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Femoral Head Osteonecrosis: Detection and Grading by Using a Rapid MR Imaging Protocol[1]

PURPOSE: To design and evaluate a limited magnetic resonance (MR) imaging examination that can be performed rapidly and potentially inexpensively in patients with clinical suspicion of osteonecrosis.

MATERIALS AND METHODS: Both a limited and a full hip MR examination were performed prospectively in 179 hips in 92 patients with clinical suspicion of femoral head osteonecrosis. The presence of osteonecrosis was determined by two radiologists. The percentage of involvement of the femoral head weight-bearing surface was evaluated subsequently for osteonecrosis-positive hips on both sets of images.

RESULTS: Both examinations were performed successfully in all cases. Agreement between the limited and full examinations for presence of osteonecrosis was 98.9% (177 of 179 cases; κ, 0.97). Forty-six (92%) of 50 patients with femoral head osteonecrosis at both examinations were placed in the appropriate quartile of percentage of femoral head weight-bearing surface involvement by both readers (weighted κ, 0.94). Incidental findings were made at the full examination that could not be made or were difficult to make at the limited examination.

CONCLUSION: There was excellent agreement between the full and screening MR examinations for both detection of and determining the extent of osteonecrosis. The time and potential cost reduction achieved with a limited examination may allow introduction of MR imaging earlier in the diagnosis of femoral head osteonecrosis, as well as its more widespread use in patient care.

Osteonecrosis of the hip is characterized pathophysiologically by ischemia of bone marrow and eventual death of trabecular bone. The key to the successful management of hip osteonecrosis is early treatment, prior to the onset of subchondral fracture and cartilage damage (1–4). Results of a meta-analysis by Mont and Hungerford (1) of 1,206 hips from 24 studies demonstrated that core decompression is successful in 84% of patients with stage I, 65% of patients with stage II, and only 47% of patients with stage III disease. Early treatment requires early diagnosis, which is made by using a good clinical history and physical examination and diagnostic imaging results. Unfortunately, conventional radiography often does not depict disease until a substantial portion of the femoral head weight-bearing surface is involved.

Magnetic resonance (MR) imaging has been shown to be the most sensitive method of detecting the presence of early femoral head osteonecrosis (5–10). A low percentage of involvement of the femoral head weight-bearing surface is well correlated with favorable outcome in patients with early-stage osteonecrosis (11) and the likelihood of femoral head collapse after core decompressive surgery (12). Using MR imaging, Beltran et al (12) demonstrated that femoral head collapse did not occur when less than 25% of the weight-bearing surface was involved, occurred in 43% of hips when 25%–50% of the surface was involved, and occurred in 87% of hips when more than 50% of the surface was involved. Since conventional radiographic diagnosis is difficult in early stages of osteonecrosis, MR imaging is often used. Thus, two goals in the MR imaging evaluation of early

TABLE 1
Patient Demographics

	Osteonecrosis*	No Osteonecrosis*
No. of Patients	29	63
Male	14 (48)	14 (22)
Female	15 (52)	49 (78)
No. of hips	50	129
Mean age (y)	38.5	48.6
Predisposing history†		
Steroid use	13 (45)	31 (49)
Sickle cell anemia	7 (24)	3 (5)
Alcoholism with hepatitis	2 (7)	2 (3)
History of slipped capital femoral epiphysis	2 (7)	0 (0)
Other or history unavailable	5 (17)	27 (43)

Note.—Data in parentheses are percentages.
* The diagnosis was based on the results of the full MR imaging examination.
† Data are the number of patients.

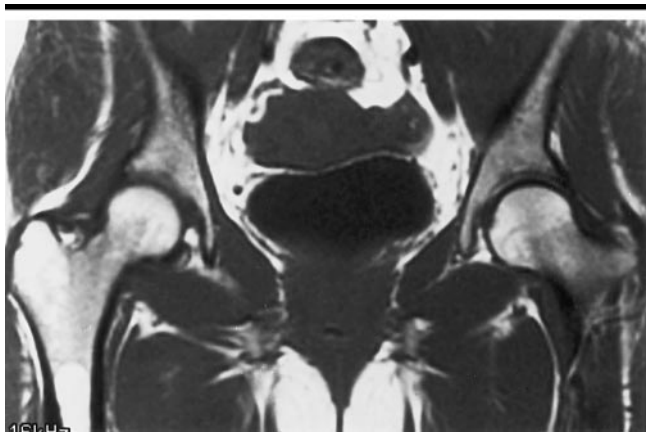


Figure 1. Right groin pain in a 37-year-old woman with a history of sarcoidosis treated with steroids. Normal coronal spin-echo T1-weighted MR image (500/12, 6-mm section thickness) from the limited MR examination shows normal high-signal-intensity bone marrow in the femoral head, without evidence of a low-signal-intensity band of osteonecrosis.

osteonecrosis include (*a*) to determine whether the disease is present and (*b*) to determine the percentage of involvement of the femoral head weight-bearing surface.

Although MR imaging is thought to be the best diagnostic modality for the evaluation of osteonecrosis of the femoral head, its high cost relative to conventional radiography can limit its use early in the diagnostic evaluation in a patient suspected of having femoral head osteonecrosis. The purpose of this study was to design and evaluate a limited MR imaging examination that is rapid and therefore potentially inexpensive for the diagnosis of osteonecrosis. Our hypothesis was that this limited screening examination would be similar to a full hip MR imaging examination in its ability to depict the presence and help in grading the extent of involvement of femoral head osteonecrosis.

MATERIALS AND METHODS

MR imaging studies were performed with a 1.5-T imager (Signa; GE Medical Systems, Milwaukee, Wis). Our technologists were trained to position patients by palpating the greater trochanter and centering the images at that level. A set of coronal T1-weighted scout images was then obtained. This first set of coronal T1-weighted images was defined as the limited examination. Pulse sequence parameters were as follows: 450-600/10-15 (repetition time msec/echo time msec), 6-mm section thickness, 2-mm intersection gap, 38-cm field of view, 256 × 192 matrix, and two signals acquired, which resulted in obtaining 12 images in approximately 3 minutes 30 seconds (Fig 1). The body coil was used for both radiofrequency transmission and reception.

The full examination was defined as images from the limited examination plus three additional imaging sequences: (*a*) transverse fast spin-echo T2-weighted images with fat suppression (4,000–5,000/102, 7-mm section thickness, 2-mm intersection gap, 34–36-cm field of view [adjusted for patient size], 256 × 256 matrix, two signals acquired, echo train length of eight) obtained from the superior end plate of S1 to the pubic symphysis, (*b*) coronal fast spin-echo T2-weighted images with fat suppression (4,000–5,000/102, 4-mm section thickness, 1-mm intersection gap, 34-cm field of view, 256 × 256 matrix, two signals acquired, echo train length of eight), and (*c*) coronal spin-echo T1-weighted images (500/10–12, 4-mm section thickness, 1-mm intersection gap, 34-cm field of view, 256 × 192, two signals acquired). If imaging of only one hip was requested owing to the presence of a unilateral hip arthroplasty (four patients), the full examination protocol was modified with the field of view reduced to 16–18 cm by using a surface coil for signal reception, with the other parameters remaining the same. Patients were positioned carefully for the coronal images to depict the posterior-to-anterior portion of the femoral head.

This imaging protocol was applied prospectively in patients who were suspected of having osteonecrosis of the hip and were referred by orthopedic surgeons or rheumatologists. Over a 62-month interval, 179 hips in 92 consecutive patients (28 male and 64 female patients; age range, 13–83 years; mean age, 45 years) were evaluated. Forty-four patients (48%) were receiving corticosteroid therapy, and 10 (11%) had a predisposing risk factor of sickle cell anemia. The remainder of the patients were suspected of having osteonecrosis secondary to various associated factors (Table 1).

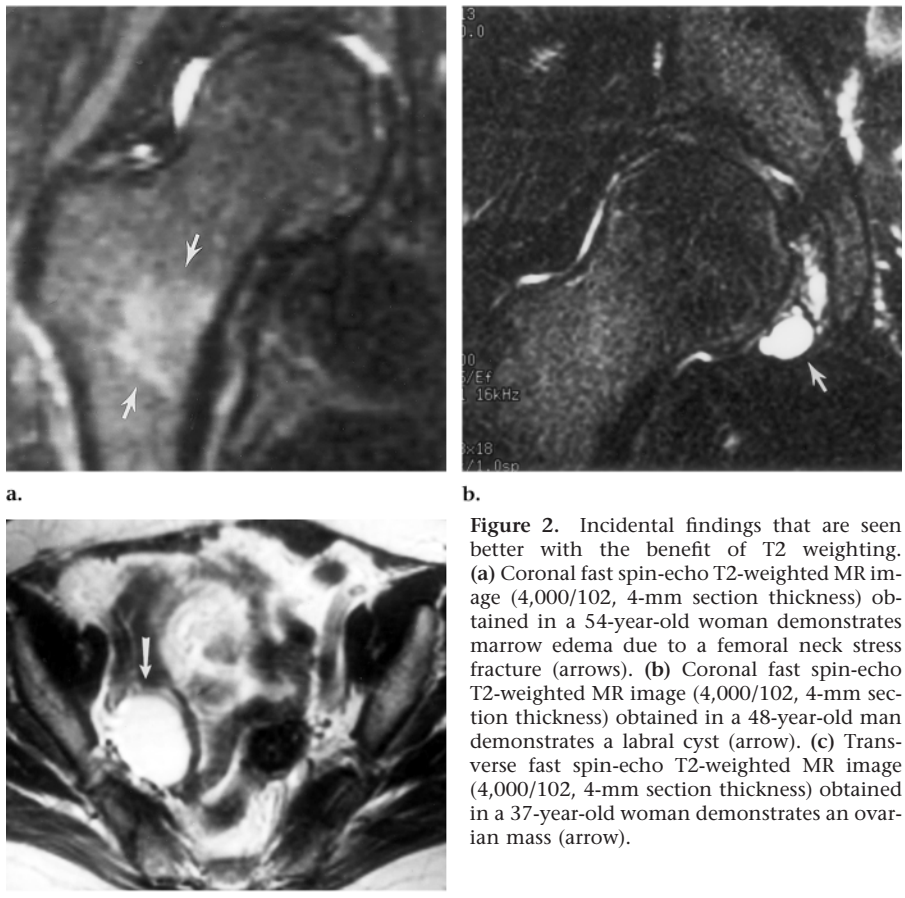
Two readers (D.A.B., A.J.K.) blinded to the final diagnosis and each other's readings first independently reviewed images from the limited examination for the presence of osteonecrosis. The results of the full examination were then interpreted by the same readers and served as the reference standard for diagnosing the presence of osteonecrosis. Images from the limited examination and those from the full examination were reviewed in random order. The images were not magnified prior to interpretation.

The presence of osteonecrosis was de-

TABLE 2
Percentage of Involvement of Femoral Head Weight-bearing Surface

Percentage of Involvement at Limited MR Imaging Examination	Percentage of Involvement at Full MR Imaging Examination			
	<25	26–50	51–75	>75
<25	10	0	0	0
26–50	2	4	0	0
51–75	0	1	11	0
>75	0	0	1	21

Note.—Data are the number of cases.



a. **b.** **c.**

Figure 2. Incidental findings that are seen better with the benefit of T2 weighting. **(a)** Coronal fast spin-echo T2-weighted MR image (4,000/102, 4-mm section thickness) obtained in a 54-year-old woman demonstrates marrow edema due to a femoral neck stress fracture (arrows). **(b)** Coronal fast spin-echo T2-weighted MR image (4,000/102, 4-mm section thickness) obtained in a 48-year-old man demonstrates a labral cyst (arrow). **(c)** Transverse fast spin-echo T2-weighted MR image (4,000/102, 4-mm section thickness) obtained in a 37-year-old woman demonstrates an ovarian mass (arrow).

fined as the presence of a band of low signal intensity in the anterior and superior portion of the femoral head. If present, the percentage of weight-bearing surface involved with avascular necrosis was calculated by dividing the area of femoral head weight-bearing surface involved with osteonecrosis by the total weight-bearing surface of the femoral head by using the technique described by Lafforgue et al (11).

The percentage of weight-bearing surface area involved was recorded by each of the two readers for each hip by using images from both the limited and the full MR examinations. Each reader placed each hip in a category—0%–25%, 26%–50%, 51%–75%, and 76%–100%—as to the degree of involvement of the femoral head. The presence of other findings (eg, masses, fractures, effusions) was recorded for both the limited and the full examinations. A consensus interpretation was determined in discrepant cases for overall statistical evaluation.

Statistical analysis of the data was performed. The κ values were calculated by using commercially available software (Stata 4.0; Stata, College Station, Tex). A weighted κ value was used to assess interobserver agreement for percentage of the weight-bearing surface of the femoral head involved by osteonecrosis.

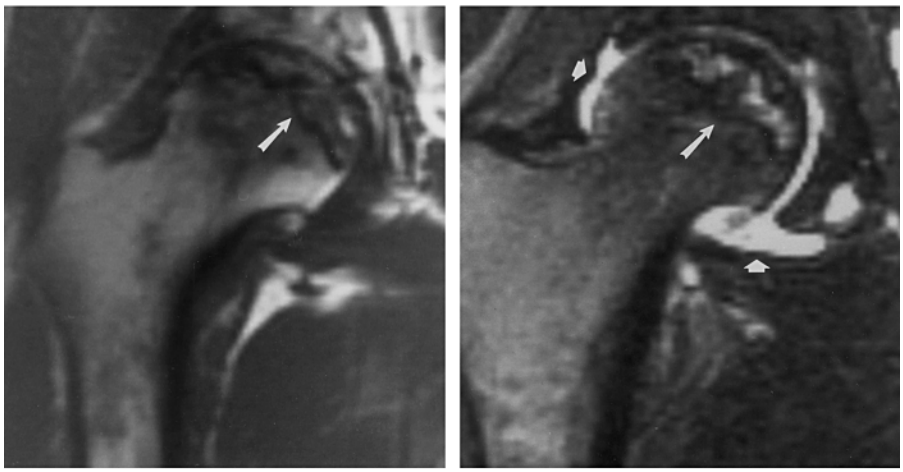
RESULTS

The limited and full examinations were performed successfully in all cases. The mean age of the patients demonstrating osteonecrosis of the femoral head at the full examination was 38.5 years, whereas the mean age for patients demonstrating normal femoral heads was 48.6 years. Twenty-nine (32%) of 92 patients demonstrated MR imaging signs of osteonecrosis in 50 (28%) of 179 hips at the full examination (Table 1).

Images from the limited MR examination failed to depict the presence of osteonecrosis in one patient in whom osteonecrosis was seen at the full examination; this represented a false-negative examination. There was one patient in whom images from the limited examination were interpreted as positive for the presence of osteonecrosis, whereas images from the full examination were interpreted as negative; this represented a false-positive examination. The agreement between the full and screening examinations was 177 (98.9%) of 179 cases; the κ value for agreement between the full and screening examinations was 0.97.

For the hips that demonstrated evidence of osteonecrosis at both the limited and the full examinations, 46 (92%) of 50 patients were placed in the appropriate quartile of percentage of involvement of the femoral head at the limited examination by means of consensus (Table 2). Discrepancies between the full and limited examinations differed by one quartile at most in the remaining patients (percentage of agreement, 97%; weighted κ, 0.94). For interobserver comparison of the quartile of percentage of involvement of osteonecrosis, the readers were completely concordant in 45 of 50 patients. Readers differed by one quartile in four of the remaining patients and by two quartiles in one patient (percentage of agreement, 96%; weighted κ, 0.91).

In addition to osteonecrosis, diagnoses were made by using the full study that could not be made or that were difficult to make by using the limited study. Sixty-five findings other than femoral head osteonecrosis were made at the full MR imaging examination. Only 17 such findings were made at the limited MR imaging examination. Several findings such as spine and hip degenerative arthritis could be seen at both the limited and full examinations. However, other findings such as myositis, greater trochanteric bursitis, and labral cyst required the benefit of the T2 weighting and additional imaging planes provided by the full examination (Fig 2). Images from the full examination depicted the presence of small joint effusions in 22 patients, whereas none were noted at the limited examination (Fig 3).



a. **b.**

Figure 3. Right hip and groin pain in a 34-year-old woman with a history of sickle cell anemia. **(a)** Coronal spin-echo T1-weighted MR image (500/12, 6-mm section thickness) from the limited examination demonstrates involvement of approximately 90% of the femoral head weight-bearing surface of the right hip (arrow). **(b)** Coronal fast spin-echo T2-weighted MR image (4,000/102, 4-mm section thickness) from the full MR examination demonstrates the double-line sign (thin arrow). A small hip joint effusion (thick arrows) is now seen.

DISCUSSION

Conditions that result in interruption of the blood supply of the femoral head, such as femoral neck fracture or sickle cell anemia, clearly are related to the development of osteonecrosis. Other conditions such as corticosteroid therapy, alcohol abuse, connective tissue disorders, and marrow storage diseases also have been associated with osteonecrosis, although the causes are less clear. Exposure to corticosteroids and alcohol intake account for approximately 90% of all reported causes of osteonecrosis (13,14). Regardless of the underlying cause, the major concern in each patient with this disease process is the risk of progression to subchondral fracture and eventual collapse of the femoral head, often in patients who are young and otherwise physically active. Patients at risk for osteonecrosis may have hip pain at various intervals during the course of the disease; this can be disconcerting for health care providers, since conventional radiographs are not sensitive for early-stage disease (5–10).

In contrast to radiographic detection of early osteonecrosis, MR imaging findings of osteonecrosis of the femoral head are detected readily on T1-weighted images (5–10). Furthermore, on T2-weighted images, a double-line sign consisting of a high-intensity inner band adjacent to a low-intensity band has been described and is thought to be specific for the disorder (9,10,15). In our experience, however, this sign is uncommon with the use of fast spin-echo sequences with or without fat suppression and is not necessary for diagnosis of the disease (16).

Osteonecrosis is diagnosed on T1-weighted images as a band of low signal intensity in the anterosuperior portion of the femoral head, and the appearance is characteristic (17). We thus postulated that T1-weighted images alone in the coronal plane would be highly effective in diagnosing osteonecrosis. Furthermore, technologists can position patients easily for hip imaging by palpating the greater trochanter. Therefore, scout images were unnecessary for successful MR imaging of the hips; in this study, diagnostic coronal T1-weighted images of both hips were obtained without additional time obtaining scout images. In 179 hips, one hip was falsely positive for the diagnosis of osteonecrosis, and one hip was falsely negative with the use of only the coronal T1-weighted sequence for diagnosis. Current-generation MR imagers can use higher resolution acquisition matrices and thinner sections than those used in our study. These improvements could potentially further aid in rapid detection of osteonecrosis by using only the coronal T1-weighted sequence.

In addition to disease detection, MR evaluation of osteonecrosis also involves determining the extent of disease. The importance of determining the percentage of involvement of the femoral head weight-bearing surface area has been established. A classification system proposed by Mont and Hungerford (1) combines the Ficat and Arlet (18) staging system, quantification of femoral head involvement by means of MR imaging, and location of the necrotic focus to predict outcome. Lafforgue et al (11) evaluated three different means of determining the degree of femoral head involvement and found that the percentage of weight-bearing femoral cortex involved with osteonecrosis was the most reliable parameter in predicting good clinical or radiographic outcome versus poor outcome. Shimizu et al (5) confirmed these findings and found a 74% rate of femoral head collapse by 32 months if the region of osteonecrosis involved more than two-thirds of the weight-bearing surface area. In our study, the limited examination could be used to determine the weight-bearing surface accurately when quartiles of percentage of the femoral head involved were assigned.

A typical MR imaging protocol of the hips involves both T1- and T2-weighted images, often in multiple planes. At our hospital, this requires about 30 minutes to complete. The limited MR imaging examination that we evaluated for osteonecrosis of the hip required approximately 3 minutes and 30 seconds of imaging time. Although the total MR imaging room time also requires time to position the patient, a limited MR examination of the hips can be performed in about 10 minutes by competent technologists.

At our hospital, the relative costs of the two examinations were $312 for the full MR examination and $104 for the screening examination, not including professional fees. Hospital charges are regulated by the State of Maryland, and charges have been reduced correspondingly for the screening examination from $817 to $258 for the full and screening examinations, respectively, not including professional fees. The corresponding charge for a unilateral hip radiograph is $121. With reduced examination cost that is more comparable to the cost of conventional radiographs, orthopedic surgeons and other health care providers may be more willing to obtain MR images for early diagnosis of osteonecrosis. Our study of the use of limited MR examinations for such screening purposes is ongoing. However, we have also modified our MR imaging procedures to perform rapid T1-weighted screening examinations of the knees and shoulders for patients who are at high risk for multiple sites of involvement of osteonecrosis.

The use of rapid screening MR examinations is not widespread, and a litera-

ture search revealed few examples of this approach. Medina et al (19) showed that a 5-minute brain examination could be used to detect intracranial tumor in children and adolescents. Robertson et al (20) used a 2.5-minute pulse sequence to detect lumbar spondylosis. A fast MR imaging screening protocol for occult lumbosacral dysraphism in children and young adults was unsuccessful relative to a full MR examination (21). In these cited studies, the authors have recognized MR imaging as the superior modality for detecting a specific disease entity. In the case of osteonecrosis, an advantage for the limited MR examination is that the femoral heads are relatively large structures, such that even body coil imaging is successful for disease diagnosis. Thus, the technical requirements are low and the optimal pulse sequence is simple. Together, these factors could aid acceptance by radiologists of the limited MR examination for osteonecrosis.

There are several limitations to this study. First, the study was retrospectively analyzed and used the full MR imaging examination as the reference standard for disease state determination. Second, the patient population and risk factors for disease may affect the usefulness of a limited MR examination. For example, patients with sickle cell anemia may have extensive bone infarcts but new onset of hip pain. In these patients, the radiologist must search for additional causes of the pain, such as osteomyelitis or a septic joint. Patients at risk for osteonecrosis due to prednisone treatment may have hip pain related to fractures or infection that may not be well detected by using the limited MR sequence. Third, our study was performed at high field strength (1.5 T), so the applicability of the method to magnets of lower field strengths is unknown. Finally, at this point we have not demonstrated a direct effect on patient care.

In conclusion, our data support the use of a limited MR imaging examination for the detection of femoral head osteonecrosis and quantification of size. The time saving and the potential for cost reduction achieved with a limited screening examination may allow for the introduction of MR imaging earlier in the care of a patient suspected of having femoral head osteonecrosis, as well as its more widespread use in patient care.

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