

# Bone marrow edema and subchondral fracture in osteonecrosis of the femoral head: analysis with MRI and CT

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**Purpose:** To study the relationship between bone marrow edema (BME) and subchondral fracture in osteonecrosis of the femoral head (ONFH), and to analyze MRI findings of subchondral fracture and correlate them with those of CT.

**Materials and Methods:** Fifty seven hips in 38 patients with ONFH were studied retrospectively. Images were obtained with 1.5-T MRI unit and multidetector helical CT. Selected hips were divided into edema positive and edema negative groups. In each group presence or absence of subchondral fracture and/or collapse of femoral head was assessed, and the MR findings were compared with those of CT.

**Results:** Thirty (52.6%) of 57 hips showed BME during the course of ONFH. In these edema positive group, 29 (96.7%) of 30 hips showed subchondral fracture and/or femoral head collapse, whereas only 7 (25.9%) of 27 hips in edema negative group showed subchondral fracture and/or FH collapse ( $P < 0.0001$ ). A low-signal intensity line on T1 and T2 weighted MR images and linear lucency on CT were the most common patterns of subchondral fracture.

**Conclusion:** Our study showed significant relationship between BME and subchondral fracture/ femoral head collapse and supported the results of previous studies in considering BME as a marker for potential progression of osteonecrosis.

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**Keywords:** Osteonecrosis of femoral head (ONFH), Bone marrow edema (BME), Magnetic resonance imaging (MRI), Subchondral fracture

## Introduction

The appearance of subchondral fracture in osteonecrotic femoral head considered as an indicator for progression of the lesion to advanced stages. In these late-stage lesions surgical intervention is justified. Using Steinberg staging system [1], the following options of treatment are usually conducted: osteotomy for stages III-IV with small lesions, bipolar arthroplasty of the hip joint for stage III-VI with larger lesions, especially in young patients, and total hip arthroplasty for stage V-VI lesions [2, 3]. Because the results of hip replacement are not always satisfactory, the aim of the treatment is to save the femoral head and to avoid replacing it [2-4].

Beside the early diagnosis and accurate staging of osteonecrosis of the femoral head (ONFH), it is essential to know the factors that associated with and may help to predict the course of the disease in order to decide the most appropriate treatment options. Many studies were carried out to examine those factors including the stage [5, 6], extent, and location of osteonecrotic lesion [7-10], clinical symptoms, and presence of bone marrow edema (BME) [11-17].

To the best of our knowledge only one study directly examined the correlation between BME and collapse of the femoral head in steroid-induced osteonecrosis [11]. However, the relation between BME and subchondral fracture of the femoral head was only suspected. This relation was also suspected in other reports studying the association

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between BME and clinical symptoms [12-14], and those studying the MRI finding of ONFH [14-17]. Our purpose was to examine the relationship between BME and subchondral fracture/ femoral head collapse in ONFH. We also analyze the MRI findings of subchondral fracture and correlate them with those of CT scans.

## Material and methods

### *Patients:*

Institutional review board approval was obtained, and the study was conducted in compliance with Health Insurance Portability and Accountability Act. The need for informed consent was waived. Between January 2008 and December 2011, 57 femoral heads with osteonecrosis in 38 patients (17 men, 21 women; age range 21-76 years, mean age  $48.4 \pm 15.7$ ) were recruited consecutively from MR imaging files and studied retrospectively. Hips with severe collapse or secondary osteoarthritis, and those with history of hip trauma (femoral neck fracture or dislocation) or hip surgery were excluded. Selected hips were divided into edema positive and edema negative groups. BME was defined as an ill-defined area of low-signal intensity on T1 weighted images (T1WI) with corresponding high-signal intensity on T2 weighted images (T2WI) and short tau inversion recovery (STIR) images outside the area of osteonecrosis (Fig. 1). The edema positive group consisted of 30 femoral heads in 23 patients (12 men, 11 women; age range 21-74 years, mean age  $42.46 \pm 14.8$ ); the edema negative group consisted of 27 femoral heads in 25 patients (10 men, 15 women; age range 23-76 years, mean age  $51.9 \pm 14.6$ ). In

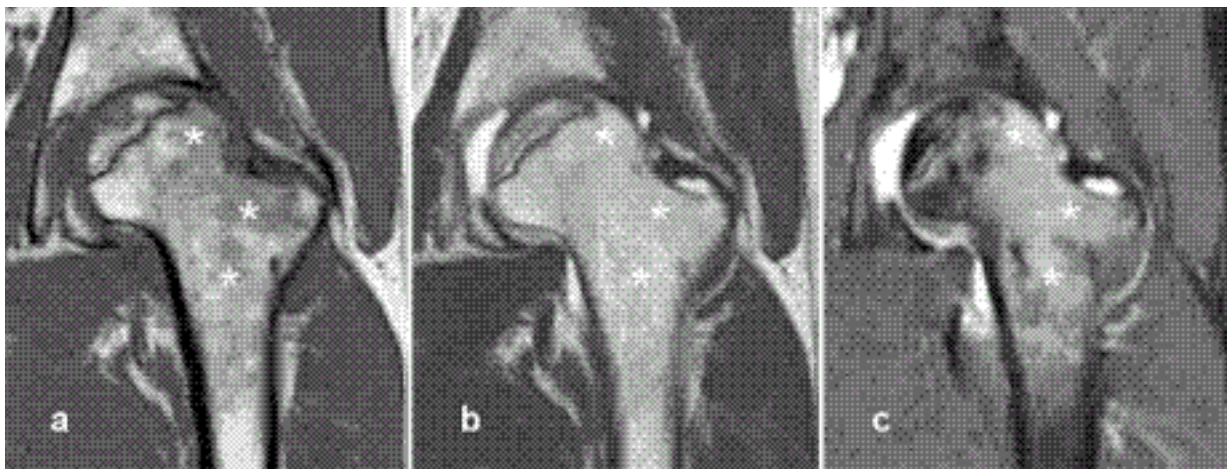
each group presence or absence of subchondral fracture and/or collapse of femoral head was assessed on MRI and CT. The MR findings were compared with those of CT.

### *Imaging techniques:*

MR imaging was performed on a 1.5-T system (Horizon, GE Medical Systems, Milwaukee, Wis.) using a torso phased array coil. Spin-echo (SE) T1WI (TR (msec)/TE (msec), 350-600/14.0), fast SE T2WI (3000/100.8-103.5), STIR images (3000/14.5; inversion time, 160) were obtained in the coronal planes. T1WI (350-600/14.0) and/or T2WI (3000/100.8-103.5) were obtained in the sagittal planes. The field of view was  $32 \times 32$  cm for coronal planes and  $26 \times 26$  cm for sagittal planes. Section thickness was 5 mm with an intersection gap of 1 mm. The matrix size was from  $256 \times 256$  to  $512 \times 512$ , depending on the size of the patients.

### *Imaging assessment:*

All images were evaluated by consensus of two musculoskeletal radiologists (M.U. and T.Y.). MR images were evaluated for the following findings: Extent of BME (in edema positive group), extent of osteonecrosis, presence of subchondral fracture and its signal intensity, and presence of femoral head collapse (in both groups). The extent of BME was graded as follows: localized in the femoral head, extended from the femoral head to the femoral neck, or extended from the femoral head to the intertrochanteric region. The extent of osteonecrosis was graded as follows; mild (less than 15% of femoral head), moderate (from 15% to 30% of femoral head), and severe (more than 30% of



**Figure 1.** Imaging assessment of BME in left femoral head of 47-year-old man. The BME (asterisks) was defined as an ill-defined area of low-signal intensity on T1WI (a) with corresponding high-signal intensity on T2WI (b) and STIR (c) outside the area of osteonecrosis.

femoral head). Subchondral fracture and head collapse was detected by MRI and/or CT. On MR images, a fracture was defined as a curvilinear or irregular subchondral low-signal intensity line on T1WIs and a variable-signal intensity line on T2WIs. On CT scans, a subchondral fracture was defined as a curvilinear or irregular subchondral radiolucent line that may have breached the articular surface.

#### *Stages of osteonecrosis:*

Stages of ONFH were classified according to the system of Steinberg et al. [1]: stage I, normal findings on radiography; stage II, cystic and sclerotic change; stage III, subchondral lucency or crescent sign; stage IV, flattening of the femoral head; stage V, joint space narrowing; and stage VI, advanced degenerative change.

#### *Statistical analysis:*

For evaluation of statistical significance, the Fisher's exact test was performed, and a  $P$  value of less than 0.05 was considered significant.

## Results:

#### *Findings in edema positive and edema negative groups:*

The presence/absence of subchondral fracture/femoral head collapse in each group was shown in (Fig. 2). The re-

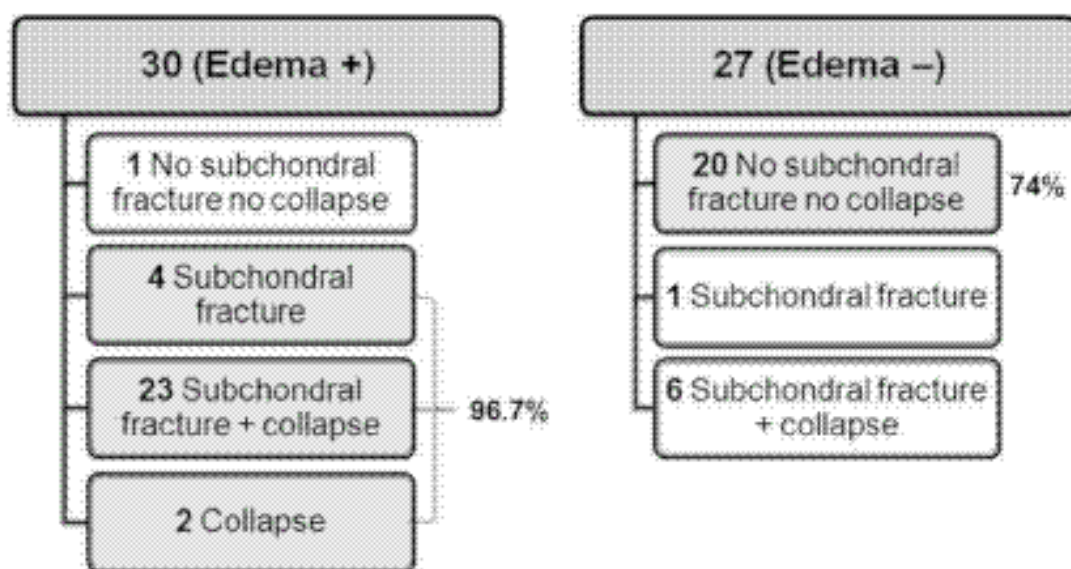
lation between BME and various factors was shown in (Table 1).

Out of total 57 hips with osteonecrosis, 30 (52.6%) hips showed BME, and in 27 (47.4%) hips did not show BME. The grade of the extent of ONFH was as follows: in edema positive group; mild in 13 hips, moderate in 12 hips and severe in 5 hips, in edema negative group; mild in 18 hips, moderate in 4 hips and severe in 5 hips. No significant difference was seen between the two groups (Fisher's exact test;  $P > 0.05$ ). BME extended from the femoral head to the femoral neck in 25 hips (83.3%), and from the femoral head to the intertrochanteric region in 5 hips (16.7%).

Subchondral fracture and/or FH collapse was diagnosed in 29 (96.7%) hips of edema positive group, and in 7 (25.9%) hips of edema negative group. BME was highly correlated with subchondral fracture and with collapse of the femoral head (Fisher's exact test;  $P < 0.0001$ ). Surgical intervention was conducted on 26 hips (86.7%) in edema positive group (arthroplasty in 20 hips, resurfacing in 4 hips, and osteotomy in 2 hips), and only in 6 hips (22.2%) in edema negative group (arthroplasty in 6 hips). Surgical intervention was significantly more in edema positive group (Fisher's exact test;  $P < 0.05$ ).

#### *MRI and CT examination of Subchondral fracture of femoral head*

The total number of subchondral fracture detected in both groups was 34. Twenty nine of them depicted on MRI and 25 depicted on CT. On MR imaging, low signal inten-



**Figure 2.** The presence/absence of subchondral fracture/femoral head collapse in edema positive and edema negative groups

**Table 1.** Relation between BME and various factors

Factor	Bone Marrow Edema					
	Positive (30)			Negative (27)		
Age (mean $\pm$ SD)	42.46 $\pm$ 14.8			51.9 $\pm$ 14.6		
Male : Female	12 : 11			10 : 15		
Extent of ONFH	A (13)	B (12)	C (5)	A (18)	B (4)	C (5)
Extent of BME	H (0)	N (25)	IT (5)			
Subchondral fracture	27			7		
Collapse	25			6		

A= mild; B= moderate; C=sever; H = head; N = neck; IT = intertrochanteric

**Table 2.** Correlation between MRI and CT findings of subchondral fracture

The total number of selected cases (13)		Combined signal intensity patterns of T1WI and T2WI		
		LL (7)	LH (4)	LM (2)
CT	Lucent (8)	2	4	2
	Sclerotic (3)	3		
	Mixed (2)	2		

LL low-low, LH low-high, LM low-mixed

sity was detected in 100% of T1WI (29 hips), 65.5% of T2WI (19 hips), and 58.6% of STIR (17 hips). High signal intensity was detected in 20.7% of T2WI (6 hips), and in 13.8% of STIR (4 hips). Mixed signal intensity was detected in 13.8% of T2W (4 hips), and in 27.5% of STIR (8 hips). On CT examination, subchondral fracture appeared as lucent lesion in 17 hips (68%), sclerotic lesion in 5 hips (20%), and mixed attenuation lesion in 3 hips (12%).

#### *Correlation between MRI and CT findings of subchondral fracture*

Thirteen hips, in which MRI and CT were performed within a period of one month, were selected. A low signal intensity line on T1 and T2 weighted MR images and linear lucent lesion, on CT, were the most common patterns of subchondral fracture. The combination of MR signal pattern of T1WI and T2WI were correlated with CT findings as shown in (Table 2). No significant correlation could be concluded from these data (Fisher's exact test;  $P > 0.05$ ).

## **Discussion:**

In the current study, we confirmed that BME in osteonecrotic femoral head is frequently and significantly associated with subchondral fracture and/ or collapse of the femoral head.

In a previous study of the correlation between BME and collapse of the femoral head in steroid-induced osteonecrosis, Iida et al. [11] found that 11 (84.6%) of 13 hips, in which bone edema was detected, progressed to advanced stages (2 stage III, 9 stage IV), compared to non in those without edema. In study of BME pattern on MRI in ONFH Kim et al. [17] came to believe that the BME appears to be a secondary reaction to the subchondral fracture. They found that from 138 hips showing edema 136 hips (98.6%) were in advanced stages (stag III or higher), while from 205 hips without edema 93 (45.4%) were in advanced stages (stag III or higher). Although Sakai et al. [15] could not confirm the relation between BME and femoral head collapse, we calculated from their results the percentage of the advanced stage lesions (stage III and IV) as follows; 13 (86.7%) of 15 in hips with edema and 9 (27.3%) of 33 in hips without edema. Our results are comparable with these previous studies; we found that 29 (96.7%) of 30 hips in edema

positive group showed subchondral fracture and/ or collapse of femoral head (stage III or higher), compared to only 7 (25.9%) of 27 hips in edema negative group.

Kubo et al. [16], in their study of the initial MRI findings of ONFH in renal allograft recipients, performed MRI examination just after onset of pain in eight of the 12 collapsed femoral heads and they detected BME around the necrotic lesion. Although they suspected that the BME might be induced by collapse of the femoral head, the number of cases was small to confirm their speculation. Huang et al. [14] and Ito et al. [12] both reported that the peak of BME is in stage III lesion; (72%) and (64%) respectively. These studies coincide with our study in showing that the advanced stages (stage III or higher) are more common in lesions with BME.

On the other hand, Koo et al. [13] reported no significant difference between the collapse rate in hips with and without edema; 10 (83.3%) of 12 hips vs. 19 (76%) of 25 hips, respectively. This could be due to the effect of treatment with core decompression they conducted in the occurrence of the edema.

There is no agreement about the mechanism responsible for BME in ONFH. Some investigators have speculated that bone marrow edema could be a secondary reaction to subchondral fractures and collapse of femoral head arising from mechanical stress [11, 12, 16, and 17]. Sakai et al. [15] reported that extrasional reactive changes with diffuse enhancement were detected along the boundary most frequently in stage III hips in the form of dilated vessels and bone marrow edema, which may represent an inflammatory change in the reactive process after collapse of the femoral head. Koo et al. [13] proposed that BME is a secondary reaction after an ischemic attack in the area surrounding the necrotic region, such as brain ischemia. In this explanation, it is not clear why all necrotic femoral heads do not always show bone marrow edema in the course of the disease, and why the time discrepancy between the occurrence of necrosis and the occurrence of bone marrow edema is not consistent. We think that BME does not represent the ischemic change of early osteonecrosis; rather, it represents a secondary reaction to an abnormal mechanical stress due to trabecular micro-fractures. These micro-fractures have high possibility to progress to subchondral fracture and collapse of the femoral head.

For the diagnosis of subchondral fracture of the femoral head we used both MRI and CT. Curvilinear subchondral low-signal intensity line on T1WI constantly used as a diagnostic criterion of subchondral fracture. However, there is no agreement of the signal intensity that should be used

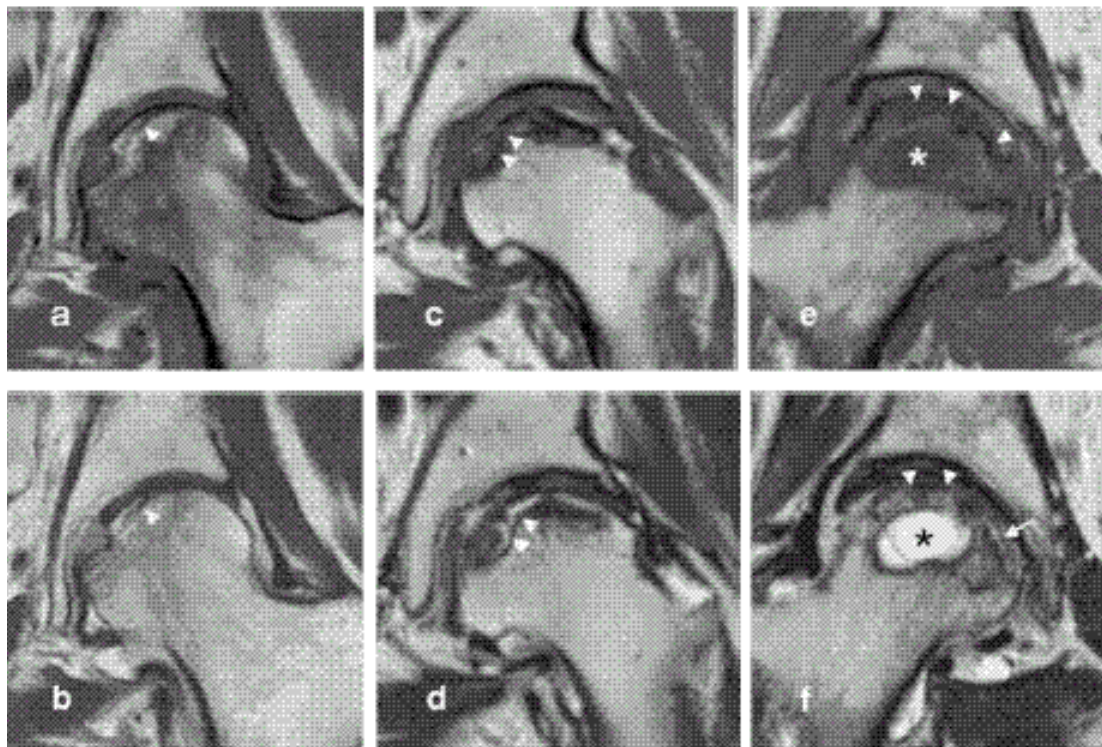
on T2WI. Steven et al. [3] used a high-signal intensity line on T2WI, while Yeh et al. [2] considered high or low signal on T2WI as definitive criterion. In current study we found low-signal intensity line on T1WI in all the cases of the subchondral fracture. On T2WIs low, high or mixed-signal intensity was found (Fig. 3). We believe that mixed and high-signal intensity line on T2WI represents a fracture space filled with fluid partially or completely, whereas a low-signal intensity lesion may represent a fracture with sclerotic change without fluid.

CT was used as the gold standard for detecting subchondral fracture in previous studies [2, 3]. In general, CT is excellent for depicting the cortical surface of bones, an area devoid of signal on MR imaging, and is widely used in trauma to detect fractures. We consider CT as an important and sensitive technique, but not as a gold standard for diagnosis of subchondral fracture. One fracture seen on radiography and MR imaging was not visualized on CT in Steven et al [3] study. In our study 5 fractures seen on MR imaging was not visualized on CT. Our results showed that subchondral fracture appeared as lucent lesion in 17 hips (68%), sclerotic lesion in 5 hips (20%) and mixed attenuation lesion in 3 hips (12%). These sclerotic and mixed lesions may represent the impaction of the fractured trabeculae. As there is no gold standard for the detection of subchondral fracture, both MRI and CT studies could be used for this purpose.

Our study has several limitations. First, a retrospective type of the study may lead us to miss some cases of edema in early stages. Second, we did not include clinical evaluation of pain, because of lacking of pain-scoring system in the medical records. Third, the time difference between MR and CT examinations has exceeded one month in many cases. A prospective study of high risk subjects for ONFH with MRI and CT examination and assessment of clinical condition would be helpful for more precise results. Despite of these limitations, we believe that our results are representative for the significance correlation between BME and subchondral fracture/ femoral head collapse. Also they showed clearly the prognosis in hips with and without edema; surgical intervention was conducted on 26 hips (86.7%) in edema positive group, and only in 6 hips (22.2%) in edema negative group. The fate of osteonecrotic lesion could be predicted and more efficient treatment options could be applied.

In conclusion, BME is strongly correlated with subchondral fracture and femoral head collapse in ONFH. BME should be considered as a marker for potential progression of osteonecrosis.





**Figure 3.** Variable MR signal intensities on T2WI for subchondral fracture in three patients. a, b MRIs of left femoral head in 31-year-old woman show subchondral fracture (arrowheads) as a low-signal intensity line on both T1WI (a) and T2WI (b). c, d MRIs of left femoral head in 52-year-old woman show subchondral fracture (arrowheads) as an irregular line with low-signal intensity on T1WI (c) and high-signal intensity on T2WI (d). e, f MRIs of right femoral head in 74-year-old man show subchondral fracture as an irregular line with low-signal intensity on T1WI (e) and mixed-signal intensity on T2WI (f); the low-signal intensity part marked with arrowheads and the high-signal intensity part marked with an arrow. There is a cystic lesion in the necrotic area (asterisk)

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