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Magnetic resonance imaging of avascular necrosis of the femoral head

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Abstract. This study investigates the role of magnetic resonance imaging (MR) in identifying avascular necrosis (AVN) of the femoral head and in monitoring its therapy. The detection of AVN, particularly in its early stages, is imperative to give therapeutic intervention the best opportunity for successful management. The results of magnetic resonance imaging are compared with those of the standard diagnostic modalities in evaluation of patients with the lesion. Examinations were performed at 0.12 T with a repetition time (TR) of 143 ms and times to echo (TE's) of 10 or 20 ms. This study represents a retrospective review of 90 hips which were examined in 45 consecutive patients. Of these, 52 hips were biopsied as part of treatment. MR was shown to be sensitive in the detection of AVN. Comparison of MR with radionuclide imaging showed comparable sensitivity and specificity. MR was also noted to be sensitive in the detection of early AVN. Preliminary results suggest that MR can monitor treatment of the affected hip, and may even be able to predict patient response to therapy. Although further work is necessary to determine the role of MR in the evaluation of the patient presenting with hip pain, MR is a sensitive method in detecting AVN and in monitoring its course in patients suspected of having the disease.

Key words: Magnetic resonance imaging – Osteonecrosis – Bone disease, hip

Avascular necrosis of the femoral head when treated conservatively typically follows a relentless and progressive course from the time of detection to eventual total hip replacement [7]. Current treatment is aimed at early detection of disease with early treatment by core decompression and grafting and on occasion, electrical stimulation. It is hoped that these surgical interventions may slow the disease process, if not halt and heal the lesion. Magnetic resonance imaging has been applied to the diagnosis of musculo-skeletal disease [5]. There has been a limited experience with MR of avascular necrosis [1, 3, 8]. The purpose of this study is to determine the appearance of avascular necrosis (AVN) on magnetic resonance images, to assess the potential of MR in identifying the lesion and in following the therapeutic management of the patient, and to compare MR with other diagnostic imaging modalities.

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Materials and methods

The available clinical records, radiographic images, and reports of the interpretations of the imaging procedures in 45 patients examined for suspected avascular necrosis of the femoral head were reviewed. The diagnostic examinations included were plain films of the hips and pelvis (PF), routine tomography (TOM), radionuclide scintigraphy (RN), computerized tomography (CT), and magnetic resonance imaging (MR). Some studies were performed at other hospitals and only interpretations were available for review. The interpretations were used in data collection. The sequence of the examinations was not controlled and varied from patient to patient. No attempt was made to limit the interpreters' knowledge of the results of other imaging examinations. However, frequently initial interpretation of the images was performed without such knowledge, and always prior to pathologic diagnosis.

Patients were divided into two groups: those that had pathologically proven AVN from biopsy specimens removed at the time of surgical treatment (38 patients) and those that were not biopsied (seven patients). In 24 of the 38 patients in whom biopsy was performed, the examinations were obtained within one week of each other and in only six patients were the examinations performed greater than a month apart (6 weeks to 8 months). In the seven patients who did not undergo a biopsy,

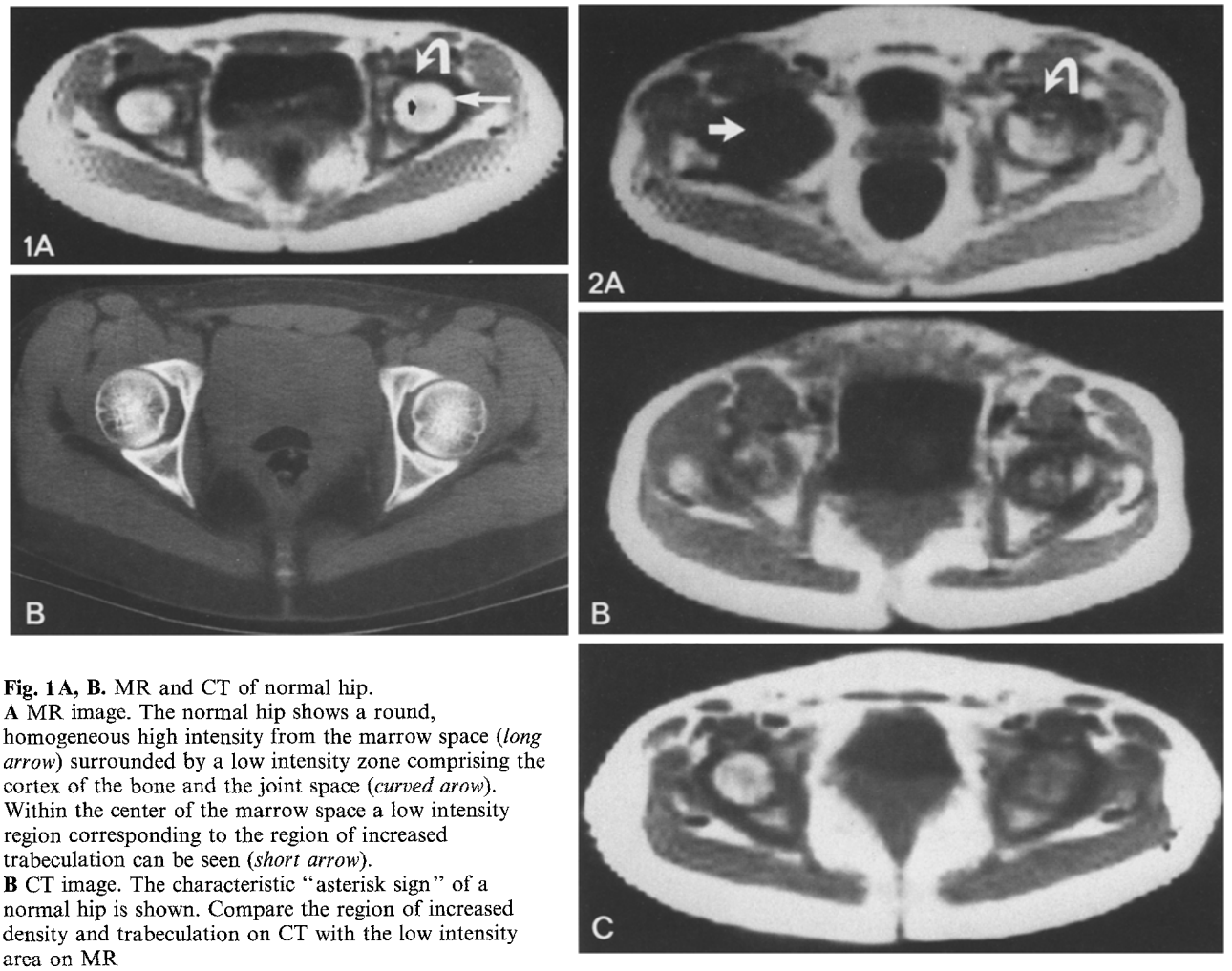

Fig. 1A, B. MR and CT of normal hip.
A MR image. The normal hip shows a round, homogeneous high intensity from the marrow space (*long arrow*) surrounded by a low intensity zone comprising the cortex of the bone and the joint space (*curved arow*). Within the center of the marrow space a low intensity region corresponding to the region of increased trabeculation can be seen (*short arrow*).
B CT image. The characteristic "asterisk sign" of a normal hip is shown. Compare the region of increased density and trabeculation on CT with the low intensity area on MR

Fig. 2A–C. Three patterns of abnormality noted on MR images. **A** Focal decreased intensity. There is a wedge-shaped focal region of decreased signal intensity along the antero-superior portion of the left hip (*curved arrow*). There is lack of both signal and artifact from the right hip in this patient with a total hip prosthesis (*arrow*). **B** In this patient with bilateral disease, there is flattening of the femoral head, in addition to focal regions of decreased intensity. **C** This patient had a diffuse decrease in intensity from the left femoral head

the studies were performed within four weeks of each other in three and greater than four weeks of each other in four (3–6 months).

In five patients with advanced disease who underwent surgery for total hip replacement, the removed hip specimen was imaged by MR and by CT. Those images and the in vivo images were compared to cross-sectional gross pathologic and microscopic sections.

The magnetic resonance images were obtained on a previously described developmental resistive imager operating at 0.12 Tesla [4]. All images were made using a single spin-echo partial-saturation pulse sequence. The repetition time (TR) was 143 ms and the time to echo (TE) was either 10 or 20 ms. Transverse images were obtained of a single slice with a slice thickness which varied between 1 and 2 cm. Data were acquired on a 128×128 matrix and interpolated to 256×256 for display. The imaging time was typically 2.5 minutes per slice.

MR images were displayed at window settings typical for soft tissue detail. CT images were examined at both soft tissue and bone windows. Most radionuclide images included anterior and posterior views of the pelvis, as well as pin-hole views of the hips.

Results

Forty five patients with a high clinical index of suspicion for avascular necrosis of the femoral head were examined by MR. This group consisted of 24 men ranging in age from 24 to 58 years and 21 women ranging in age from 19 to 61 years. A variety of etiologic factors were present in these patients. These consisted of steroid use in 22, alcohol use in five, and trauma in two. In 16, no causative factor was found.

The normal hip on MR appears as a smooth, round, homogeneous high signal medullary portion surrounded by a thin, signal free zone (Fig. 1)

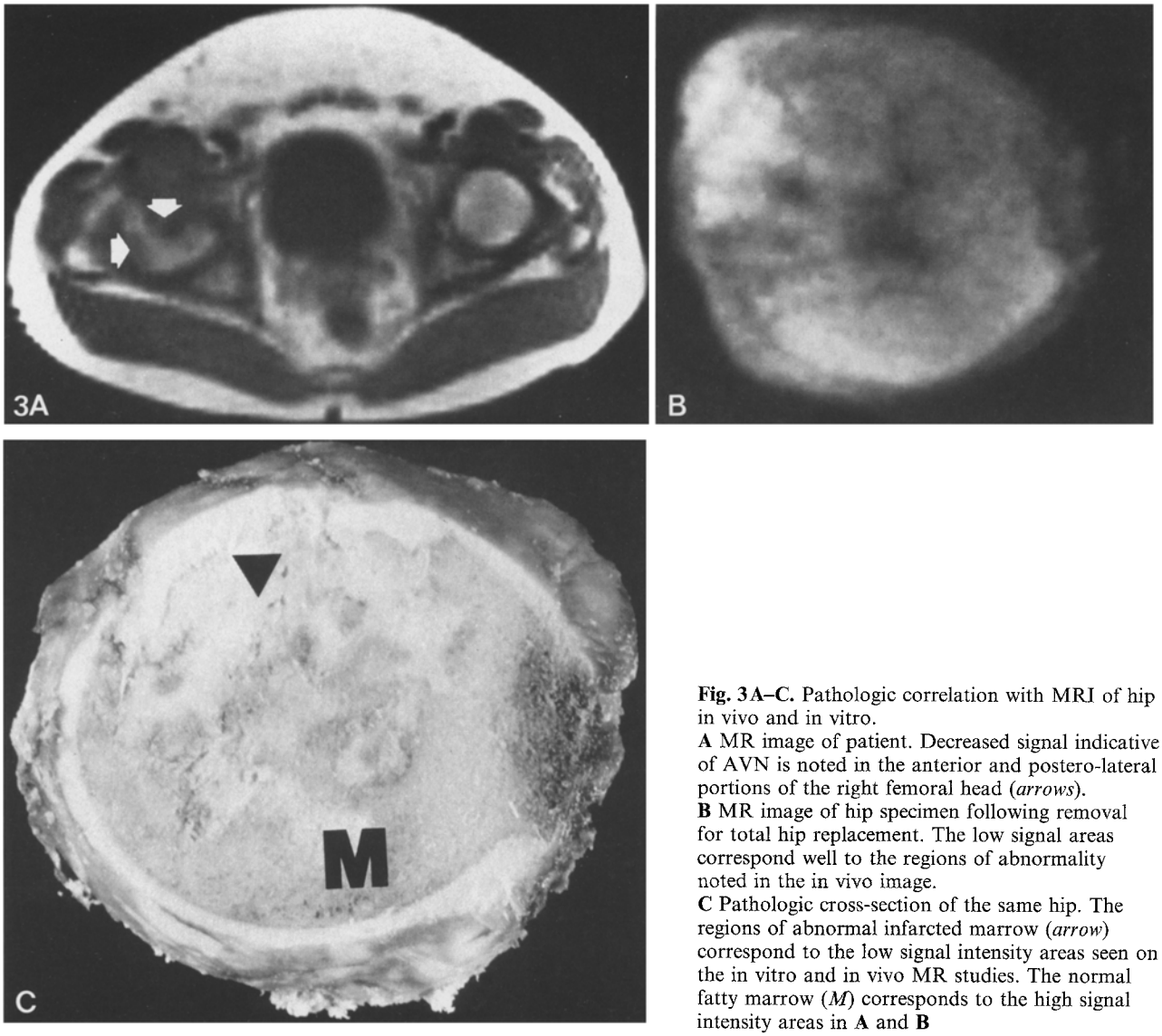

Fig. 3A–C. Pathologic correlation with MRI of hip in vivo and in vitro.
A MR image of patient. Decreased signal indicative of AVN is noted in the anterior and postero-lateral portions of the right femoral head (*arrows*).
B MR image of hip specimen following removal for total hip replacement. The low signal areas correspond well to the regions of abnormality noted in the in vivo image.
C Pathologic cross-section of the same hip. The regions of abnormal infarcted marrow (*arrow*) correspond to the low signal intensity areas seen on the in vitro and in vivo MR studies. The normal fatty marrow (*M*) corresponds to the high signal intensity areas in **A** and **B**

[1]. The high signal from the medullary region is related to the short T1 relaxation time of fatty marrow. The thin signal-free zone is composed of several structures. The cortex of the femur and the cortex of the acetabulum do not produce signal due to the lack of mobile protons within cortical bone. The fluid within the joint space has a long T1 relaxation time which would produce little signal at the repetition times used in this study. With higher field strengths, the cartilaginous surfaces have been seen [8]. In some hips, a region of slightly decreased signal can be seen within the central portion of the medullary space. This corresponds to the area of increased trabecular density as seen on CT images.

Three morphologic patterns were noted in patients with AVN on MR (Fig. 2). In 61 cases (86%), a focal area of decreased signal intensity was noted, typically along the superior and anterior borders of the femoral head. Less commonly a deformity of the contour of the bone was noted. This occurred in the presence of focal areas of decreased signal. In 10 cases (14%), a diffuse decrease in the signal intensity of the marrow space could be noted. Although patients with more severe disease as seen on plain film or CT had severe loss of signal and deformity on MR, some patients who did not exhibit advanced changes on plain film or CT also had marked signal loss on MR. Thus, we could not correlate the appearances of these patterns with the clinical stage and severity of the disease.

In the patients who underwent total hip replacement, the MR image of the specimen showed

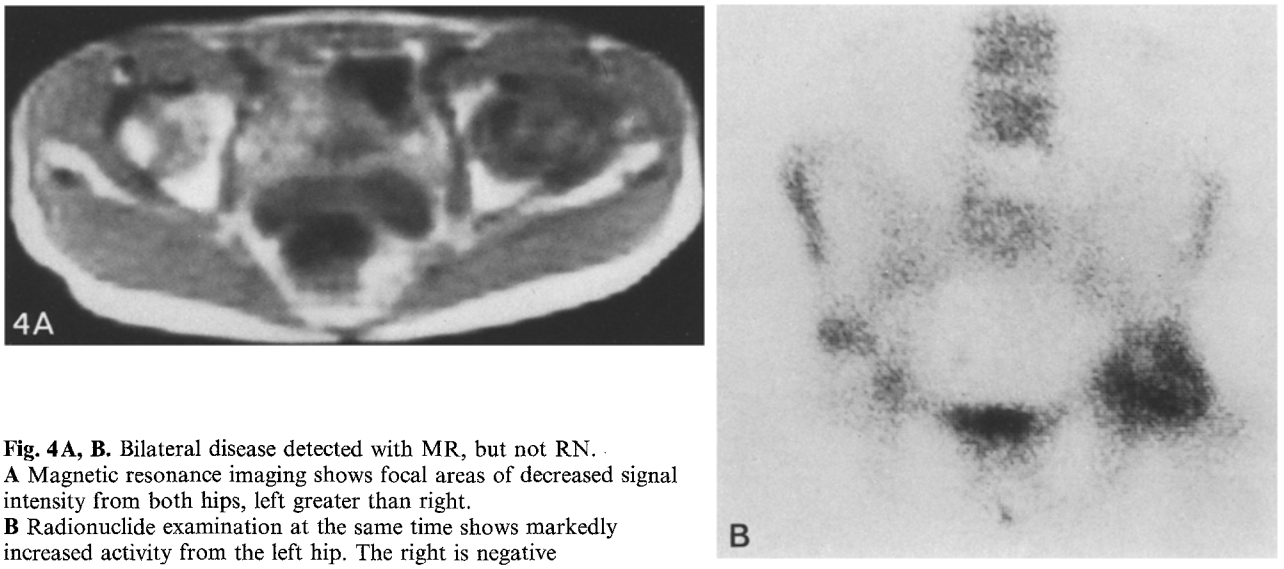

Fig. 4A, B. Bilateral disease detected with MR, but not RN.
A Magnetic resonance imaging shows focal areas of decreased signal intensity from both hips, left greater than right.
B Radionuclide examination at the same time shows markedly increased activity from the left hip. The right is negative

Table 1. Positive results of the various imaging examinations in 52 hips (39 patients) with biopsy-proved AVN

Examination	Positive	Examined
Magnetic resonance	52	52
Computed tomography	38	41
Radionuclide	34	39
Tomography	24	27
Plain film	36	42

good correlation with the images of the hip in vivo. Areas of decreased signal intensity corresponded to areas of sclerosis and cyst formation on CT. Comparison with the pathologic section showed good correlation with the MR of the specimen (Fig. 3). Areas of decreased signal intensity on MR corresponded to the areas of infarcted bone. The high intensity regions on MRI corresponded to the pathologically defined areas of normal fatty marrow.

Of the 90 hips examined in the 45 patients, AVN was pathologically proven in 52. In one hip, the results of biopsy showed fatty marrow. The clinical history and all the radiologic studies suggested AVN. This biopsy result is felt to represent a sampling error. There were 37 hips were not surgically treated and therefore not biopsied.

The results of the imaging tests on the 52 biopsy proven cases of AVN are seen in Table 1. Only the results of studies performed prior to biopsy are included in this analysis. There were some hips which were not studied by all of the different imaging modalities. The MR examination was positive in all cases of biopsy proven AVN. Within this group of patients, CT missed three hips with AVN, radionuclide imaging missed five, and routine tomography and plain films missed three and six hips, respectively.

In 26 hips (21 patients) with pathologically proven AVN, all studies were performed. MR was again positive in each case. In this group, CT missed one, radionuclide imaging missed four, and routine radiography (including plain film and tomography) missed two. These results indicate that MR is sensitive in detecting disease in these proven cases.

We then reviewed the five cases of discrepancy in the radionuclide examination. In three cases, pinhole views of the hips were obtained. The hips were imaged less than one month prior to biopsy. The missed lesions occurred in situations with bilateral disease, particularly when there was a difference in the severity of the disease affecting the hips (Fig. 4).

To obtain an estimate of specificity, data on the hips that were not biopsied were analyzed. A determination of a normal hip was a diagnosis of exclusion. First, hips were judged to be clinically positive. The criteria for clinical positivity were the presence of hip pain, a suggestive clinical history, and at least one positive imaging procedure, excluding magnetic resonance imaging. Although MR may prove to be a very sensitive test for the detection of AVN, this has not been shown conclusively and, therefore, was not used as part of the definition of clinically positive AVN. The hips that did not meet these criteria were called normal.

There were 38 hips in 31 patients that were not biopsied. Of these, 15 hips were normal and 19 hips were clinically positive. In four patients,

Table 2. Results of magnetic resonance imaging in 33 hips (28 patients) that were not biopsied

True positive	18
True negative	10
False positive	4
False negative	1
Sensitivity	94%
Specificity	71%

Table 3. Results in 66 hips (40 patients) studied with both magnetic resonance and radionuclide imaging

	Radionuclide imaging	Magnetic resonance
True positive	45	51
True negative	11	10
False positive	3	4
False negative	7	1
Sensitivity	86%	98%
Specificity	79%	71%

four hips had total hip replacements at the time of the MR examination and these are excluded from further analysis. In another hip, the MR examination was unsatisfactory due to artifact and poor patient positioning. In the remaining 33 hips, MR made a true negative diagnosis in 10 hips (Table 2). There were four false positive decisions. The specificity of MR was 71% and the sensitivity was 94% in this group of patients.

Radionuclide imaging is considered the optimal method for evaluating AVN, and MR must be assessed in respect to this standard. To compare the results of MR and RN, data from both biopsied and nonbiopsied groups were analyzed. There were 66 hips in 40 patients that had both an MR and an RN study. Hips were classified as positive if they had a positive biopsy result or if they were clinically positive by the previously stated criteria. The remaining hips were normal. The results are shown in Table 3. For radionuclide imaging, the sensitivity was 86% and the specificity was 79%. For magnetic resonance imaging, the sensitivity was 98% and the specificity was 71%. These results indicate a slight tendency for better detection of AVN by magnetic resonance in this highly selected group of patients.

An important aspect in the diagnosis of AVN is the detection of early disease. In this study, early AVN in a hip was defined as a positive nuclear medicine examination with a normal plain radiograph. Within this group of patients, there were 12 hips in nine patients that had suspected early AVN using this definition. However, nine hips were positive (five by biopsy and four by clinical picture using the above guidelines). The results of the MR imaging showed eight true positive, three true negative, and one false negative decisions. Note that using the above definition RN made three false positive diagnoses of AVN. It appears that MR is sensitive in the detection of early AVN as defined. However, there was one positive case where MR was performed twice. At the time of the positive radionuclide study, the initial MR scan was normal (Fig. 5). However, on reexamination 3 months later, the MR was positive. This patient underwent surgical treatment 6 months after the initial examination and the hips were positive for AVN.

Using radionuclide imaging as the gold standard for early AVN may exclude some cases of early disease. In this regard, there were two patients in which MR was the only positive study. On follow-up examination, AVN was confirmed in one case by CT 9 months later and in the other by plain film 6 months later (Fig. 6).

Seven patients who underwent decompression and grafting as treatment for their AVN were imaged both before and after treatment. Nine hips were involved in these patients. Comparison of the post-treatment MR with the initial scan showed a recovery of marrow signal intensity in three, no change in signal in four, and a further decrease in signal intensity in two. Although too early to reliably assess the results of therapy, preliminary clinical findings show that two of the three with improvement on the MR image as judged by recovery of marrow signal also showed clinical improvement in mobility of the hip and pain relief. The third patient is stable. The four with an unchanged MR follow-up study are all stable. The two with progressive MR changes of avascular necrosis have also shown clinical worsening.

An attempt was made to compare the pattern of AVN seen on the initial study with the findings of the post-treatment study. In two of the three hips that showed improvement on MR, the initial study showed a diffuse decrease in signal (Fig. 7). All of the hips that were unchanged or worse on follow-uip examination had an initial MR study that showed focal areas of decreased intensity and/or deformity (Fig. 8). These numbers are small and it is too early to determine whether MR will be of value in predicting response to therapy.

Discussion

The MR appearance of avascular necrosis of the femoral head correlates well with the pathologic

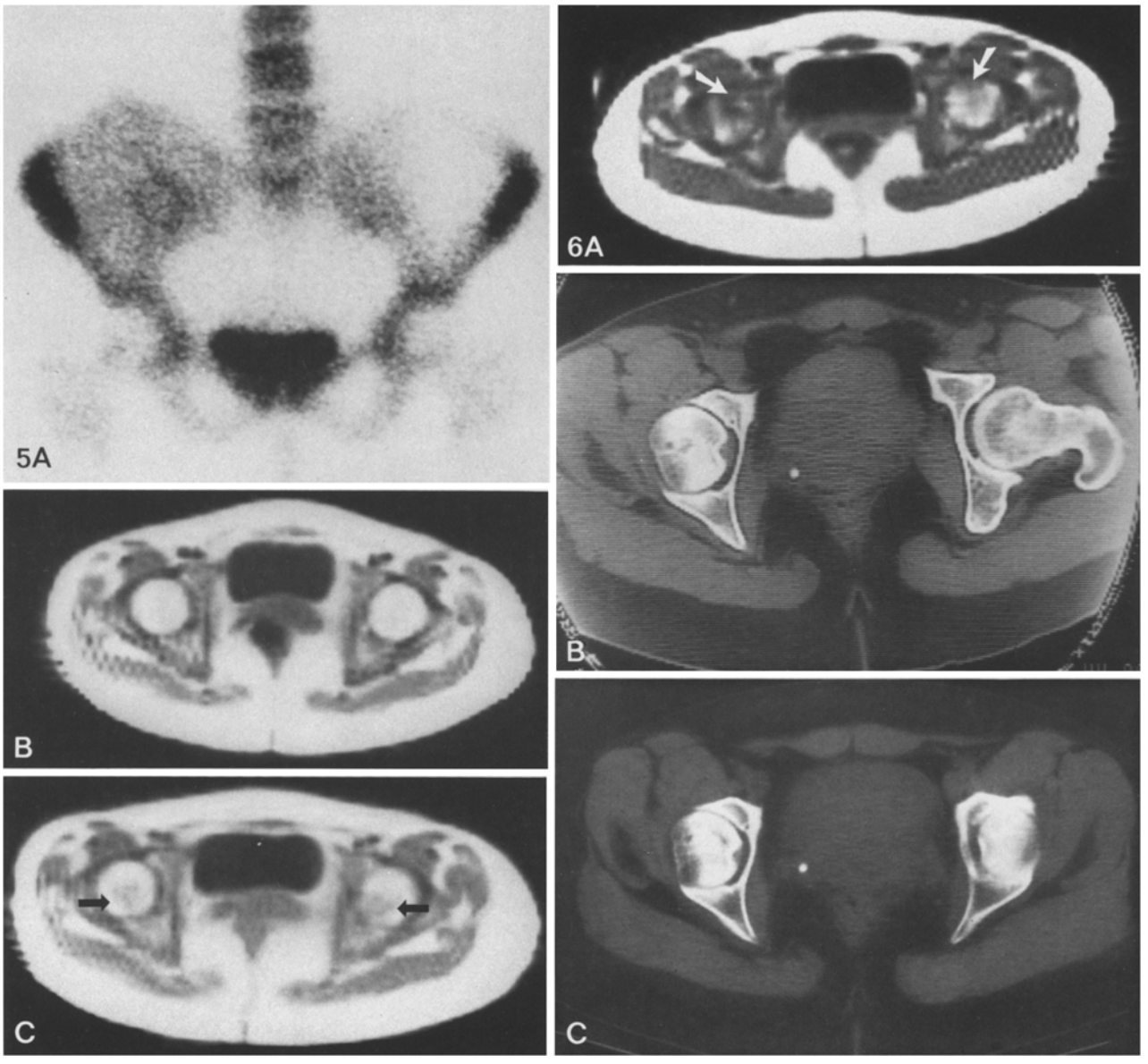

Fig. 5A–C. Early AVN first detected with RN. **A** Radionuclide study shows bilateral photopenic areas in both hips characteristic of early AVN. **B** MR performed at the same time shows homogeneous marrow signal without evidence of AVN. **C** MR performed 3 months later shows areas of decreased signal intensity from both hips (*arrows*)

Fig. 6A–C. Early AVN first detected with MR. **A** MR shows focal areas of decreased intensity from both hips, right greater than left (*arrows*). **B** CT image at the same time shows regions of sclerosis and bone loss anteriorly on the right, but the left is normal. **C** CT image 9 months later again shows changes on the right, but now sclerosis is seen on the left confirming AVN

picture of loss of medullary fat in ischemic regions. The areas of ischemia and necrosis appear as regions of low signal intensity on T1 weighted MR images. The regions of normal fatty marrow appear as areas of high intensity. With the knowledge that the areas of abnormality seen on MR represent the areas of AVN, three aspects of the diagnosis of AVN were examined: (1) the ability of MR to detect the lesion and the comparison of the results of MR with other diagnostic imaging modalities, (2) the ability of MR to detect early AVN, and (3) the role of MR in following the disease.

First, it is important to determine whether MR imaging can detect AVN when it exists, i.e., sensitivity. Typically, AVN is seen on T1 weighted images as varying sized regions of decreased signal intensity within the normally homogeneous high intensity marrow space. The analysis of the data

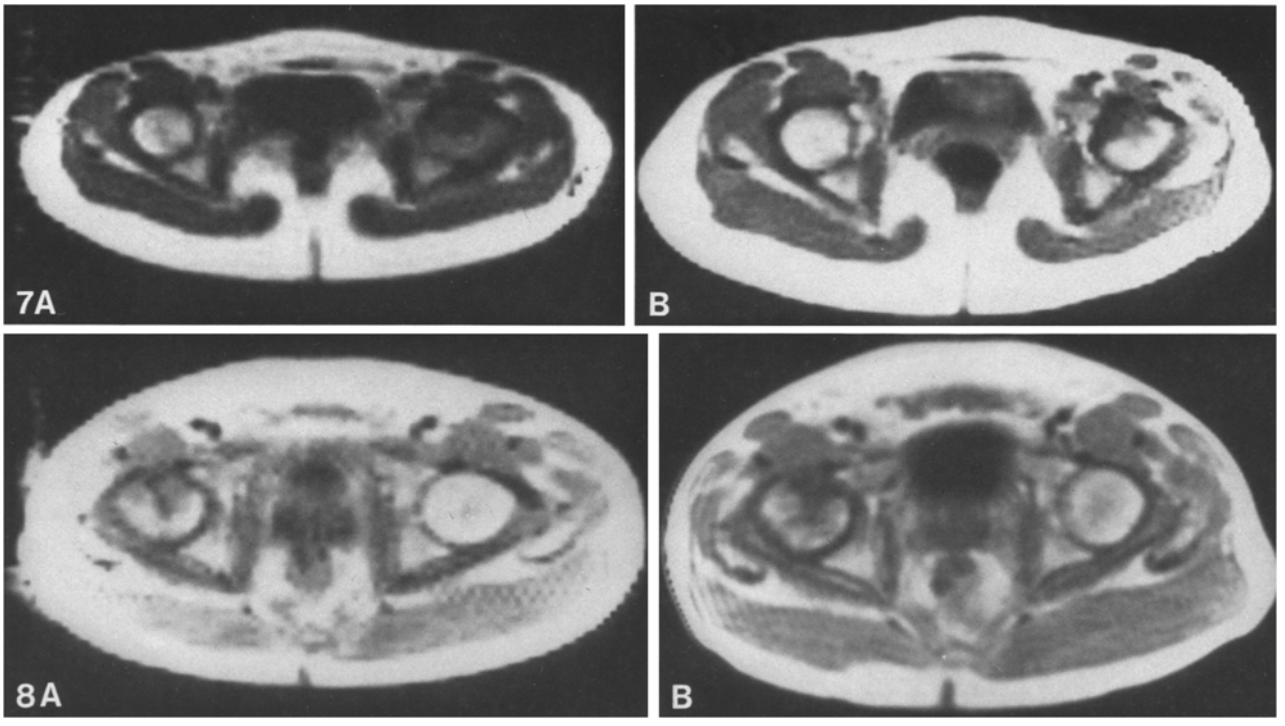

Fig. 7A, B. Improvement following treatment. **A** Initial MR shows diffuse decrease signal intensity from the left femoral head. **B** Following treatment there is recovery of marrow signal intensity

Fig. 8A, B. Worsening after treatment. **A** Initial MR shows regions of focal decreased signal intensity from the right hip. **B** After treatment, there is further decrease in signal from the marrow space

on the biopsy proven hips with AVN shows that MR is a very sensitive test for the detection of AVN. MR was positive in every case of pathologically proven AVN. In this selected group of hips, MR performed better than any of the other modalities. It is interesting to note that the radionuclide study was negative in five of the biopsy proven cases, even with the use of pinhole views. This decreased sensitivity occurred in cases with bilateral involvement. This was true particularly when one hip was in the reactive phase of AVN, and showed increased activity on radionuclide study, while the other hip was in the ischemic phase and showed photopenic areas. Since interpretation of radionuclide study uses symmetry comparisons, when there is bilateral involvement, radionuclide interpretation is hampered. Another factor less commonly encountered was technical. At times, the study appeared as if insufficient counts had been performed, and in some studies pinhole views were not obtained.

Although the sensitivity of a test is important, the specificity also has clinical importance since this reflects the false positive decisions that are made. The results show that MR did produce false positive decisions. However, the specificity was comparable to the radionuclide study and certainly it was within an expected and acceptable range for the clinical population comprising the study. In fact the overall comparison of MR with RN, showed comparable specificity with a slight edge to MR in sensitivity. The differences in the decisions were too small to calculate a statistical difference. Further analysis is necessary to determine which, if either, study is better in the detection of AVN.

The second area examined was the problem of the detection of early AVN. This is of clinical concern because there is evidence to suggest that early surgical intervention may retard or even heal the disease process [6]. Typically, radionuclide study has been the preferred imaging method for the detection of early AVN. Magnetic resonance imaging in patients likely to have early AVN by a positive radionuclide examination but a negative radiograph show that MR is as sensitive in detecting early cases. In this group, the data also show a greater specificity for MR, since no false positive decisions were made. There were three false positive decisions in this group by radionuclide study. Of interest are two cases where MR was the only positive imaging study when the patient first pre-

sented, and AVN was later confirmed by a follow-up study. It appears that magnetic resonance imaging is a sensitive means for the detection of early AVN. This was also suggested by Easton and colleagues [2].

Another subset of patients examined consisted of those who underwent MR following their surgical treatment. This group is of interest because it may allow one to assess the response of the hip to the therapeutic intervention. It is hoped that MR may provide a more accurate and reliable means of assessing therapeutic outcome than that provided by subjective assessments of changes in symptomatology by the patient. In addition, the evaluation of the post-treatment group may provide a means of selecting the appropriate treatment for various patients. Different MR patterns of abnormality may be found that would be predictive of therapeutic outcome.

The average time between surgical decompression and follow-up study was one year. Although this is too short a time to accurately assess the clinical status of the patient, a preliminary assessment indicates that the MR image appearance correlates well with the clinical assessment of the patient's condition. Thus when the MR shows a recovery of signal intensity from the marrow space or no change in size of the regions of decreased intensity, the clinical assessment is one of improvement or stability. The latter is considered of clinical benefit since the disease is generally progressive. When MR showed a progressive decrease in intensity of the marrow cavity of the hip or an expansion of the regions of decreased intensity, the clinical assessment was of further deterioration.

The initial MR examination was somewhat predictive of therapeutic outcome. In those patients who showed improvement on the subsequent MR study, most had a pattern of diffuse decrease in signal intensity from the hip on the initial examination. Those patients who remained stable or worsened showed a pattern of focal decrease in signal intensity or deformity of the femoral head on the initial examination. The number of cases is very small and the period of follow-up is short which makes the significance of this observation uncertain. Further investigation and follow-up is necessary to determine if this observation is correct.

In summary, magnetic resonance imaging is a sensitive method for the detection of avascular necrosis of the femoral head. It appears that MR will also be sensitive for the detection of early AVN. Our preliminary results indicate that MR may have a role in following the therapeutic results and, perhaps, in predicting outcome of surgical intervention. Finally, the sensitivity and specificity of magnetic resonance imaging appears comparable to other techniques. However, this is based upon a selected patient group. In addition, this study is based upon images that are not now state of the art. While these results are encouraging, the role of MR in assessing AVN is likely to be underestimated in light of the recent improvements in MR. We hope that these encouraging results will be substantiated and improved with the newer imagers. Also, further study is necessary to determine the role of MR in the evaluation of the patient with hip pain and in assessing the contribution of MR to the care of the patient with AVN.

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