Extent of Osteonecrosis on MRI Predicts Humeral Head Collapse

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Abstract Although MRI is useful for predicting progression of osteonecrosis (ON) of the femoral head or femoral condyle, predicting outcome of atraumatic osteonecrosis of the humeral head using MRI has not been previously examined. We asked whether the prognosis was related to the extent and location of necrotic lesions on MRI. We investigated 46 radiographically noncollapsed humeral heads in 27 patients, 24 steroid-related and three alcohol-related, using MRI and serial radiographs. The minimum followup was 24 months (mean, 84.9 months; range, 24–166 months). The necrotic lesion was typically located at the medial and superior aspect of the humeral head. The necrotic angle, which expressed the extent of the necrotic lesion, was measured on midoblique-coronal plane (range; 0°–134.7°) and on midoblique-sagittal plane (range; 0°–150.6°). Of the 46 lesions, 34 were less than 90° and did not collapse, whereas 11 of the other 12 lesions of more than 90° (92%) collapsed within 4 years. Of these 11 collapsed lesions, four of less than 100° did not progress, followed by reparative reaction on plain radiographs, whereas the other seven of more than 100° progressed to osteoarthritis. The extent of a necrotic lesion on MRI is useful to predict collapse of the humeral head.

Level of Evidence: Level IV, prognostic study. See the Guidelines for Authors for a complete description of levels of evidence.

Introduction

Atraumatic osteonecrosis of the humeral head (ONHH) generally develops in the subchondral region [1, 2, 4–7, 12, 13, 15–17]. In some patients, osteonecrosis (ON) can lead to collapse of the necrotic subchondral bone, development of an irregular joint surface, and subsequent joint degeneration requiring nonoperative [1, 2] or operative treatment [1–7, 12, 13, 15–17]. The rate of patients with ONHH undergoing surgery varies from 22% to 78% [1, 15, 17] in part because the natural history of corticosteroid- or alcohol-related ONHH is still not well understood. Although one study [5] suggests replacement surgery is related to the radiographic stage of humeral head involvement we did not know which cases would collapse and which would not.

Several studies suggest the extent of a necrotic lesion on radiographs correlates with the prognosis and to the results of surgical treatment in patients with corticosteroid-related ONHH or traumatic ONHH [5, 15]. These two studies reported large lesions in ONHH and patients with collapse on plain radiographs tend to have poor prognoses. However, accurate evaluation of a lesion on radiographs is difficult at best, and impossible in Stage 1 disease, which is not visualized by plain radiograph or CT scan [24]. MRI is superior to radiographs in the early detection of necrotic lesions as well as in evaluating the extent and location of lesions in hip and knee ON [22, 25]. Early diagnosis and understanding of the natural history are important for treatment planning including core decompression [12], statin therapy [20], and alendronate therapy [18].

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Given MRI is a more sensitive tool, we asked whether the likelihood of collapse of corticosteroid-related or alcohol-related ONHH is related to the extent and location of necrotic lesions on MRI. We also asked whether progression or cessation of collapse in ONHH depends on the extent of necrotic lesion visible on MRI.

Materials and Methods

Between April 1993 and May 2004, we diagnosed 220 patients with osteonecrosis of the femoral head by MRI. In these patients, we performed MRI screening of both shoulders, knees, and ankles to identify multiple regions of ON. Atraumatic ONHH was diagnosed by MRI in 29 of 220 patients (13.2%). We reviewed the MRIs of 50 shoulders of these 29 patients with atraumatic ONHH. We included symptomatic and asymptomatic patients. We diagnosed ON as an area of normal fat intensity surrounded by a low-intensity band, band pattern, on spoiled gradient-recalled echo pulse sequence (SPGR) [21, 25]. We used MRI as the gold standard since we could not obtain a histologic diagnosis in asymptomatic patients or those for whom surgery was not indicated. We excluded two patients (four shoulders) because both humeral heads of one patient had already collapsed and the other patient was lost to followup prior to 2 years. Therefore, we included 46 shoulders of 27 patients with noncollapsed, atraumatic ONHH in this study. Thirty four of the 46 shoulders were initially asymptomatic and 12 were symptomatic. Nineteen of the 27 (70%) patients also had knee ON in addition to that of the hip. There were nine men and 18 women. The mean age at diagnosis was 39 years (range, 17–64 years). The minimum followup was 24 months (mean, 84.9 months; range, 24–166 months). The followup period was defined as the period from the day of initial examination to the day of the latest examination or to the day of surgical treatment. Of the 27 patients, 24 had a history of corticosteroid therapy and the remaining three patients had a history of alcohol abuse without any history of trauma around the shoulder. The history of alcohol abuse was defined as more than 400 mL ethanol intake per week [8]. Of the 24 corticosteroid-related patients, 15 also had a history of pulse corticosteroid administration. The underlying diseases in the corticosteroid-related patients were systemic lupus erythematosus in 12 patients and nephritic syndrome in two patients. Four patients underwent bone marrow transplantation with subsequent graft versus host disease. The reasons for corticosteroid administration in the other six patients were Cushing syndrome, pure red cell aplasia, sudden deafness, sarcoidosis, pemphoid, and idiopathic sclerotic pruritis. The mean total dose of prednisolone before the diagnosis of ON was 15.6 g (range,

1.4–35 g). The mean maximum daily dose of prednisolone was 51.4 mg (range, 20–100 mg). Nineteen patients had affected bilateral shoulders.

We (TS and NS) evaluated clinical status at diagnosis and at the latest followup using the UCLA shoulder rating system [9]. Patients were followed every six months.

We examined all shoulders by anteroposterior radiographs at each visit with the arm in external rotation and internal rotation. We (TS and NS) radiographically staged the disease using the Association Research Circulation Osseous international classification staging system [24]. This staging system has been used for the femoral head ON, and we applied it to ONHH. Stage 1 is not apparent on plain radiographs or CT, but is detectable on MRI, bone scintigraphy, and biopsy. Stage 2 disease is apparent on radiographs but without collapse; typically radiographs reveal cysts or areas of increased density in the humeral head. Stage 3 exhibits collapse. Stage 4 has flattening of the humeral head with joint space narrowing (osteoarthritis). In order to investigate the intraobserver reproducibility and the interobserver reliability, we staged the disease based on plain radiographs of the initial examination and the latest followup, and then reviewed them again at 6-month intervals. The kappa intraobserver reproducibility coefficient was 0.90 (TS) and 0.90 (NS), whereas the interobserver reliability coefficient was 0.90 for the initial examination and 0.89 for the latest followup [23].

We performed imaging on patients within 4 months of the diagnosis of femoral head ON using a 1.0-Tesla superconducting magnet (Magnetom Impact; Siemens, Erlangen, Germany, or Signa; General Electric, Milwaukee, WI). To eliminate misdiagnosis, we performed not only SPGR images, but also T2-weighted or fat-saturation SPGR images. T2-weighted spin-echo images (TR/TE = 3600/105 msec), SPGR (TR/TE = 14/2.3 msec), and fat-suppression SPGR were obtained with 1.5-mm slice thickness. The image matrix was 256 × 256. The SPGR and fat-suppression SPGR image data were reconstructed using the Virtual Place-M software (Medical Imaging Laboratory, Tokyo, Japan). We resliced the humeral head on the axial view that included the humeral head center, parallel to the scapula body, and produced a midoblique-coronal image (Fig. 1) because an oblique-coronal image is common for shoulder disease [14]. Then, we also sliced the humeral head on the axial view that included the humeral head center, perpendicular to the scapular body, and produced a midoblique-sagittal image (Fig. 1). MRI images were reviewed for diagnosis by one of the authors (TN) without benefit of clinical or radiographic data.

We (TS, TH) independently estimated the extent of ONHH lesions on midoblique-coronal and on midoblique-sagittal images of the humeral head on SPGR by the necrotic angle (< AOB) of the lesion using modified

Fig. 1A–D (A, B) The necrotic angle ($< AOB$) and the median angle ($< COD$) on midoblique-coronal spoiled gradient-recalled echo (SPGR) images and (C, D) on midoblique-sagittal SPGR images of the humeral head were evaluated as the extent and location of the necrotic lesion.

Kerboul's estimation [10] (Fig. 1). In order to estimate the extent of ONHH lesions in two cross-sectional directions, the necrotic angle was not a sum of angles measured on the midoblique-coronal plane and midoblique-sagittal plane as in Kerboul's original definition. These two angles were recorded independently. The center of the humeral head was defined as point O, and two end points of the necrotic lesion on the joint surface were defined as points A and B. Even if ONHH was present in the humeral head, we estimated the necrotic angle as 0° when a necrotic lesion was not detected on the midoblique-coronal image or on the midoblique-sagittal image. The location of ONHH lesions on midoblique-coronal and on midoblique-sagittal SPGR images was expressed by the median point of each necrotic lesion using the median angle ($< COD$) (Fig. 1), because the range of angle of the necrotic lesion was so complicated as the location analysis. One medial basal point on a midoblique-coronal image or one anterior basal point on a midoblique-sagittal image was defined as Point C. The median point of the necrotic lesion was defined as Point D. The necrotic angle and the median angle were calculated on a computer using the Virtual Place-M software. The intraobserver error ($r = 0.97$) and the interobserver error ($r = 0.80$) were calculated using Spearman's rank test.

We compared the necrotic angle and the median angle among the four latest radiographic stages (stage 1, 2, 3, and

4 disease) using the Kruskal-Wallis test. We used SPSS for Windows 13.0 (SPSS Incorporated, Chicago, IL).

Results

The lesions with initial necrotic angles of more than 90° on midoblique-coronal SPGR images and on midoblique-sagittal SPGR images more often ($p < 0.0001$) progressed to collapsed radiographic stages than those with smaller angles (Table 1). Higher latest stages had greater necrotic angles (Fig. 2). Analysis of the necrotic angle on midoblique-coronal SPGR images revealed 11 of 12 lesions (92%) with more than 90° collapsed within 4 years (Fig. 3A–G), whereas 34 of 34 (100%) lesions of less than 90° did not collapse. In other words, of 46 shoulders with ONHH lesions, including 31 shoulders in Stage 1 and 15 in Stage 2 at the initial examination, 11 humeral heads collapsed (24%) within 4 years (Table 2). The range of the necrotic angle was 0° to 134.7° on the midoblique-coronal plane, and 0° – 150.6° on the midoblique-sagittal plane.

The median angle did not predict progression of ONHH since there were no differences in the median angle among the latest radiographic stages (Table 1). The mean median angle was 51.5° (range, 13.2° – 110°) on the midoblique-coronal plane and 100.7° (range, 69.1° – 131.9°) on the midoblique-sagittal plane. The necrotic lesion was typically

Table 1. Relationship between the MRI angles at initial examination and latest radiographic stage

Angles at initial examination	Stage 1* (22 shoulders)	Stage 2*(13 shoulders)	Stage 3*(4 shoulders)	Stage 4* (7 shoulders)	p Value
<i>Necrotic angle (degrees)</i>					
On midoblique-coronal plane	25.3 (0–94.7)	54.4 (13.6–85.4)	94.7 (90.8–99.2)	113.9 (96.6–134.7)	< 0.0001 [†]
On midoblique-sagittal plane	12.3 (0–102.1)	35.8 (0–72.3)	85.4 (64.5–98.2)	121.8 (100–150.6)	< 0.0001 [†]
<i>Median angle (degrees)</i>					
On midoblique-coronal plane	54.7 (13.2–110)	49.4 (32.6–77.7)	50.8 (39.2–57)	50.1 (22.3–61.8)	NS [†]
On midoblique-sagittal plane	95.5 (86.3–105.1)	106.4 (69.1–131.9)	103.6 (92.8–113.3)	95.6 (76.2–113.7)	NS [†]

*Association Research Circulation Osseous (ARCO) international classification staging system; Stage 1 = not apparent on plain radiographs or CT but are detectable on MRI, bone scintigraphy, and biopsy; Stage 2 = abnormal radiograph with cystic or sclerotic changes in the humeral head without joint collapse; Stage 3 = collapsed stage; Stage 4 = flattening of the humeral head with joint space narrowing; [†]Kruskal-Wallis test; NS = not significant.

Fig. 2 Scattergram of the necrotic angle on spoiled gradient-recalled echo (SPGR) image showed 11 of 12 necrotic lesions (92%) with more than 90° on the midoblique-coronal plane collapsed. Higher latest stages had greater necrotic angles.

located at the medial and superior aspect of the humeral head. In all cases, the necrotic lesion was located within the proximal half of the humeral head on both the midoblique-coronal and midoblique-sagittal SPGR images.

All seven shoulders with a necrotic angle of more than 100° progressed to osteoarthritis. The four shoulders with initially collapsed lesions of less than 100° did not progress, but rather developed a reparative reaction reflected by increased density at the demarcation area on plain radiographs (Fig. 4A–B). Two Stage 4 shoulders underwent hemiarthroplasty at 38 months and at 65 months, respectively.

We treated all 12 initially symptomatic shoulders with nonsteroidal antiinflammatory drugs and the avoidance of overhead shoulder motions. Twenty nine shoulders were

asymptomatic at the latest followup (Table 3). Four shoulders of the three patients with alcohol-related ONHH remained in Stage 1.

Discussion

Several studies suggest the extent of a necrotic lesion on radiographs correlates with the prognosis and to the results of surgical treatment in patients with corticosteroid-related ONHH or traumatic ONHH [5, 15] but these studies were based on plain radiographs. Given MRI is a more sensitive tool, we asked whether the likelihood of collapse of corticosteroid-related or alcohol-related ONHH is related to the extent and location of necrotic lesions on MRI. We also asked whether progression or cessation of collapse in ONHH depends on the extent of necrotic lesion visible on MRI.

Our study has several limitations. First, the number of patients was small. To estimate the extent and location of necrotic lesions accurately, we excluded patients with ONHH who were not examined by SPGR MRI and patients whose humeral head had already collapsed because we could not estimate the lesion size and location on MRI exactly as in the noncollapsed humeral heads. Although the sample size was small, this limitation is compensated for by including only one diagnosis and by ensuring accurate digital measurements of the necrotic lesion. Second, this was not a prospective study. The shoulder SPGR MRI was not always examined at initial examination because we performed shoulder MRI as screening for multiple ON after femoral head ON was diagnosed. However, the present results were not likely influenced by the timing of MRI because all patients were examined on SPGR MRI before the necrotic lesion had collapsed.

The likelihood of collapse of corticosteroid-related ONHH was related to the extent of necrotic lesion on MRI. The lesion with a necrotic angle of more than 90° on midoblique-coronal SPGR images and on midoblique-sagittal SPGR images more often progressed to the

Fig. 3A–G (A, B) A midoblique-coronal spoiled gradient-recalled echo (SPGR) image of a 33-year-old woman with steroid-related ON of the left humeral head showed the necrotic angle was 107.3° and the median angle was 51.5°. (C, D) A midoblique-sagittal SPGR image

showed the necrotic angle was 103.6° and the median angle was 82.4°. (E) An initial anteroposterior radiograph showed no demarcation (Stage 1), (F) Stage 3 at 27 months, and (G) Stage 4 at 42 months after the initial examination.

Table 2. Radiographic stage change (shoulders)

Initial examination		Latest followup	
Stage 1*	31	Stage 1*	22
		Stage 2*	2
		Stage 3*	1
		Stage 4*	6
Stage 2*	15	Stage 2*	11
		Stage 3*	3
		Stage 4*	1

*Association Research Circulation Osseous (ARCO) international classification staging system; Stage 1 = not apparent on plain radiographs or CT but are detectable on MRI, bone scintigraphy, and biopsy; Stage 2 = abnormal radiograph with cystic or sclerotic changes in the humeral head without joint collapse; Stage 3 = collapsed stage; Stage 4 = flattening of the humeral head with joint space narrowing.

collapsed stage. Collapsed lesions of less than 100° did not progress to osteoarthritis, followed by reparative reaction on plain radiographs. The median angle, which expressed location of the lesion, was not useful to prognosticate ONHH.

Large lesions in ONHH and collapsed-stage cases on plain radiographs tend to have poor prognoses [5, 15]. However, predicting outcome of atraumatic ONHH using MRI has not been previously reported, and we did not know which cases would collapse. We found a necrotic

Fig. 4A–B (A) An anteroposterior radiograph of a 17-year-old woman with corticosteroid-related ON of the left humeral head showed Stage 3 at 6 months after the initial examination, and (B) extensive reparative reaction at 1 year.

angle of more than 90° on midoblique-coronal SPGR images and on midoblique-sagittal SPGR images, whereas the location of ONHH on MRI was not related to the radiographic stage progression.

Table 3. Clinical status change

Parameters	Initial examination	Latest followup
Pain UCLA score (points)	9.4 (5–10)	8.7 (2–10)
Total UCLA score (points)	28.9 (21–30)	27.3 (10–30)
Number of symptomatic shoulders	12*	17*
Number of patients with pain on motion	10	15
Number of patients with limited range of motion	3	10
Number of patients with muscle weakness	8	8
Number of asymptomatic shoulders	34	29

*Total number of symptomatic shoulders does not equal the sum of the numbers of patients with each symptom since some patients had more than one symptom.

The necrotic lesion was typically located at the medial and superior aspect of the humeral head, namely the site of glenohumeral contact in approximately 90° of shoulder abduction, like in previous reports [1, 13, 15]. With respect to the anteroposterior location on MRI, the necrotic lesion affected the middle posterior portion to a greater extent than the anterior portion. These findings may be related to the distribution of vessels supplying nutrition. In the humeral head, the blood supply is derived from the anterior and posterior circumflex arteries [3, 11]. The anterolateral ascending branch of the anterior circumflex artery supplies almost all of the area of the humeral head, whereas the posterior circumflex artery vascularizes only the posterior portion of the greater tuberosity and a small posteroinferior part of the head [3].

The goal of treatment for ONHH should be to prevent both collapse of the humeral head and osteoarthritic change. Although most patients were using steroids, the incidence of collapse was relatively low (24%) compared with an incidence of ON of the femoral head of 77% in one study [25]. The lower collapse rate may be related to the locations of the lesions or distribution of stresses in the humeral head. Thus, the course of most patients with corticosteroid-related or alcohol-related ONHH may be better than ON of the femoral head [25]. Nonoperative treatment may be sufficient for small necrotic lesions of less than 90° on the midoblique-coronal images because they will not collapse. Necrotic lesions of more than 90° and less than 100° showed cessation of collapse and extensive reparative reaction. In femoral head ON, even if a necrotic lesion begins to collapse, some cases stabilize without further collapse [19]. In these patients, aggressive surgery may not be necessary. On the other hand, surgery may be inevitable for large necrotic lesions of more than 100° on the midoblique-coronal images. Because patients

with atraumatic ONHH are relatively young [1, 17], total shoulder arthroplasty [1, 2, 6] should be avoided if possible. For young patients, arthroscopic débridement [4, 7] or core decompression [12, 16, 17] may be indicated. The efficacy of these treatment modalities should be assessed after evaluating the extent of necrotic lesions on MRI in the future.

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