A second retrospective study the same year examined 38 patients undergoing MRI and CT myelography for a variety of suspected cervical and thoracic spinal lesions. MRI was superior for a variety of findings, while CT myelography was better for other lesions, but technical changes in both modalities since that time render this information useless.[32] A large multi-center study with prospective enrollment of emergency department patients with suspected epidural abscess is needed to evaluate the sensitivity and specificity of CT and MRI. A well-planned study of this type would involve imaging with both modalities in all patients and a gold standard for diagnosis, including clinical follow-up or microbiological and surgical findings.

Studies on the accuracy of MRI for spinal disorders are also complicated by the choice of a diagnostic reference standard. If MRI demonstrates a lesion, how can one determine whether the lesion is real? For some scenarios, pathology, surgical findings, and microbiological cultures can confirm MRI findings. In other cases, MRI is assumed to be correct, as no alternative imaging or diagnostic test is available. A study of 46 consecutive patients with surgically and microbiologically-proven spinal infection found some MRI findings to be extremely sensitive for infection, while other published findings of infection were insufficiently sensitive to be diagnostically useful to rule out infection.[33] **(See Table 4.)** A study of this type that does not include patients with negative evaluations for spinal infection cannot evaluate the specificity of the MRI findings. What is the overall diagnostic sensitivity of MRI for spinal epidural abscess? Is MRI ever normal in patients with real disease? No studies exist to answer these questions. The author is aware of 1 case of spinal epidural abscess apparently missed on initial MRI – the patient returned for worsened symptoms and MRI was then positive.

Given the limited evidence, MRI remains the best test by expert opinion for the diagnosis of spinal epidural abscess and other nontraumatic spinal cord lesions.

Table 4. MRI Findings Predictive Of Spinal Epidural Abscess

MRI Finding	Sensitivity
Presence of paraspinal or epidural inflammation	(n = 43, 97.7% sensitivity)
Disk enhancement	(n = 42, 95.4% sensitivity)
Hyperintensity or fluid-equivalent disk signal intensity on T2-weighted images	(n = 41, 93.2% sensitivity)
Erosion or destruction of at least one vertebral endplate	(n = 37, 84.1% sensitivity)
Effacement of the nuclear cleft	(n = 15, 83.3% sensitivity)
Decreased height of the intervertebral space	(n = 23, 52.3% sensitivity)
Disk hypointensity on T1-weighted images	(n = 13, 29.5% sensitivity).

MRI For Occult Hip Fracture

Hip fractures (fractures of the femoral head and neck, intertrochanteric region, and subtrochanteric region) are a major cause of morbidity and even mortality in older adults. Delay in diagnosing occult hip fractures may be associated with increased morbidity; however, a Cochrane meta-analysis found no evidence of increased mortality in patients treated non-operatively, based on randomized trials.[34] A retrospective review found improved survival, decreased infectious complications, decreased length of stay, and decreased cost from early fixation of fractures.[35]

The ACR recommends limited field MRI as the most appropriate test in a patient with normal plain films but suspected subacute insufficiency fracture due to osteoporosis or chronic steroid use, with a rating of 9 of 9 (most appropriate). This recommendation does not address the more common ED scenario of suspected acute traumatic fracture. The ACR finds CT, repeat x-ray in 10 to14 days, and bone scan all to have an appropriateness of 1 (least appropriate). In cases where bone scan is performed and is equivocal, CT through the region of bone scan abnormality is given an ACR rating of 2.[36, 37]

A PubMed search using the terms "MR CT hip fracture" with the limits "randomized-controlled trial/clinical trial/meta-analysis" found 1 match – an indication of the limited studies on this topic. "MRI hip fracture" with the same limits identified 3 studies, 2 not relevant to our clinical question.[38]

What Is The Sensitivity Of X-ray For Hip Fracture?

X-ray sensitivity for hip fracture is believed to be between 90% and 98%, based on multiple studies including a retrospective study of 825 consecutive admissions for hip fracture.[39-41] More recently, a retrospective study of 545 ED patients with negative hip radiographs found a 4.4% (95% CI, 3.0 to 6.5%)

rate of fracture, all diagnosed by MRI. Although this study suffers from verification bias, since only 62 of these patients underwent MRI, follow-up did not reveal additional missed fractures. Surprisingly, in the practice setting of this retrospective study at the Mayo Clinic in Phoenix, Arizona, 11.4% of patients with negative initial radiographs underwent hip MRI during their ED visit.[9]

Delay in recognition of non-displaced fractures can lead to displacement of fractures.[39] Non-displaced fractures and fractures in patients with osteoporosis are less likely to be recognized on plain film. When x-rays are non-diagnostic but clinical suspicion of hip fracture remains, options include 7 to 10 days of bed-rest, followed by repeat plain films to evaluate for fracture displacement or callus formation. Alternatively, radionuclide bone scan can be performed, with a reported sensitivity of 93% and specificity of 95% based on a 1990 study that suffers from verification bias due to varying gold standards.[42] Bone scans may not be positive immediately after fracture but are thought to become positive 24 to 72 hours after injury, according to a 1979 study in which 80% of fractures were detected on bone scan by 24 hours and 95% by 72 hours after injury. This study is the basis for the recommendation to delay bone scan to enhance sensitivity, but its applicability to the patient with an occult fracture is unclear as all patients in the study had fractures visible on plain film. From this study it is not certain when bone scan becomes positive in patients with radiographically occult fractures.[43] An additional option is CT scan, which in the past has been thought to miss small impacted fractures and non-displaced fractures parallel to the axial plane. As previously described, thin-slice modern CT with multiplanar reconstruction reduces the likelihood of missing such fractures.[44] **(See Figure 5, page 7.)**

What Is The Sensitivity Of MRI for Occult Hip Fracture?

MRI has been called the "study of choice" when clinical suspicion of hip fracture persists despite negative plain film, but rigorous studies with excellent gold standards and sufficient numbers are lacking. MRI with limited field of view focused on the hip and using T1-weighted sequences primarily for fracture detection can be performed in less than 15 minutes at less cost than wider MRI views of the hip and pelvis. However, studies asserting the 100% sensitivity and specificity of this method are small (20 to 60 patients) and suffer from selection and verification bias.[45-48] These studies do not compare findings on limited MRI with more complete MRI of the hip to determine the sensitivity and specificity of this method. In addition, these studies suffer from incorporation bias, as the final diagnosis was based on the combination of MRI and clinical outcome.[45-47] Other studies report the sensitivity and specificity of more complete MRI as 100% but suffer from the same problems of small numbers and selection, verification, and incorporation bias.[49]

Is MRI Cost-Effective In The Evaluation Of Occult Hip Fracture?

Authors have argued that MRI appears cost-effective when delayed diagnosis, complications, and the costs of other delayed testing are considered. However, a cost-effectiveness analysis by Rubin et al makes the assumption that all patients with MRI negative for fracture can be sent home from the ED. This ignores the common scenario of the elderly patient with inability to ambulate due to pain or of co-morbid conditions such as possible syncope that require hospital admission even if no fracture is present.[49] Another purported advantage of MRI over other imaging modalities is that it may show alternative diagnoses such as pelvic fractures or soft tissue injuries in 23% and 74% of patients, respectively, although the impact on patient outcomes of these diagnostic improvements is unknown. Moreover, detection of these additional injuries requires a larger field of view, which is more costly and time-consuming to perform than the limited MRI examinations described above.[50] A limited MRI cost approximately $450 in 1993, compared with $455 for bone scan, $299 for linear tomography (a method rarely used today, not to be confused with computed tomography), and $797 for CT.[45] The cost of a complete hip MRI (including both technical and professional charges) was reported to be $1280 in 1996, with bone scan costing $460 at that time.[49] To put this in perspective, a Danish study of MRI for emergency diagnosis of occult hip fracture found that the cost of MRI was twice that of the ED visit and equal to that of a day of hospital admission. Despite this, the authors found a slight cost advantage to early MRI, again making the questionable assumption that negative MRI would allow immediate discharge.[51]

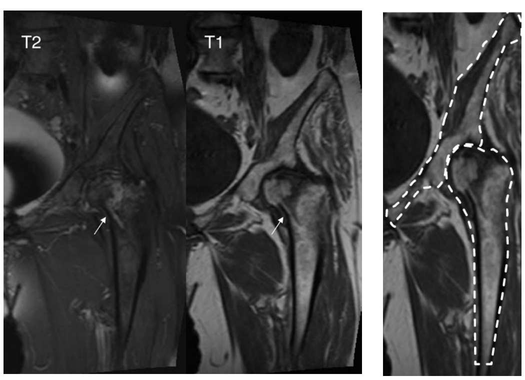
Which Patients With Negative Hip X-rays Need MRI?

Unfortunately, a clear clinical decision rule for selecting patients for MRI after a negative hip plain film does not exist. Studies suggest that only about 5% of all patients undergoing hip evaluation will have fracture despite negative x-rays. Among those undergoing MRI, the reported rate of fracture is high – over 30% in several studies – indicating that clinicians are relatively astute at selecting high-risk patients for additional imaging.[9,47] The clinical factors that select this high-risk group from their uninjured cohort have not been prospectively identified. A retrospective study assessing clinical

Figure 8. Possible Hip Fracture, Non-diagnostic Plain Films

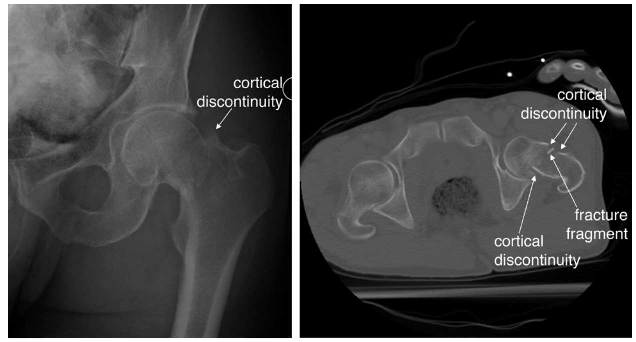
This patient had an extensive history of prior hip arthritis and injury, including percutaneous pinning of a prior fracture with subsequent removal of hardware. When she presented acutely with new hip pain, x-rays appeared little changed from prior examinations. The radiologist's interpretation was post-traumatic and post-surgical deformities of the left femoral neck, with deformity of the left femoral head and increased sclerosis and irregularity, concerning for changes from avascular necrosis. No acute fracture was noted on plain film, and MRI was recommended. See Figure 9.

Figure 9. False Positive MRI?



Possible hip fracture diagnosed by MRI. Bone cortex appears black on all MRI pulse sequences, due to lack of resonating protons.Increased signal on T2 images (arrow) indicates fluid within bone marrow at the site of a possible fracture. Decreased signal on T1 images (arrow) also marks the possible fracture site.Intra-operatively, the patient had evidence of advanced degenerative joint disease affecting the hip both on the acetabular and femoral side. There was significant evidence of femoral head collapse and avascular necrosis, but no evidence of fracture. Ultimately, the patient underwent total hip arthroplasty–which may have been clinically required regardless of MRI findings given the patient's non-ambulatory status. The T1 image on the right has the pelvis and femur outlined for orientation.

Figure 10. X-ray And CT Of Hip Fracture

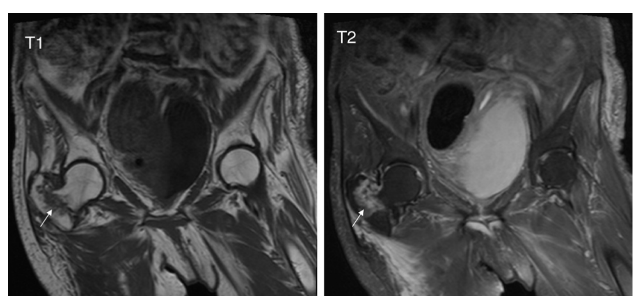


Hip fracture visible on x-ray (arrow), and further characterized on CT. Subtle cortical defects that may be difficult to recognize on x-ray may be found on CT. CT for the diagnosis of hip fracture is currently recommended as "least appropriate" by the American College of Radiology (ACR), while MRI is "most appropriate" by ACR criteria.

Figure 11. Femoral Neck Fracture, Suspected On Plain Film And Confirmed On MRI

The radiologist noted a displaced fracture of the lesser trochanter and deformity of the proximal femur concerning for an inter-trochanteric fracture. MRI was recommended by radiology. See Figure 12.

Figure 12. Femoral Neck Fracture, Suspected On Plain Film And Confirmed On MRI



Bone cortex appears black on all MRI pulse sequences, due to lack of resonating protons.T1 images show relative lack of signal (black) from fluid in the fracture zone, while surrounding normal marrow fat has high signal (white).T2 images show a bright signal from fluid in the fracture zone, while normal marrow fat appears dark.The patient was ultimately managed non-operatively due to dementia and significant cardiac co-morbidities. Whether MRI influenced management in this case is unclear.

All images are courtesy of Joshua Broder, MD.

factors predictive of fracture found 2 factors to be associated with fracture: pain on axial loading of the limb and pre-fracture restricted patient mobility. However, neither factor was sufficiently sensitive or specific to be of value.[52] A prospective study of 35 patients with suspicion of hip fracture despite negative x-rays (based on persistent hip pain, history of trauma, inability to weight-bear, and painful straight leg raise or hip rotation) found 29 injuries including 21 femoral neck fractures. All operative injuries occurred in patients over the age of 70, which the authors suggested should be used as a prospective clinical criterion for performance of MRI.[48] However, some injuries in the patients less than 70 years of age might be clinically important to diagnose – they included acetabular fractures, sacral, and pubic rami fractures. This study is too small to reliably define an age cut-off, with only 10 patients under the age of 70. The upper 95% confidence interval limit, when 0 of "n" total study patients experience an adverse outcome, can be calculated by the 3/n approximation, which means that as many as 30% of patients might be found to have injuries if a larger study were conducted.[53]

Is MRI Better Than CT For The Diagnosis Of Hip Fracture?

Representative x-ray, MR, and CT images of radiographically occult hip fracture are shown in **Figures 8 through 12**. A number of studies have attempted to identify CT or MRI as superior for the diagnosis of hip fracture. These studies are subject to the limitations described in our discussion of research bias. A PubMed search for the terms "CT MR hip fracture randomized-controlled trial" found no matches. In one study of 45 patients undergoing radiography, CT, and MRI as part of a larger multi-center trial of patients undergoing operative therapy of osteonecrosis of the femoral head, CT found more fractures than radiography or MRI at 6 and 12 months post-operation. MRI had a sensitivity of only 38% compared with CT, even lower than the sensitivity of plain film (71%).[38] Clearly this study is flawed by the use of CT as the gold standard – the authors assumed that fractures seen on CT were real, stating "on the corresponding CT scans, the fracture clearly breached the femoral cortex."[38]

A second study comparing CT and MRI reviewed only 13 patients – 6 undergoing CT and MRI and 7 undergoing MRI alone. The authors failed to state whether their study was prospective or retrospective. They concluded that 4 of the 6 CT scans yielded inaccurate results, but it is unclear what independent gold standard was used. The authors cited the MRI result in describing the ultimate diagnosis, indicating incorporation bias. In the MRI-only group, the authors concluded, "all the results were accurate." Small studies such as this unfortunately give no true evidence of the superiority of MRI over CT, but they are frequently cited in other studies.[41]

Yet another small retrospective study concluded that MRI may be the test of choice for suspected femoral neck fracture. Remarkably, in a retrospective study of 25 patients undergoing follow-up x-ray, bone scan, and/or CT, the authors concluded that early MRI could markedly reduce costs – though no patients in their study underwent MRI.[54] A retrospective study of 33 ED patients in a 1-year period who underwent MRI after a negative plain film of the hip reported a sensitivity of 100% – gauged against the "gold standard" of outcomes noted in the patient medical record. The authors reported high inter-observer agreement and suggested cost savings due to rapid diagnosis and treatment.[51]

Given the best available evidence, MRI appears to be a relatively cost-effective method of early detection of occult hip fracture. More studies are required to determine which patients with negative plain films require MRI, as wide application of MRI to all patients with negative x-rays would be costly. Multi-detector CT has not been well-studied in this specific setting but is considered highly sensitive for fractures in other settings and may be a reasonable alternative when MRI is not available or is contraindicated. Prospective trials comparing CT and MRI could better delineate the sensitivity, specificity, and cost-effectiveness of these diagnostic modalities. Delayed bone scan is another accepted alternative in patients who cannot undergo MRI or in those who would require admission for pain control or evaluation of other conditions.

MRI For Occult Scaphoid Fracture

Occult scaphoid fractures, or fractures clinically suspected but not visualized on plain x-ray, are a serious concern in emergency medicine. Missed scaphoid injuries are a frequent cause of malpractice litigation.[55] Though the source of their figure is unclear, eMedicine© states that 41% of malpractice claims involving the wrist are related to scaphoid fractures and/or perilunate dislocations.[56] Delay in diagnosis and treatment of scaphoid fracture may contribute to avascular necrosis and nonunion and chronic arthritis – all of which may occur despite appropriate and timely diagnosis and treatment. Between 7% and 40% of clinically suspected occult scaphoid fractures are ultimately found to be true fractures, and, consequently, the majority of patients with wrist injuries are subjected to possibly needless immobilization and follow-up.[57-60] When plain films do not reveal scaphoid fracture but clinical suspicion remains high, management choices include immobilization and repeat plain films in 10 to 14 days, nuclear scintigraphy (bone scan), CT, and MRI. Studies of the sensitivity and specificity of imaging for this diagnosis are complicated by the uncertainty of the gold standard. When plain films, CT, or scintigraphy are negative for fracture but MRI demonstrates an abnormality, is the MRI always correct, or are false positive MRI results possible? Moreover, are follow-up x-rays an appropriate gold standard?

The ACR recommends casting with follow-up x-ray in 10 to 14 days or MRI as the most appropriate imaging modalities for suspected acute scaphoid fracture following normal plain x-rays (both receive a score of 8 on the 1 to 9 scale used by the ACR, with 9 being most appropriate).[61] CT receives a score of 4, with the caveat that CT is appropriate if MRI or casting and follow-up are contraindicated.[61] An international survey of 105 hospitals found marked practice variation, with the usual follow-up examination after plain film being MRI in 31/105 (30%), CT in 19/105 (18%), and scintigraphy in 14/105 (13%). Some hospitals had no fixed protocol and others used a combination of modalities, including MRI, following any negative CT study.[62] This variation in practice reflects the limited evidence available regarding the optimal imaging protocol. X-ray, MR, and CT images of acute wrist injuries are shown in **Figures 13 and 14**.

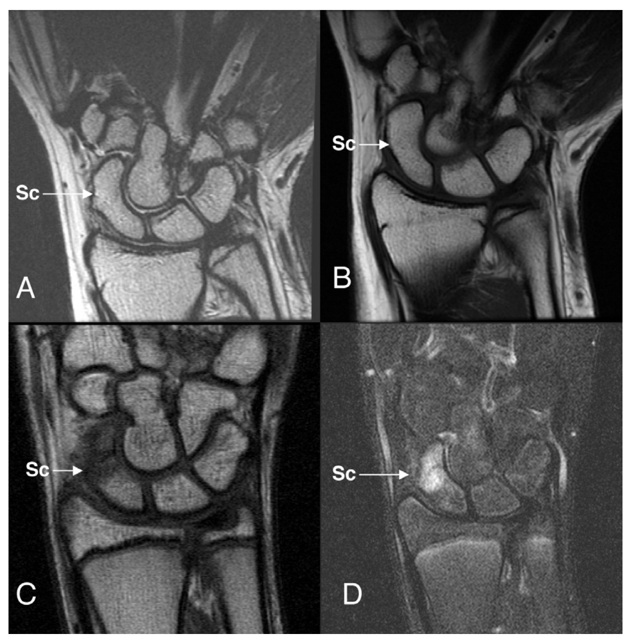
What Are The Potential Advantages Of Early Wrist MRI?

The theoretical value of early MRI includes detection of additional wrist injuries, such as non-scaphoid fractures of the wrist and forearm and soft tissue injuries requiring operative repair. In theory, a normal early MRI could eliminate the need for prolonged immobilization and additional follow-up. Few studies have actually evaluated these hypothetical benefits. A small prospective trial enrolled 22 patients with suspected occult scaphoid fractures. All patients underwent MRI within 24 hours, with 13 showing no fractures. MRI revealed 6 scaphoid fractures as well as 2 distal radial fractures and 1 hamate fracture. Among the 13 patients with negative initial MRI, clinical follow-up in 5 days and repeat MRI in 8 to 10 days did not reveal any additional fractures. The authors concluded that early MRI is sensitive and can avoid needless immobilization.[63] This study suffers from several limitations. First, the gold-standard is uncertain and includes the test under consideration. Using the test being tested as its own gold standard for the presence or absence of injury is called incorporation bias and is a serious flaw in methodology.[6] Secondly, small studies with 0 events ("0 missed fractures") should report confidence intervals, which can be estimated by the 3/n methodology. Simply put, if 0 events occur in n subjects, the upper 95% confidence interval is 3/n. In this study, 0 missed fractures occurred in 13 patients (the 13 with negative MRI). The upper 95% confidence limit for fractures missed by

Figure 13. Scaphoid Fracture, Plain Film

A 13-year-old soccer goalie fell on his outstretched wrist while blocking a shot. He had direct tenderness to palpation in the anatomic snuffbox. A series of x-rays were taken over a 3-week period, with no definite fractures appreciated. The subtle cortical irregularity (A) was noted by the radiologists but not felt to represent a fracture. Follow-up MRI confirmed a fracture. (Image is courtesy of Joshua Broder, MD.)

Figure 14. Scaphoid Fracture With Normal MRI For Comparision



Bony cortex is black on all MRI sequences. On T1 images, fat is bright, while fluid is dark. On T2 images or fast T2 images with fat saturation, fat is dark, while fluid is bright. (A.) Normal scaphoid. A T1-weighted thin coronal slice, showing homogeneous marrow fat (bright white). (B.) Normal scaphoid. A T2-weighted coronal slice, showing homogeneous marrow fat (bright white). (C.) Scaphoid fracture. A T1-weighted coronal slice, showing fluid within the marrow space (dark). (D.) Scaphoid fracture. A fast T2-weighted coronal slice with fat suppression, showing fluid within the marrow space (dark). (Image is courtesy of Joshua Broder, MD.)

MRI would be 3/13, or 23%.

Another study of 56 patients undergoing low-field MRI early (within 4 days of injury) and 53 patients undergoing delayed MRI (at 10 days - 6 weeks) for persistent symptoms found 7 scaphoid fractures in the early group as well as 6 radial fractures and 4 other fractures. The late group had 14 scaphoid, 9 radial, and 3 other fractures. The authors performed a cost analysis suggesting reduced overall costs with early, rather than later, scanning.[64] Like other studies of this type, many key assumptions about costs of immobilization and loss of productivity may be incorrect, potentially altering the outcome of the cost analysis.

In a study of 195 patients with suspected scaphoid fracture despite negative initial plain films, 19% of patients had scaphoid fractures, while 14% had distal radius fractures, and 5% had other carpal bone fractures.[60] This study examined patients undergoing MRI within 14 days of injury, so it is not proof of the necessity of MRI from the ED. Nonetheless, it implies that follow-up MRI may be of value in patients with suspected occult scaphoid fracture. This study did not evaluate the percentage of patients in whom these additional fractures would have been detected by follow-up plain films. In addition, without clinical follow-up, it is unclear whether these fractures required additional treatment. The authors assert that management was altered by MRI in 92% of patients, based on a questionnaire administered to the treating physician.[60]

Are Plain Films Sensitive For Acute Scaphoid Fracture?

The true answer to this question is unknown from the literature. Studies show that 7% to 40% of patients with negative initial plain films have scaphoid fractures confirmed on some form of follow-up.[65,66] This wide range reflects variable gold standards and selection bias from losses to follow-up, with patients with true fractures being more likely to seek follow-up due to continued pain. In addition, referral biases depending on the level of concern of the practitioner can significantly influence the reported rate of occult fracture. Not surprisingly, if the clinical practice is to immobilize and refer all patients with any degree of wrist pain, few will have confirmed scaphoid injuries, compared with a population of patients who are referred for exquisite pain and tenderness in the anatomic snuffbox. No large trials have been conducted with equal workup in all patients with wrist injuries, regardless of initial x-ray results and clinical findings.

Are Follow-up Plain Films Sensitive In Detecting Fractures For Suspected Occult Scaphoid Fractures? How Sensitive And Specific Are Follow-up X-rays For The Diagnosis Of Scaphoid Fracture? Do Plain Films Offer Sufficient Inter-Observer Reliability To Be Considered Valid?

A study of 50 sets of initial and follow-up x-rays with paired MRI as the gold standard demonstrated poor inter-observer reliability between 4 expert readers (coefficient was 33%, less than the 60% reliability coefficient generally accepted as the threshold to consider a diagnostic test to be reliable). Moreover, the sensitivity of the individual readers ranged from 9% to 49% and the specificity from 80% to 93%.[67] The authors of this study concluded that follow-up plain films are not a valid method for confirming or ruling out fractures. Unfortunately, studies of this type do not fully answer the questions they raise. This study assumes MRI findings to be true positives and does not consider clinical outcomes in patients. If patients

Key Points

- MRI is recommended by the ACR as the most appropriate test when scaphoid fracture is suspected despite normal plain x-rays.
- MRI is recommended by the ACR as the most appropriate test when hip fracture is suspected despite normal plain x-rays.
- Definitive studies have not been conducted comparing CT and MRI for acute scaphoid fracture. MRI is likely more useful due to better soft tissue contrast for ligamentous and cartilaginous injuries.
- Definitive studies have not been conducted comparing CT and MRI for acute hip fracture. Cost effectiveness of early MRI for suspected scaphoid and hip fractures is suggested by multiple studies.
- MRI is the definitive study for suspected non-traumatic spinal cord conditions including inflammatory, infectious, neoplastic, and compressive conditions.
- Nephrogenic systemic fibrosis is a potentially fatal condition seen in patients with advanced renal disease receiving gadolinium contrast. Dialysis patients and patients with acute renal failure not yet on dialysis are at particular risk.
- MRI may be performed with careful preparation in patients with implanted cardiac pacemakers and defibrillators when benefit of MRI is felt to outweigh risk.
- MRI is believed to be safe in pregnancy, but the effect of gadolinium contrast on the fetus is unknown. Avoid gadolinium in pregnancy whenever possible.

with "negative" plain films but positive MRI have good clinical outcomes when treated with brief immobilization and no surgery, then x-ray may indeed be a valid method for scaphoid evaluation.

A prospective blinded study of 121 consecutive patients with negative initial plain films but suspicion of scaphoid fracture comparing clinical follow-up and additional x-rays with early MRI (within 3 days of injury) as the gold standard found that the combination of repeated clinical examination and repeat x-rays allowed correct diagnosis of all scaphoid injuries within 38 days. However, this protocol was resource intensive with 3 follow-up examinations by hand surgeons, at 10, 24, and 38 days. Patients remained immobilized for extended periods. The authors concluded that repeat examination and x-rays are adequate, though a reader could reasonably conclude that this strategy led to significant delay in ultimate diagnosis. Strangely, the study abstract claims that randomization was used, though no randomization appears to have occurred according to the full study manuscript.[65]

In a study of 42 patients with negative initial plain films but clinical suspicion of scaphoid fracture, MRI revealed an apparent fracture in 33%. The authors also concluded that MRI is 100% sensitive and specific, compared with follow-up x-rays at 6 weeks as the diagnostic standard. The authors also concluded that early MRI is indicated, but arguably follow-up x-rays are equally accurate and are an appropriate diagnostic pathway.[68]

Are Plain Films Adequate In Children With Skeletal Immaturity? Should MRI Be Used For These Patients When Scaphoid Fracture Is Suspected?

Theoretically, plain film may fail to detect scaphoid fracture with high sensitivity in the pediatric patient with skeletal immaturity. A study of 18 children with acute wrist injury found that 4 of 6 fractures detected on MRI were not seen initially on x-ray – though all were evident on follow-up plain film. No fractures were found at follow-up in patients with a normal initial MRI.[69] This study is too small to prove that plain film is less reliable in children or that negative MRI excludes fracture in this patient group. The significance of fractures detected on MRI but not visible on plain film is unknown. Fortunately, scaphoid fractures are thought to be relatively rare in children.[70]

Is CT Scan Useful In Assessment Of Acute Wrist Trauma?

As previously described, the ACR rates CT as intermediate in its appropriateness for assessment of acute wrist trauma, well below MRI. However, CT has potential advantages in the ED. CT is widely available at all hours in many EDs, in contrast to MRI. While CT uses ionizing radiation, CT of the wrist does not expose important radiosensitive organs such as breast, thyroid, and gonads to significant ionizing radiation.[61] The examination can be performed even in pregnant patients with no significant fetal irradiation. No contrast is needed for CT examination. A disadvantage of CT compared with MRI is that CT does not evaluate ligaments and cartilage of the wrist that may be injured and may ultimately require surgical repair.

Limited studies evaluate early CT in the assessment of suspected scaphoid fracture. An observational study of 47 adults found that early CT identified 17 of 18 fractures, including all scaphoid fractures. However, this study was not restricted to radiographically occult fractures – in fact, the authors could not report the number of fractures visible on plain film, so the incremental value of CT is unclear. In addition, verification bias occurred in this study, with some patients undergoing MRI while others were re-evaluated clinically and with repeat x-ray. The authors reported 94% sensitivity and 100% specificity, though without a consistent gold standard these assertions are unproven.[71]

A second study of 29 patients with suspected scaphoid fracture despite normal initial x-rays compared sensitivity of CT with narrow collimation (0.5 mm) and thin (0.7 mm) multiplanar reconstructions to MRI using a 1 Tesla machine with multiple sequences. CT and MRI were performed in all patients within 6 days after trauma, and 6 week follow-up x-rays were used as the gold standard. Follow-up x-rays showed 11 patients (38%) with fractures, including 8 with a cortical fracture and 3 with findings interpreted as trabecular fractures. No false positives were seen with CT or MRI. Early CT identified all cortical fractures but failed to detect trabecular fractures. Early MRI detected all patients with fractures but did not demonstrate 5 of 8 cortical fractures.[58] This small study suggests that CT is highly accurate at detection of cortical but not trabecular fractures and that MRI is superior at detection of trabecular but not cortical fractures. Limits of this study include its small size, which leads to wide confidence intervals for the results. It is not possible to conclude definitively from such a small study that CT or MRI is superior. Moreover, the clinical significance of isolated trabecular fractures without cortical involvement is uncertain. It would be vital to know whether unrecognized isolated trabecular fractures lead to significant disability.

Case reports and small series suggest that CT may miss fractures when neither cortical nor trabecular bone displacement are present, though it is unclear how common or clinically important this scenario may be.[72] A series of 52 consecutive patients with suspected scaphoid fracture undergoing MRI within 7 days of injury found scaphoid fractures in 33% (18/52). CT was performed in 16 of these 18 patients and identified 16 fractures. Workup bias makes interpretation of this study impossible – CT was not performed in patients with negative MRI, so it is uncertain whether it would have detected fractures in this group.[73]

In a retrospective study from the United Kingdom, 118 upper extremity fracture clinic patients with negative x-rays underwent CT. Twenty-two percent had scaphoid fractures on CT. However, this study is subject to referral bias, since patients had already undergone initial evaluation and were presumably sufficiently high-risk to be referred to a specialty clinic. Findings may not be applicable to unselected wrist trauma patients in the ED. In addition, the gold standard for this study was not uniform and the sensitivity and specificity of CT in this setting is not demonstrated.[74] In a study of radiologists' agreement on scaphoid fracture displacement based on x-ray or CT, CT was found to have a higher inter-observer agreement. The authors reported the sensitivity and specificity of x-ray (75% and 64%, respectively) and CT (72% and 80%, respectively) for fracture displacement, although the gold standard in their study is not stated – casting doubt upon these numbers.[75] The authors recommend that CT be performed in all patients with scaphoid fracture to rule out fracture displacement. Because this study examines scaphoid fractures apparent on plain film, the role of CT for radiographically occult fractures is less clear. Other publications have recommended CT classification systems for selecting patients for operative or nonoperative treatment; however, these classification schemes have not been validated.[76]

How Sensitive Is Radionuclide Scintigraphy (Bone Scan) For Occult Scaphoid Fracture?

Scintigraphy has been used to detect bony pathology including scaphoid fracture. Increased tracer uptake in areas of injury results in increased counts in these regions. In a study of 51 patients with suspected scaphoid fracture undergoing 16 detector CT and

Risk Management Pitfalls For Musculoskeletal MRI

1. **When plain films of the wrist are negative but a scaphoid fracture is suspected, immobilization and follow-up x-rays, immediate MRI, or immobilization and early MRI are needed to definitively rule out a fracture**. CT is an alternative when MRI or follow-up is not feasible.
2. **When plain films are negative for scaphoid fracture, scaphoid fracture or other fractures and soft tissue injuries may be detected on MRI.** Warn the patient of this possibility.
3. **When plain films of the hip are negative, MRI may detect non-displaced fracture.** Delayed diagnosis may result in displacement, which has a poorer prognosis.
4. **Gadolinium contrast material may pose a risk of fatal systemic nephrogenic fibrosis in patients with advanced renal disease, including those already receiving dialysis.** The risk is small but avoidance of gadolinium, restriction of the dose, or early dialysis is recommended.
5. **Gadolinium contrast should be avoided in pregnancy when possible, and consent for gadolinium contrast should be obtained from a pregnant patient.** The fetal effect of gadolinium in pregnancy is unknown. Gadolinium crosses the placenta, is excreted by the fetal kidney, and remains in the amniotic fluid.
6. **Patients with cardiac pacemakers may undergo MRI at low magnetic field strength, with careful planning with a radiologist, a cardiologist, and specific consideration of the patient's device.** The ACR does not recommend this practice as routine but on a case-by-case basis with risks and benefits considered. Document your reasons for performing MRI in a patient with an implanted pacemaker or defibrillator, and carefully consider other imaging options. Devices cleared for use in a particular field strength should not be assumed to be safe at other field strengths.
7. **Thermal burns from induced electrical currents may occur during MRI.** All unnecessary metallic material should be removed from the patient – including metal leads and metal foil drug patches. Tattoos may pose a small risk of burns, and even circuits created by the patient's body (such as crossed legs) can result in thermal injury.
8. **Epidural abscesses may be present even in the absence of a neurological deficit. Because the neurological outcome is dependent on the neurological state prior to surgery, early diagnosis is essential, and emergency physicians should insist on early MRI when this condition is seriously suspected, despite a normal neurological examination.** Document your discussion with the radiologist on the need for MRI.
9. **Allergic reactions to gadolinium contrast are described.** Asthma and prior gadolinium reactions should be considered as risk factors.
10. **CT is an alternative to MRI for some emergency applications, including suspected hip and scaphoid fractures.** However, because the ACR ranks MRI as more appropriate for some of these applications, the decision to perform an alternative imaging technique should be documented with the appropriate clinical reasons (eg, MRI unavailable in a reasonable time-frame or contraindications to MRI).

99Tcm-MDP (methylene diphosphonate), 23 apparent fractures were detected on scintigraphy, while only 16 were found on CT. Follow-up radiographs and MRI were used in some cases to assess for fracture in those cases detected by scintigraphy but not CT. These follow-up imaging studies did not demonstrate fractures. The authors concluded that these increased areas of uptake might indicate bone bruising.[77] This study is limited by lack of clinical follow-up. Even if the authors' conclusion is correct, it is not clear that detection of a bone bruise is clinically important. Instead, positive scintigraphy might lead to unnecessary follow-up imaging, immobilization, or surgery. From a clinical perspective, where the goal is to identify patients with scaphoid injuries requiring explicit treatment, these may represent false positive scintigraphy studies in 7 of 35 patients with negative CTs, or a 20% false-positive rate.

A review in the Best Evidence Topic series compared MRI and bone scintigraphy for the diagnosis of occult scaphoid fractures.[78] A MEDLINE search from 1966 until March 2005 found only 4 studies relevant to the question, "In an adult with a [clinically suspected scaphoid fracture] is [magnetic resonance imaging better than bone scintigraphy] at [reaching a diagnosis]?" The authors noted that only 145 patients had been enrolled in studies directly comparing the two modalities, and MRI appeared slightly more accurate based on the studies, with the additional benefit of diagnosing important soft tissue injuries. MRI is also faster than bone scan.[78]

Is MRI Cost-Effective For Evaluation Of Occult Scaphoid Fracture?

If MRI is the most sensitive modality for detection of scaphoid fractures, is emergent MRI a cost-effective strategy? Calculations of cost-effectiveness must include consideration of the economic costs of unnecessary immobilization of suspected fractures that are ultimately ruled out on follow-up (including missed work or decreased productivity) as well as the cost of follow-up imaging and clinic visits. A cost estimate may also vary substantially with changes in assumptions about disease prevalence, the sensitivity and specificity of the diagnostic tests used, and the costs of over-treating and under-treating. An economic analysis conducted in the UK in 2006 found that the mean cost per patient evaluated for suspected occult scaphoid fracture was £144 for immobilization and 2 week follow-up, £302 for MRI, £243 for radionuclide bone scan, £202 for CT, and £113 for ultrasound.[57] This analysis used the best reported sensitivity and specificity for each modality published at that time, which may overestimate the efficiency of each modality and underestimate the cost of each. A more accurate method might be to utilize the mean diagnostic accuracy published for each modality, as this may more closely reflect real-world test performance.

A randomized controlled trial enrolled 28 patients to either MRI within 5 days of injury or usual management consisting of immobilization, clinical follow-up, and repeat x-rays. A cost-effectiveness analysis found MRI to be slightly more expensive on average ($594 U.S.) than management with usual care ($428 U.S.), though there was no statistical difference in this study. Mean cost per day saved from unnecessary immobilization was $44 for MRI[79] – though clearly this cost may vary with the individual's job requirements, ability to function productively despite immobilization, and income. In addition, MRI in the ED might be more cost-effective than MRI on day 5 by eliminating several additional days of immobilization.

A New Zealand study found an average cost of $470 (N.Z.) for early MRI and $533 (N.Z.) for usual care with immobilization, clinical follow-up, and repeat radiographs. The study authors suggested early MRI as a cost-effective strategy.[80] A cost-effectiveness analysis of actual costs of usual care in 124 patients in the UK, compared with hypothetical costs of a variety of early imaging strategies, also found early imaging to be comparable in cost – though the many assumptions in this model make this no more than a hypothesis.[81]

Based on the limited available evidence, MRI appears to be a sensitive and specific modality for detecting scaphoid and other carpal and forearm fractures, as well as important soft tissue injuries. In most cases, MRI of the wrist is probably unnecessary in the ED. Some MRI examinations would likely be unnecessary if clinical follow-up showed no residual wrist pain. Cost-effectiveness models may overestimate the economic benefit of early MRI. CT scan is a reasonable alternative when MRI is unavailable or contraindicated, although non-contrast CT does not allow evaluation of structures such as the triangular cartilage of the wrist. CT arthrography can evaluate these structures when MRI is not possible.

Table 5. MRI Costs

Procedure Description	Procedure Charge/Technical Fee
Hip MRI, without contrast	$800
Wrist MRI, without contrast and again with contrast	$1,800* * Not including fee for contrast material
Spine MRI without contrast	$800 - $900
Spine MRI, without contrast and again with contrast	$1,800

Cost of MRI

The cost of emergency MRI may vary considerably, depending on the hospital charge and radiologist fee. Additional charges for contrast material may occur – between $150 and $300 depending on patient weight and materials used. **Table 5** lists approximate charges for MRI of the hip, wrist, and spine.[82]

How Long Does An MRI Examination Take?

The length of an MRI examination depends on many factors, including the number and types of sequences acquired, patient positioning, and needs for sedation or pain control. Additional time is needed to reconstruct the images, though fast computers make this process brief. Because of the large number of images generated, the time required by a radiologist to review the images may be considerable. Studies on MRI for hip fracture suggest that limited view sequences may be adequate, and these are relatively rapid to perform. A T1 coronal view of the hip can be acquired in as little as 5 minutes.[83] The sensitivity of these limited views has not been well-validated. In general, an MRI of the hip, wrist, or a single region of the spine should be expected to take approximately 45 minutes.

Summary

MR allows musculoskeletal imaging with exquisite detail. It is the recommended imaging modality by the ACR for suspected hip or scaphoid fracture in patients with negative plain film x-rays. Studies suggest high sensitivity and specificity for important conditions such as epidural abscess, nondisplaced femoral neck or intertrochanteric fracture, and scaphoid fracture, though defining an unequivocal gold standard remains difficult. Studies also suggest that early MRI in the ED may be cost effective compared with other diagnostic and treatment strategies. Large prospective studies with strong gold standards are needed to further delineate the relative value of MRI compared with other more available imaging modalities such as CT.

Case Conclusions

The 85-year-old female with suspected epidural abscess underwent contrast CT, which was non-diagnostic due to metallic streak artifact from her surgical hardware as well as the limited sensitivity of CT for spinal epidural abscess. You insisted on MRI that confirmed epidural abscess. Unfortunately, during the 8 hours which elapsed prior to MRI, the patient developed lower extremity weakness which persisted after surgical drainage.

The 70-year-old female with suspected femoral neck fracture underwent MRI that confirmed a non-displaced femoral neck fracture. She was admitted to the orthopedic service and underwent surgical fixation.

The 30-year-old violinist with suspected scaphoid fracture underwent MRI which showed no scaphoid fracture and no other significant bone, ligament, or cartilage injury. You removed his splint and he was able to continue his concert tour as planned.

Note

Higher resolution version of all images in this article can be found online at www.ebmedicine.net/topics.

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Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study, will be included in bold type following the reference, where available.

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CME Questions

1. Verification bias occurs when:

a. All subjects do not undergo the same gold standard testing
b. Researchers know the results of testing
c. Subjects know the results of testing
d. Surgery is not performed to prove the diagnosis
e. Subjects are not sequentially enrolled

2. When reviewing an MR image, pathological processes appear:

a. Bright on all sequences
b. Bright on some sequences and dark on others
c. Dark on all sequences
d. MRI is not useful for identifying pathology
e. Red on all sequences

3. **When reviewing an MR image, bone cortex appears:**
   a. Black on all sequences
   b. White on all sequences
   c. Shades of gray, depending on the pulse sequence
   d. White when gadolinium is used for contrast
   e. White on T2-weighted images

4. **Gadolinium-DPTA is:**
   a. A radionuclide used for contrast in MRI
   b. Dark on all sequences
   c. Essential for all musculoskeletal MRI
   d. Rarely needed for emergency musculoskeletal MRI of the hip and wrist
   e. Safe in patients with renal insufficiency

5. **The overall likelihood of a hip fracture being detected on MRI when plain films are negative is about 5%. When MRI is performed in patients with a high suspicion of injury, the rate of injury is about:**
   a. 5%
   b. 10%
   c. 20%
   d. 30%
   e. >50%

6. **MRI of the hip has been studied primarily:**
   a. In large case-control trials
   b. In large prospective controlled trials
   c. In small retrospective studies
   d. In trials with excellent gold standards
   e. Only in animals

7. **MRI of the wrist for suspected scaphoid fracture has which of the following putative benefits?**
   a. It identifies other unrecognized fractures.
   b. It identifies soft tissue injuries that may require surgical repair.
   c. It rules in scaphoid fracture, allowing earlier surgery.
   d. It rules out scaphoid fracture, allowing earlier mobilization.
   e. All of the above

8. **Which of the following is true of gadolinium associated NSF?**
   a. The condition is common, affecting 25% of patients undergoing MRI with contrast.
   b. Patients on dialysis are not at risk, since their kidneys have already failed.
   c. Patients with severe renal disease but not yet on dialysis are not at risk.
   d. The risk appears dose-dependent, with the greatest risk at large doses.
   e. Sodium bicarbonate administration has been shown to reduce the risk.

9. **Which of the following is TRUE of MRI in pregnancy?**
   a. The ACR states that consent is unnecessary for gadolinium.
   b. Gadolinium does not cross the placenta.
   c. Gadolinium is known to be completely safe in pregnancy.
   d. Low birth weight is a common effect of MRI.
   e. The magnetic field has no known adverse fetal effects.

10. **Which of the following is TRUE of allergic reactions to gadolinium?**
   a. Asthma and prior gadolinium reactions are risk factors.
   b. Diabetes and renal disease are risk factors.
   c. No risk factors have been identified.
   d. They are of no clinical consequence because they are always mild.
   e. They do not occur, because gadolinium is not biologically active.

11. **Regarding pacemakers and MRI, which of the following is FALSE?**
   a. Side effects of MRI could include reprogramming of the device.
   b. Heating of the device or the leads could occur.
   c. MRI is uniformly fatal in patients with these devices.
   d. Patients with pacemakers have undergone MRI safely.
   e. Ventricular fibrillation can be induced.

12. **Thermal burns from MRI have been described with:**
   a. Circuits formed by the patient's limbs
   b. Metal foil drug delivery patches
   c. Metal monitoring leads attached to the patient
   d. Tattoos
   e. All of the above

13. **Which of the following is TRUE of MRI?**
   a. MRI causes radiation exposure by inducing x-ray emission from hydrogen ions.
   b. MRI has perfect sensitivity and specificity for most conditions.
   c. MRI is nonspecific in some conditions, such as back pain and breast lesions.
   d. MRI is widely available and inexpensive.
   e. When MRI shows an abnormality, the lesion always requires surgical intervention.

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An Evidence-Based Approach To Musculoskeletal MRI In The Emergency Department

Broder J. March 2009, Volume 11; Number 3

In this issue of Emergency Medicine Practice, an overview of the technical features of MRI will be presented in order to provide a framework for understanding its limits and potential benefits. Frequently asked questions will be addressed, including the role of contrast in MRI, contraindications to contrast, and contraindications to MRI. Some of the common methodological flaws that limit the internal and external validity of specific studies will be reviewed. A focused discussion will be provided on the diagnostic accuracy of MRI for spinal epidural abscess, occult hip fractures, and occult fractures of the wrist.

EVIDENCE-BASED CLINICAL RECOMMENDATIONS FOR PRACTICE

Key Points	References	Comments
MRI is recommended by the ACR as the most appropriate test when scaphoid fracture is suspected despite normal plain x-rays.	69	A study of 18 children with acute wrist injury found that 4 of 6 fractures detected on MRI were not seen initially on x-ray – though all were evident on follow-up plain film. No fractures were found at follow-up in patients with a normal initial MRI.
MRI is recommended by the ACR as the most appropriate test when hip fracture is suspected despite normal plain x-rays.	9,47	Unfortunately, a clear clinical decision rule for selecting patients for MRI after a negative hip plain film does not exist. Studies suggest that only about 5% of all patients undergoing hip evaluation will have fracture despite negative x-rays. Among those undergoing MRI, the reported rate of fracture is high – over 30% in several studies – indicating that clinicians are relatively astute at selecting high-risk patients for additional imaging.
Definitive studies have not been conducted comparing CT and MRI for acute scaphoid fracture. MRI is likely more useful due to better soft tissue contrast for ligamentous and cartilaginous injuries.	61	The ACR recommends casting with follow-up x-ray in 10 to 14 days or MRI as the most appropriate imaging modalities for suspected acute scaphoid fracture following normal plain x-rays (both receive a score of 8 on the 1 to 9 scale used by the ACR, with 9 being most appropriate). CT receives a score of 4, with the caveat that CT is appropriate if MRI or casting and follow-up are contraindicated.
Definitive studies have not been conducted comparing CT and MRI for acute hip fracture. Cost effectiveness of early MRI for suspected scaphoid and hip fractures is suggested by multiple studies.	45	A limited MRI cost approximately $450 in 1993, compared with $455 for bone scan, $299 for linear tomography (a method rarely used today, not to be confused with computed tomography), and $797 for CT.
MRI is the definitive study for suspected non-traumatic spinal cord conditions including inflammatory, infectious, neoplastic, and compressive conditions.	25	A review of the literature from the New England Journal of Medicine concluded that the single most important predictor of neurological outcome is the patient's neurological status prior to surgery. Therefore, a vigilant effort to diagnose the patient prior to the progression of neurological signs and symptoms is imperative.
Nephrogenic systemic fibrosis is a potentially fatal condition seen in patients with advanced renal disease receiving gadolinium contrast.	13	Dialysis patients and patients with acute renal failure not yet on dialysis are at particular risk.
MRI may be performed with careful preparation in patients with implanted cardiac pacemakers and defibrillators when benefit of MRI is felt to outweigh risk.	17	There are now over 230 published prospective cases of patients with pacemakers safely having undergone low-field MRI.
MRI is believed to be safe in pregnancy, but the effect of gadolinium contrast on the fetus is unknown. Avoid gadolinium in pregnancy whenever possible.	15	The ACR recommends that gadolinium-based contrast agents not be used routinely in pregnancy. Gadolinium-based contrast may be used in pregnancy on a case-by-case basis with consideration of the risk-benefit ratio, which should be documented in the patient's chart.

** See reverse side for reference citations.*

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