Prognostic Factors Associated with a Subchondral Insufficiency Fracture of the Femoral Head

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Purpose

Subchondral insufficiency fractures of the femoral head (SIF) often occur in osteoporotic elderly patients [1-9]. Patients usually suffer from acute hip pain without any obvious antecedent trauma. Radiologically, a subchondral fracture is seen primarily in the superolateral portion of the femoral head [4, 5, 10]. The T1-weighted magnetic resonance (MR) images reveal a very low-intensity band in the subchondral area of the femoral head, which tends to be irregular, disconnected, and convex to the articular surface [2, 4, 5, 7, 9, 11]. This low-intensity band in SIF was histologically proven to correspond with the fracture line with associated repair tissue [5, 9]. Some cases of SIF resolve after conservative treatment [5, 11-14], while others progress until collapse, thereby requiring surgical treatment [4-10, 15]. The prognosis of SIF patients remains unclear.

The purpose of this study is to investigate the risk factors that influence the prognosis of SIF based on the progression to collapse.
Methods and Materials

The present retrospective study was approved by the institutional review board at the Kyushu University.

Patients

We retrospectively reviewed 29 consecutive patients who were diagnosed with SIF between 2002 and 2009 at our institution and followed for at least 2 years. There were 8 male subjects and 21 female subjects, ranging from 16 to 88 years of age (mean age, 57.5 years). Patients with a history of any surgery, infection in the hip joint or Perthes disease were excluded. The body mass index (BMI) (16) and the follow-up period were documented for all patients. Of the 29 patients, 4 had a known diagnosis of osteoporosis (3 patients used bisphosphonates), 3 had a history of corticosteroid therapy, and 1 had chronic renal failure. No patients had any other stress fractures or syndromes of transient osteoporosis. In young patients (under 30 years of age), blood and hormonal examinations were performed, which revealed no conditions that predisposed these patients to osteoporosis, such as hyperparathyroidism or abnormalities in calcium or phosphate metabolism. The bone mineral density measurements were performed by dual energy X-ray absorptiometry (DEXA) in 12 patients.

The diagnosis of SIF was based on the following published criteria (4, 5, 10): (1) hip pain that began without any apparent history of trauma; (2) radiographs that were normal or that showed the collapse of the femoral head and/or a linear patchy sclerotic area in the superior portion of the femoral head; a bone marrow edema pattern in the femoral head and/or neck on the MR images; and (3) a subchondral low signal intensity band on the T1-weighted MR images which was serpiginous, or paralleled the articular surface.

All patients were initially administered conservative treatments, which consisted of anti-inflammatory drugs and the avoidance of weight bearing for 6 to 8 weeks.

Radiological measurements

Radiographs were taken using the same technique throughout the study period. The presence of the collapse at the first attendance was evaluated on the anteroposterior (AP) radiographs. We evaluated the progression of a collapse 12 months after the first attendance. Twenty-nine injured hips were divided into 2 groups: non-progression of a collapse group (Group N) and progression of the collapse group (Group P). All of the patients in Group N resolved after conservative treatment, while all of the patients in Group P underwent surgical treatment (hip arthroplasty or anterior rotational osteotomy).
The following radiographic measurements were investigated using a radiograph taken at the first attendance: Sharp angle (17), center-edge (CE) angle, acetabular roof angle (ARA) (18), acetabular head index (AHI) (19) (Figure 1).

Two authors (KI, RY) independently investigated the radiographs of all patients. All markings and reference points were determined on a radiograph, including the femoral head center, lateral acetabular margin, and the distal point of teardrop, by two authors. After this process, one of the investigators (KI) performed the measurements. To test the reproducibility, one author (KI) measured all radiographs two times, with an interval of 2 weeks between measurements. These values were averaged and statistically analyzed.

**MR imaging evaluations**

Twenty patients underwent an examination using a 1.5-T MR system (Siemens MAGNETOM Symphony or Vision (Siemens AG, Munchen, Bayern, German); Philips Achieva (Philips Medical Systems, Amsterdam, Netherlands)), and 9 patients underwent examination using a 3.0-T MR system (Philips; Achieva, Amsterdam, Netherlands). The T1-weighted MR images (repetition time/echo time [TR/TE] = 400-600/8-19 msec) and T2-weighted MR images (TR/TE = 3000-4000/81-108) in the coronal and oblique axial planes (paralleling the femoral neck axis) were available for all patients.

(1) The band length, (2) band thickness, (3) length of the weight-bearing portion, and (4) band length ratio were measured on the T1-weighted MR images in the coronal plane. (1) The band lengths were measured at the slice in which the longest band was detected, and similarly, (2) the band thickness was measured at the slice in which the thickest band was detected. (3) The length of the weight-bearing portion was measured at the slice through the femoral head center. The weight-bearing portion of the femoral head is defined as the area lateral to the mid-vertical line through the acetabular edge and the teardrop bottom. (4) The band length ratio represents the length of the fracture line relative to the length of the weight-bearing portion, and thus the band length ratio was measured at the slice through the femoral head center (Figure 2).

Three authors (observer 1: KI, observer 2: SI, and observer 3: TY) assessed all the MR images in a blind trial and independently estimated these values. We calculated the mean of three values as estimated by 3 observers. To test the reproducibility, one author (KI) measured all s two times, with an interval of 2 weeks between measurements. These values were averaged and statistically analyzed.

All measurements on MR images were carried out using the; CIS-Image Viewer (IBM, New York, USA), Image J (National Institute of Health, Maryland, USA), and Synapse (Fujifilm, Tokyo, Japan) image analysis software programs.

**Statistical analysis**
Between Group N and Group P, the age, BMI, Sharp angle, CE angle, ARA, AHI, band length, band thickness and band length ratio were analyzed using Student's unpaired t-test. Fisher's exact test was used to analyze the gender proportions. Differences with p-values of less than 0.05 were considered to be statistically significant. The cut-off points of these radiographic valuables were calculated by a receiver operating characteristic (ROC) analysis. The survivorship data were calculated by a Kaplan-Meier analysis, and the survival curves between the two groups were compared using the log-rank test. To evaluate the intra-observer and inter-observer reproducibility of the measurements on the radiographs, the reliability of the measurements were evaluated by Spearman's correlation coefficient, and values greater than 0.7 were considered to be in good agreement. All of the statistical analyses were performed using the JMP software program, version 9.0.1 (SAS Institute Inc. Cary NC).
Fig. 1: The radiographic indices used for evaluation of the hip are shown. (1) = the horizontal line between the pelvis teardrops, (2) = the line between the lateral edge of the acetabular roof and the inferior tip of the pelvic teardrop, (3) = the line between the lateral edge of the acetabular roof and the femoral head center, (4) = the line between the lateral edge of the acetabular roof, and the intersection of the horizontal and vertical components of the acetabulum. # = Sharp angle; # = Center-edge angle; # = Acetabular roof angle. The Acetabular head index was calculated with the formula: a/b × 100 (a = the distance between medial tip of the femoral head and the lateral edge of acetabular roof; b = the size of femoral head).
Fig. 2: Diagram showing the method to measure the morphology of the low-intensity band on a T1-weighted MR image. The band length and band thickness are expressed in (A) and (B), respectively. The weight-bearing portion of the femoral head is defined as the area lateral to the mid-vertical line through the acetabular edge and the teardrop bottom (C). The band length ratio is shown as (A/C).
Results

Clinical data

All subjects showed unilateral involvement. The mean BMI ranged from 18.3 to 31.6 kg/m² (mean: 20.8 kg/m²). The follow-up period ranged from 2.2 to 5.5 years (mean: 2.9 years). Bone mineral density measurement was available for 12 patients, and showed either osteopenia or osteoporosis in 9 patients (T-score < -1.0). The clinical data are summarized in Table 1. No significant differences were observed in gender, age, BMI or follow-up period between the non-progressive and progressive patients of the collapse group. The bone mineral density (T-score) was significantly lower in Group P (p = 0.030).

Table 1 Characteristics of the 29 patients included in the study

<table>
<thead>
<tr>
<th></th>
<th>Group N (n=14)</th>
<th>Group P (n=15)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>male : female</td>
<td>4:10</td>
<td>1:14</td>
<td>0.370</td>
</tr>
<tr>
<td>Age</td>
<td>60.4 ± 15.0</td>
<td>66.0 ± 10.8</td>
<td>0.274</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>23.2 ± 3.7</td>
<td>23.0 ± 3.9</td>
<td>0.888</td>
</tr>
<tr>
<td>Follow-up period (years)</td>
<td>3.0 ± 1.2</td>
<td>3.0 ± 0.9</td>
<td>0.954</td>
</tr>
<tr>
<td>Bone mineral density (T-score)</td>
<td>-1.32 ± 0.39*</td>
<td>-2.15 ± 0.65**</td>
<td>0.030</td>
</tr>
</tbody>
</table>

* n = 5 ** n = 7

Group N: Non-progression of a collapse group

Group P: Progression of the collapse group

Radiographic findings

The results of the radiological measurements are summarized in Table 2. The Sharp angle was significantly greater in Group P. The center-edge angle was significantly lower in Group P. The acetabular roof angle was significantly greater in Group P. The acetabular head index was significantly lower in Group P. Therefore, Group P showed the tendency of inadequate acetabular coverage in all 4 valuables.
MR imaging evaluations

The T1-weighted MR images showed serpiginous, irregular, and discontinuous low-signal-intensity bands in all cases. The band length in Group P was 20.5 mm, while the band length in Group N was 13.2 mm. The band length in Group P was significantly higher than that in Group N. The band length ratio in Group N was 38.2%, while the band length ratio in Group P was 57.7%. The band length ratio in Group P was significantly higher than that in Group N (Table 2).

Table 2 The results of the radiological measurements

<table>
<thead>
<tr>
<th></th>
<th>Group N (n=14)</th>
<th>Group P (n=15)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp angle (degrees)</td>
<td>40.1 ± 2.7</td>
<td>42.9 ± 3.9</td>
<td>0.0292</td>
</tr>
<tr>
<td>Center-edge angle</td>
<td>30.3 ± 4.2</td>
<td>23.3 ± 10.5</td>
<td>0.0284</td>
</tr>
<tr>
<td>Acetabular roof angle (degrees)</td>
<td>14.8 ± 5.6</td>
<td>21.6 ± 6.2</td>
<td>0.0051</td>
</tr>
<tr>
<td>Acetabular head index</td>
<td>79.9 ± 4.3</td>
<td>71.7 ± 8.8</td>
<td>0.0038</td>
</tr>
<tr>
<td>Band length (mm)</td>
<td>13.2 ± 4.1</td>
<td>20.5 ± 6.6</td>
<td>0.0014</td>
</tr>
<tr>
<td>Band thickness (mm)</td>
<td>1.6 ± 0.5</td>
<td>1.6 ± 0.3</td>
<td>0.9437</td>
</tr>
<tr>
<td>Band length ratio (%)</td>
<td>38.2 ± 11.7</td>
<td>57.7 ± 16.3</td>
<td>0.0010</td>
</tr>
</tbody>
</table>

Group N: Non-progression of a collapse group

Group P: Progression of the collapse group

ROC analyses and Kaplan-Meier survivorship analysis

The receiver operating characteristic (ROC) analyses demonstrated the cutoff points in Table 3. The Kaplan-Meier survivorship analysis using these cutoff points, with operative intervention as the end point, predicted two-year survival rate in these 6 valuables. There were significant differences between 2 groups in all 6 valuables using the log-rank test (Figure 4).

The inter-observer variability in Sharp angle, CE angle, ARA, AHI, the band length, band thickness, and band length ratio are summarized in Table 4. The linear correlations
between the measurements (Spearman's correlation coefficient) were considered to be in good agreement (> 0.7) for all measurements.

**Table 3** The receiver operating characteristic (ROC) analysis

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Cutoff point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp angle</td>
<td>66.7</td>
<td>85.7</td>
<td>42.6</td>
</tr>
<tr>
<td>Center-edge angle</td>
<td>100.0</td>
<td>53.0</td>
<td>22.8</td>
</tr>
<tr>
<td>Acetabular roof angle</td>
<td>73.3</td>
<td>85.7</td>
<td>19.4</td>
</tr>
<tr>
<td>Acetabular head index</td>
<td>92.9</td>
<td>70.6</td>
<td>74.3</td>
</tr>
<tr>
<td>Band length</td>
<td>83.3</td>
<td>64.8</td>
<td>16.7</td>
</tr>
<tr>
<td>Band length ratio</td>
<td>75.0</td>
<td>70.6</td>
<td>48.3</td>
</tr>
</tbody>
</table>

**Table 4** The linear correlations between the measurements (Spearman's correlation coefficient)

<table>
<thead>
<tr>
<th></th>
<th>Intra-observer reproducibility</th>
<th>Inter-observer reproducibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp angle</td>
<td>0.840</td>
<td>0.790</td>
</tr>
<tr>
<td>Center edge angle</td>
<td>0.932</td>
<td>0.851</td>
</tr>
<tr>
<td>Acetabular roof angle</td>
<td>0.882</td>
<td>0.838</td>
</tr>
<tr>
<td>Acetabular head index</td>
<td>0.866</td>
<td>0.842</td>
</tr>
<tr>
<td>Band length</td>
<td>0.872</td>
<td>0.858</td>
</tr>
<tr>
<td>Band thickness</td>
<td>0.853</td>
<td>0.812</td>
</tr>
<tr>
<td>Band length ratio</td>
<td>0.868</td>
<td>0.847</td>
</tr>
</tbody>
</table>
Images for this section:

Fig. 3: (A), (B), (C): A 58-year-old female patient complained of severe right hip pain. (A) A radiograph at the first attendance shows no obvious abnormalities. Sharp angle: 41.5 degrees, center-edge angle: 23.9 degrees, acetabular roof angle: 15.7 degrees, acetabular head index: 77.1. (B) A T1-weighted MR image (repetition time/echo time [TR/TE] = 400/15 msec) demonstrates a low signal-intensity band (white arrows) just beneath the articular cartilage. (C) A radiograph obtained 12 months later does not show progression of a collapse in the femoral head. (D), (E), (F): A 77-year-old female patient complained of severe right hip pain. (D) A radiograph at the first attendance reveals no obvious abnormalities. Sharp angle: 46.5 degrees, center-edge angle: 24.8 degrees, acetabular roof angle: 24.3 degrees, acetabular head index: 71.5. (E) A T1-weighted MR image (TR/TE = 470/15 msec) reveals a low signal-intensity band (white arrows) just beneath the articular cartilage. (F) A radiograph obtained three two months later demonstrates a progression of a collapse in the femoral head (black arrows).

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Fig. 4: The Kaplan-Meier survival curve shows the radiological survival rate. The endpoint is the time when the operation was performed. A: A two-year survival rate in Sharp angle was 70.6% in the lower Sharp angle group (≤ 42.6) and 16.7% in the higher Sharp angle group (> 42.6). There were significant differences between the two groups (p = 0.0019, log-rank test). B: A two-year survival rate in CE-angle was 66.7% in the higher CE-angle group (> 22.8) and 0% in the lower CE-angle group (≤ 22.8) (p < 0.0001). C: A two-year survival rate in Acetabular roof angle was 75.0% in the lower Acetabular roof angle group (≤ 19.4) and 15.4% in the lower Acetabular roof angle group (> 19.4) (p = 0.0006). D: A two-year survival rate in AHI was 75.0% in the higher AHI group (> 74.3) and 8% in the lower AHI group (≤ 74.3) (p < 0.0001). E: A two-year survival rate in band length was 84.8% in the lower band length group (≤ 16.7) and 18.6% in the higher band length group (> 16.7) (p = 0.0002). F: A two-year survival rate in band length ratio was
78.6% in the lower band length ration group (# 48.3) and 20.0% in the higher band length group (> 48.3) (p = 0.0014).

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Conclusion

In the current study, the prognosis of SIF varied, even though all the patients received similar conservative treatments. If the prognosis for SIF can be predicted at an early stage, it would allow the design of optimal treatments for each patient. In this preliminary investigation, the inadequate acetabular coverage, the band length and band length ratio were demonstrated to be useful when selecting the optimal treatment for in the predicting of femoral head collapse in SIF.
References


