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SHORT COMMUNICATION

Clinical and imaging features of a subchondral insufficiency fracture of the femoral head after internal fixation of a femoral neck fracture: a comparison with those of post-traumatic osteonecrosis of the femoral head

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Objective: Recent articles have demonstrated that subchondral insufficiency fractures (SIFs) of the femoral head can occur following internal fixation of femoral neck fractures (FNFs), in addition to post-traumatic osteonecrosis (ON) of the femoral head. The purpose of this study was to determine the clinical and imaging features of SIF after internal fixation of FNFs compared with those of post-traumatic ON.

Methods: We reviewed five hips in five patients, who received internal fixation for the treatment of FNF and were diagnosed as having SIF according to the shape of the low-intensity band on the T_1 weighted MR image. Four hips of four patients with post-traumatic ON were compared with the SIF cases. Both the clinical and imaging findings were investigated.

Results: There were no significant differences in the age, sex, body mass index, stage of FNF or duration from injury to surgery between SIF and post-traumatic ON. Regarding the prognosis, one of the five cases (20%) with SIF underwent prosthetic replacement owing to a progressive collapse of the femoral head. Two of the four cases (50%) with post-traumatic ON underwent prosthetic replacement.

Conclusion: The results of this study suggest that SIF should be considered a possible condition following the internal fixation of FNFs, and it is important to differentiate SIF from post-traumatic ON.

Advances in knowledge: SIF should be considered a possible condition following the internal fixation of FNFs.

INTRODUCTION

Surgical treatment options for femoral neck fractures (FNFs) include internal fixation and hip replacement. It is the consensus that young patients with undisplaced FNFs should be treated with internal fixation. However, post-traumatic osteonecrosis (ON) of the femoral head is a common complication of internal fixation of FNFs.^{1–3}

Post-traumatic ON primarily occurs in patients with displaced FNFs, with a mean overall incidence of 25%.^{1–3} Patients with post-traumatic ON may have relatively mild symptoms; however, approximately half of these patients require prosthetic replacement.⁴ It remains unclear when ON occurs after surgery.

Previous studies have shown that subchondral insufficiency fractures (SIFs) of the femoral head need to

be differentiated from non-traumatic ON, as these two conditions have several features that overlap in both their clinical and imaging findings.^{5,6} Recent articles according to the imaging or histopathological findings have demonstrated that SIFs can occur following internal fixation of FNFs, as well as post-traumatic ONs.^{7,8} Thus, the purpose of this study was to investigate the clinical and imaging features of SIF after internal fixation of FNFs compared with those of post-traumatic ON.

PATIENTS AND METHODS

The institutional review board approved the study. We retrospectively reviewed 27 consecutive hips in 27 patients, who received internal fixation for the treatment of FNF with available post-operative MR images between January 2008 and March 2012. The subjects comprised 5 males and 22 females, with a mean age of

Figure 1. (a) A schematic diagram showing the Garden classification. Stage I: incomplete fracture, valgus impacted; Stage II: complete fracture, undisplaced; Stage III: complete fracture, displaced <50%; and Stage IV: complete fracture, displaced. (b) Subchondral insufficiency fracture (SIF) of the femoral head: the low-intensity band on the T_1 weighted MR image is irregular, convex to the articular surface and discontinuous. Post-traumatic osteonecrosis (ON): the low-intensity band is smooth, concave to the articular surface and circumscribes all necrotic segments.

68 years (range, 38–98 years) at the time of surgery. The fracture type according to the Garden⁹ classification was Stage I in 4 cases, Stage II in 17 cases and Stage III in 6 (Figure 1a). All patients underwent internal fixation using cannulated cancellous screws for the treatment of the FNF. The mean duration from the time of injury (Day 1) to surgery was 2.1 days (range, 1–6 days). The mean duration from the time

of surgery to the MRI examination was 7.8 months (range, 2–24 months). No abnormal findings were observed on the MR images in 16 cases. According to the findings on the MR images, five patients were diagnosed with SIF and four patients were diagnosed with post-traumatic ON (Figure 1b). The mean duration from the time of surgery to the identification of a T_1 low-intensity band in patients with SIF was

Figure 2. A patient with a subchondral insufficiency fracture (SIF) of the femoral head (a 83-year-old female; SIF number 5 in Table 1). (a) An anteroposterior (AP) radiograph obtained at the time of the femoral neck fracture (Garden III). (b) The patient underwent internal fixation using three cancellous screws. (c, d) 6 months after the surgery, bone union of the femoral neck was observed on both a plane radiograph (c) and CT (d). (e) An AP radiograph of the right hip obtained at the onset of pain shows a crescent sign at the superolateral portion of the femoral head (arrows). (f, g) MRI findings at the onset of pain. A coronal T_1 weighted image [repetition time/echo time (TR/TE) = 483/8.5 ms] (e) demonstrating a diffuse low-signal intensity in the femoral head and neck, corresponding with the high signal intensity on a fat-saturated T_2 weighted image (TR/TE = 4000/41.7) (f). (g) The low-intensity band on the T_1 weighted image is parallel to the subchondral bone end plate (arrows). (h) Fat-saturated contrast-enhanced MRI (TR/TE = 683/11.4) in which both the low-intensity band and proximal portion beyond the band exhibit high intensity (arrows). (h) Both protection of the weight-bearing capacity for 4 weeks and teriparatide administration were performed. 5 months after the onset, a radiograph shows no progression of the collapse, and the crescent observed in (c) is no longer apparent.

8.4 months (range, 6–12 months), while in patients with post-traumatic ON, it was 3.5 months (range, 3–4). All five patients with SIF underwent MRI examinations after the onset of hip pain, while three of the four patients (75%) with post-traumatic ON underwent MRI examinations without any hip pain in order to determine the presence or absence of ON. Non-union was observed in two cases.

The diagnoses of SIF and post-traumatic ON were differentiated according to the findings of the T_1 weighted MR images, as previously described.^{6,7} SIF was diagnosed based on the presence of a low-intensity band of the convexity of the articular surface that is irregular, serpiginous and discontinuous (Figures 1b, 2e and 3d), while post-traumatic ON was diagnosed based on the presence of a low-intensity band of the concavity of the articular surface that is smooth and circumscribed (Figures 1b and 4c). The interobserver variability between the two observers (SI and TH) using the kappa statistics was 0.7805, which indicated a substantial agreement.

The MR images were obtained with a 1.5-T MR unit (GE Healthcare, UK). T_1 weighted spin-echo images (repetition time/echo time = 400–668/8–19 ms) and fat-saturated T_2 weighed images (repetition time/echo time = 3000–4000/81–128) in the coronal and axial (and/or oblique axial: paralleling the femoral neck axis) planes were obtained. The ranges of the matrix size, slice thickness and fields of view were 192–256 × 256–512, 3.5–5.0 mm and 330–350 mm, respectively. Images obtained after the administration of 10 ml of gadolinium (Magnevist; Bayer HealthCare, Leverkusen, Germany) with fat saturation were available in one case, and the imaging parameters used to obtain enhanced imaging were similar to those used to obtain unenhanced T_1 images. The duration of the MR examinations ranged from 30 to 40 min.

RESULTS

The clinical findings of patients with SIF and post-traumatic ON are compared in Table 1. There were no significant differences in the sex, age, body mass index, duration from the time of injury

Figure 3. A patient with subchondral insufficiency fracture (SIF) (a 72-year-old female; SIF number 2 in Table 1). (a) Initial radiographs obtained at the time of the femoral neck fracture (Garden II). (b) The patient underwent internal fixation using three cancellous screws. (c) An anteroposterior radiograph of the left hip obtained 3 months after the onset of pain showing the collapse of the femoral head at the superolateral portion (arrows). (d, e) A coronal T_1 weighted image [repetition time/echo time (TR/TE) = 450/17] (d) demonstrating a diffuse low-signal intensity in the femoral head and neck, corresponding with the high signal intensity on a fat-saturated T_2 weighted image (TR/TE = 3000/122) (e). (d) The low-intensity band on the T_1 weighted image is parallel to the subchondral bone and end plate (arrows). (f, g) The progression of both the collapse of the femoral head and joint space narrowing was observed (f); thus, the patient underwent total hip arthroplasty (g).

to surgery or the stage of fracture between the SIF and post-traumatic ON groups. One of the five cases (20%) with SIF underwent prosthetic replacement owing to a progressive collapse of the femoral head (Figure 3). Two of the four cases (50%) with post-traumatic ON underwent prosthetic replacement (Figure 4). The post-operative bone mineral density of the femoral neck was calculated in one case in each group (young adult mean: SIF 67%, ON 64%), and the patients were categorized as having osteoporosis (young adult mean 70% = T-score -2.5 standard deviation).

DISCUSSION

In this series (27 consecutive patients, who received internal fixation for the treatment of a FNF with available post-operative MR images), five patients (18.5%) were diagnosed with SIF and four patients (14.8%) were diagnosed with post-traumatic ON, according to the findings of the MR images, which indicate that SIF should be considered a possible condition following internal fixation of FNFs. Therefore, it is

important to differentiate SIF from ON at the early stage, as some patients with SIF have been reported to heal following conservative therapy.^{10,11} In patients with SIF, the shape of the low-intensity band on T_1 weighted MR image is generally irregular, serpiginous, convex to the articular surface and often discontinuous (Figures 2e and 3d).^{5,6} In contrast, in patients with ON, the low-intensity band is generally smooth, concave and circumscribes all necrotic segments, as the low-intensity band represents the repaired tissue (Figure 4c).^{5,6} On the enhanced MR image of SIF, both the low-intensity band and proximal portion tend to exhibit a high intensity, as observed in our case^{6,7} (Figure 2g). In patients with ON, because the proximal portion beyond the band represents an osteonecrotic area, it is not enhanced.^{6,7}

Kawasaki *et al*¹² revealed that the development of post-traumatic ON can be predicted within 6 months after surgery on MRI. In the present study, the mean duration from the time of surgery to the identification of the T_1 low-intensity band in patients with

Figure 4. A patient with post-traumatic osteonecrosis (ON) (a 73-year-old female; ON number 4 in Table 1). (a) Initial radiographs obtained at the time of the femoral neck fracture (Garden II). (b) The patient underwent internal fixation using three cancellous screws. (c) The low-intensity band on the T_1 weighted image (repetition time/echo time = 516/10) is concave to the articular surface (arrows). (d, e) A collapse of the femoral head was observed (d); thus, the patient underwent total hip arthroplasty (e).

post-traumatic ON (3.5 months) was shorter than that observed in patients with SIF (8.4 months). Therefore, the timing of the MRI examination after internal fixation of a FNF may be useful for differentiating SIF from post-traumatic ON, in addition to the findings of MRI. Further prospective studies with scheduled MRI evaluations are necessary.

T_1 low-intensity bands (fracture lines) on coronal MR images were observed mainly at the weight-bearing portion in SIF cases reported previously,^{5,6} while those in the present study were observed at the lateral portion of the femoral head (Figures 2c and 3d). We consider that valgus deformities of the femoral head (Figures 2b and 3b) might be associated with the portion of the low-intensity band in SIF cases after internal fixation of a FNF.

Both protecting the weight-bearing capacity and administering drugs, including non-steroidal anti-inflammatory drugs and/or bisphosphonates, are crucial for the conservative treatment of SIF.⁷ Recently, teriparatide has been used to accelerate fracture healing and treat severe osteoporosis.¹³ In the present study, one patient with SIF was administered teriparatide subcutaneously. 3 months after the onset, the

patient reported that the hip pain had resolved. No collapse of the femoral head was observed on radiographs 12 months after the surgery.

There are some limitations associated with the present study. The first is the small number of cases examined (SIF: five cases, post-traumatic ON: four cases). Therefore, our results have limited validity, and statistical analyses were not performed owing to the small number of patients in the study. Further studies with a large number of cases are necessary to determine the useful clinical and imaging features for differentiating SIF from post-traumatic ON. The second limitation is that contrast-enhanced MR images were obtained in only one of five patients with SIF. In our institution, contrast-enhanced MRI is performed only in cases in which differentiating SIF from ON is difficult using non-enhanced MRI. The third limitation is that no histopathological findings were observed. However, a previous histopathological study showed that ON and SIF can be differentiated according to the shapes of the low-intensity band on the T_1 weighted images.⁶ The fourth limitation is that the timing of the MRI examination after surgery varied in each case. Further prospective studies with scheduled MRI evaluations are

Table 1. Clinical data for subchondral insufficiency fracture (SIF) and post-traumatic osteonecrosis (ON) groups

Case	Age (years)	Gender	BMI (kg m^{-2})	Follow-up (months)	Garden classification	Injury to surgery (days)	Prognosis	
							Collapse	Treatment
1 (SIF number 1)	85	Male	17.2	12	II	1	–	Conservative
2 (SIF number 2)	72	Female	23.1	12	II	2	+	Prosthetic replacement
3 (SIF number 3)	53	Female	20.1	18	II	2	+	Conservative
4 (SIF number 4)	77	Female	22.0	12	II	4	–	Conservative
5 (SIF number 5)	83	Female	23.7	12	III	3	–	Conservative
6 (ON number 1)	84	Female	19.2	24	III	5	–	Conservative
7 (ON number 2)	60	Male	21.0	36	III	1	–	Conservative
8 (ON number 3)	82	Female	19.1	8	II	1	+	Prosthetic replacement
9 (ON number 4)	73	Female	17.3	12	II	3	+	Prosthetic replacement

BMI, body mass index.

Follow-up, duration from the surgery for the treatment of the femoral neck fracture to the final follow-up (end point: prosthetic replacement).

necessary to determine the optimal time point for MRI examinations to detect post-traumatic ON, as well as differentiate SIF from ON. The final limitation is that bone density measurements were obtained in only two cases. We consider that osteoporosis was present in the majority of cases because the patients had a history of FNF without high-energy trauma. However, it is necessary to obtain bone density measurements

using dual-energy X-ray absorptiometry to treat osteoporosis post-operatively.

In conclusion, SIF is an important condition that must be differentiated from post-traumatic ON, particularly when a low-intensity band on T_1 weighted images is observed at the femoral head following internal fixation of FNFs.

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