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# Favorable Clinical and Radiographic Results of Transtrochanteric Anterior Rotational Osteotomy for Collapsed Subchondral Insufficiency Fracture of the Femoral Head in Young Adults

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**Background:** Subchondral insufficiency fracture of the femoral head (SIF) occurs infrequently in young adults. As the collapsed SIF lesion is usually located at the anterior portion of the femoral head, young adults with SIF are considered to be candidates for transtrochanteric anterior rotational osteotomy, similar to patients with osteonecrosis of the femoral head (ON). In the present study, we assessed the clinical and radiographic results of anterior rotational osteotomy for the treatment of SIF as compared with ON.

**Methods:** We retrospectively reviewed 28 consecutive patients who underwent anterior rotational osteotomy for the treatment of unilateral SIF (7 patients) or unilateral ON (21 patients). The mean duration of follow-up was 3.7 years (range, 2.0 to 6.2 years). Clinical and radiographic assessments were performed with use of the Harris hip score (HHS), sequential radiographs, and single-photon emission computed tomography/computed tomography (SPECT/CT) with $^{99m}$Tc-hydroxymethylene diphosphonate performed 5 weeks after surgery.

**Results:** The mean HHS (and standard deviation) in the SIF group improved significantly from 51.6 ± 11.7 preoperatively to 91.9 ± 7.1 at 1 year after surgery and to 96.9 ± 3.8 at the time of the latest follow-up ($p = 0.0010$ and 0.0002, respectively). Similarly, the mean HHS in the ON group improved significantly from 52.4 ± 13.7 preoperatively to 80.7 ± 10.0 at 1 year after surgery and to 88.2 ± 12.6 at the time of the latest follow-up ($p < 0.0001$ for both). The HHS was significantly higher in the SIF group than in the ON group at 1 year after surgery ($p = 0.019$), but there was no significant difference between the groups at the time of the latest follow-up ($p = 0.10$). A postoperative intact ratio (calculated as the intact area of the femoral head divided by the weight-bearing area of the acetabulum on an anteroposterior radiograph) of >80% was achieved in association with smaller femoral neck-shaft varus angles in the SIF group (10.0° ± 4.2°) as compared with the ON group (15.3° ± 8.2°). Postoperative progression of collapse at the anteriorly rotated subchondral lesion was observed in 5 patients (23.8%) in the ON group but no patients in the SIF group. SPECT/CT images showed that rate of increased tracer uptake at the collapsed lesions in the SIF group was significantly higher than that in the ON group ($p < 0.0001$).

**Conclusions:** The present study suggested that the absence of progression of collapse and a sufficient postoperative intact ratio without the need for marked varus realignment may be associated with favorable results following anterior rotational osteotomy for the treatment of SIF in young adults.

**Level of Evidence:** Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

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Subchondral insufficiency fracture of the femoral head (SIF) recently has been recognized as a cause of femoral head collapse resulting in degeneration of the hip joint, which is known to occur in association with osteonecrosis of the femoral head (ON)[1-5]. Although SIF generally occurs in osteoporotic elderly patients[1-6], several reports have demonstrated that SIF can occur in young adults[6-11]. Iwasaki et al., in a study of young adults with SIF, reported that histological analysis showed thin, disconnected bone trabeculae, indicating the presence of some degree of osteopenia[10].

For young patients with collapsed SIF, joint-preserving surgery to avoid secondary osteoarthritis is an ideal treatment option because of the long life expectancy and high baseline activity level of these patients. As collapsed SIF lesions usually are located at the anterior portion of the femoral head[12], young adults with SIF, similar to patients with ON[9], are considered to be candidates for transtrochanteric anterior rotational osteotomy, whereby the intact posterior area of the femoral head is transposed to the weight-bearing zone of the joint[13].

To date, there have been many studies on the outcomes of anterior rotational osteotomy for the treatment of ON[13-18]. One of those studies demonstrated that the most important factor affecting the clinical and radiographic results was a postoperative intact ratio of >40% (calculated as the intact area of the femoral head divided by the weight-bearing area of the acetabulum on an anteroposterior radiograph) as such a ratio prevents both the progression of femoral head collapse and joint-space narrowing[18]. Accordingly, an intentional varus realignment, with resultant shortening of the lower limb, usually is needed to achieve a sufficient postoperative intact ratio in patients undergoing anterior rotational osteotomy for the treatment of ON.

In contrast with the many studies of anterior rotational osteotomy for the treatment of ON, there have been few studies regarding the use of this procedure for the treatment of SIF. In the present study, we assessed the clinical and radiographic results of anterior rotational osteotomy for the treatment of SIF as compared with ON.

## Materials and Methods

### *Patients*

Our institutional review board approved the present retrospective study. We reviewed the records for 28 consecutive patients who had undergone anterior rotational osteotomy for the treatment of unilateral SIF or ON between 2010 and 2014. The study group comprised 24 males and 4 females with a mean age of 34.7 years (range, 15 to 50 years) at the time of surgery. Seven patients had unilateral SIF (SIF group), and 21 patients had unilateral ON (ON group) (Table I). The mean duration from the onset of pain to surgery was 6.0 months (range, 1.5 to 23 months). SIF was diagnosed on the basis of radiographic evidence of femoral head collapse and T1-weighted magnetic resonance imaging (MRI) scans demonstrating a low-intensity band that was irregular, disconnected, and convex to the articular cartilage[4,19]. In addition, histopathological evidence of SIF was confirmed by means of intraoperative biopsy[4,19]. ON was diagnosed on the basis of radiographic evidence of femoral head collapse, demarcating sclerosis in the femoral head, and T1-weighted MRI scans demonstrating a low-intensity band that was well circumscribed, smooth, concave, and a mirror image of the articular surface[20,21]. According to the Association Research Circulation Osseous (ARCO) staging system[22], all hips with ON were classified as stage 3. No hips showed evidence of joint-space narrowing on radiographs at the time of anterior rotational osteotomy. The mean duration of postoperative follow-up was 3.7 years (range, 2.0 to 6.2 years).

### *Operative Protocol*

Anterior rotational osteotomy was indicated when at least one-third of the posterior articular surface was intact[14] as viewed on lateral radiographs and oblique axial MRI scans. Preoperatively, we evaluated the expected postoperative intact ratio after anterior rotation of the proximal fragment. When the expected postoperative intact ratio was <40%, we inclined the intertrochanteric osteotomy plane intraoperatively to increase the varus angulation.

According to the original method[13,14], anterior rotational osteotomy was performed in the following order: (1) osteotomy of the greater trochanter, (2) intertrochanteric osteotomy from superolateral to inferomedial on the anteroposterior view, (3) osteotomy from the proximal flare of the lesser trochanter inferolaterally toward the inferomedial extent of the intertrochanteric osteotomy, (4) 70° to 90° anterior rotation of the proximal fragment, and (5) fixation of the osteotomy site. Before the intertrochanteric osteotomy, 2 Kirschner wires oriented perpendicular to the femoral neck were inserted into the intertrochanteric region through the cut surface of the greater trochanter. Under radiographic control, the intertrochanteric osteotomy plane was determined on the basis of the preoperative planning. After anterior rotation of the proximal fragment, a K-MAX Adjustable Angle Hip Screw (K-MAX AA Hip Screw; Japan Medical Materials) and 2 other cancellous bone screws were used to obtain rigid fixation of the osteotomy site under fluoroscopic control[23].

During this procedure, it is important to preserve the posterior column artery, a branch of the medial femoral circumflex artery, which supplies nutrients to the femoral head[24]. The posterior column artery is located in adipose tissue underneath the quadratus femoris muscle. It is important never to expose or release the posterior column artery. When the obturator externus is exposed and released to rotate the proximal fragment, careful and minimal release of the quadratus femoris muscle is recommended. In addition, during anterior rotation of the proximal fragment, attention must be paid to the location of the posterior column artery to avoid excessive tension on the artery.

**TABLE I Clinical Data**

| Factor | SIF (N = 7) | ON (N = 21) | P Value |
|---|---|---|---|
| Age at time of anterior rotational osteotomy* *(yr)* | 30.1 ± 9.0 | 36.2 ± 7.4 | 0.10 |
| Male:female ratio *(no. of patients)* | 7:0 | 17:4 | 0.55 |
| BMI* *(kg/m²)* | 20.9 ± 1.7 | 23.2 ± 3.5 | 0.11 |
| Duration from onset of pain to anterior rotational osteotomy* *(mo)* | 5.9 ± 2.7 | 6.0 ± 4.9 | 0.46 |
| Duration of follow-up* *(yr)* | 3.6 ± 1.4 | 3.7 ± 1.6 | 0.73 |

*The values are given as the mean and the standard deviation.

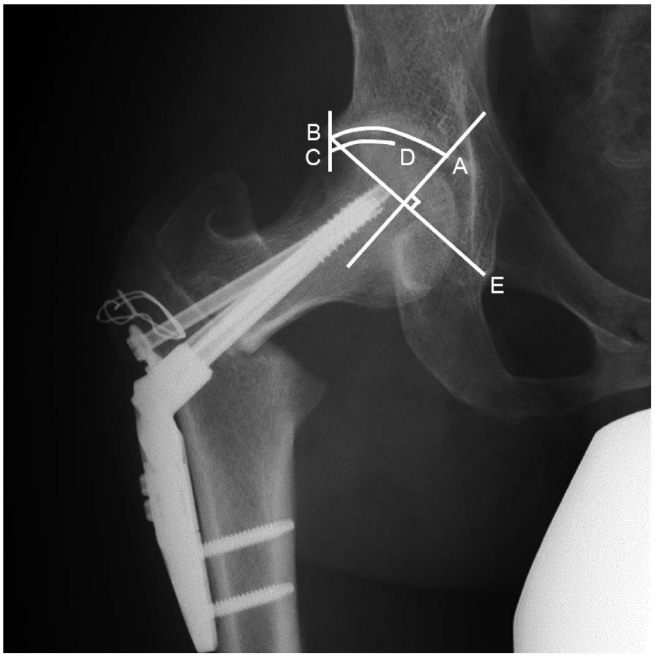


Fig. 1

The postoperative intact ratio is determined with use of an anteroposterior radiograph made 4 weeks after anterior rotational osteotomy and is expressed as the ratio of the intact articular surface of the femoral head (C to D) to the weight-bearing surface of the acetabulum (A to B). Point A is determined by drawing a perpendicular line from the midpoint between points B (the edge of the acetabulum) and E (the lowest point of the teardrop) to the acetabulum. Points C and D represent the lateral edge of the loaded portion and the medial edge of the intact surface, respectively.

A bone biopsy was performed from the center of the collapsed lesion through the articular surface with use of a trephine needle.

The postoperative regimen was identical in all cases, regardless of the diagnosis. Use of a wheelchair began 2 days after surgery, and passive range-of-motion exercises began 5 days after surgery. Patients were transferred to another rehabilitation hospital 2 weeks after surgery. Non-weight-bearing was continued until 5 weeks after surgery, at which time the patients were allowed to engage in partial weight-bearing. Full weight-bearing was permitted approximately 4 to 6 months after surgery.

### *Clinical Assessment*

Clinical assessments of pain, ability, deformity, and range of motion were performed with use of the Harris hip score (HHS)[25]. A total score of <70 points is considered poor; 70 to 79, fair; 80 to 89, good; and 90 to 100, excellent. In the present study, the HHS was assessed preoperatively, 1 year after surgery, and at the time of the latest follow-up.

### *Radiographic Assessment*

Radiographs were evaluated preoperatively and at 1, 2, 4, 6, 8, 12, 24, and 48 weeks postoperatively to evaluate the progression of collapse and joint-space narrowing. Thereafter, postoperative radiographs were evaluated annually. The degree of femoral head collapse was assessed by fitting a concentric circle to each femoral head and was defined as the maximum depth of collapse on both anteroposterior and lateral radiographs[11]. The degree of preoperative femoral head collapse was determined. The postoperative progression of collapse at the anteriorly rotated subchondral lesion was measured by comparing lateral radiographs made 4 weeks postoperatively with those made at the time of the latest follow-up. Positive progression of collapse was defined as a change of ≥2 mm.

The postoperative intact ratio was measured on anteroposterior radiographs made 4 weeks postoperatively, according to the previously described method (Fig. 1)[18]. With the same method, a preoperative intact ratio was also measured on preoperative anteroposterior radiographs.

With use of preoperative and postoperative anteroposterior radiographs, the femoral neck-shaft varus angle (calculated as the preoperative femoral neck-shaft angle minus the femoral neck-shaft angle at 4 weeks postoperatively) was measured. In addition, shortening of limb length (calculated as the preoperative limb-length discrepancy minus the limb-length discrepancy at 4 weeks postoperatively) was measured. Limb-length discrepancy was defined as the difference in the vertical distance between the top of the obturator foramen and the inferior aspect of the lesser trochanter, as the osteotomy line does not pass through the inferior aspect of the lesser trochanter[26].

### *SPECT/CT Assessment*

At our institution, bone scans and single-photon emission computed tomography/computed tomography (SPECT/CT) with $^{99m}$Tc-hydroxymethylene diphosphate are routinely performed 5 weeks after anterior

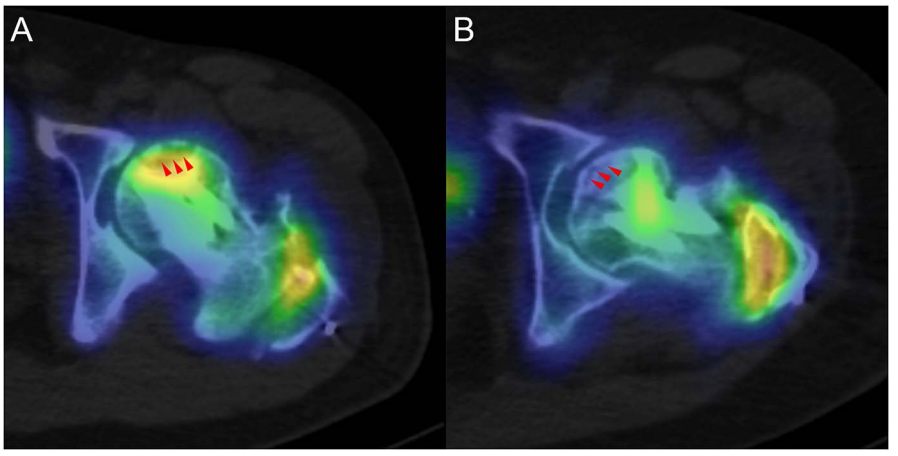


Fig. 2

**Fig. 2-A** SPECT/CT image showing increased tracer uptake at the collapsed lesion (the area around the fracture line within the femoral head). The arrowheads indicate the subchondral fracture line. **Fig. 2-B** SPECT/CT image showing an absence of tracer uptake at the collapsed lesion.

**TABLE II Radiographic and SPECT/CT Findings**

| Factor | SIF Group (N = 7) | ON Group (N = 21) | P Value |
|---|---|---|---|
| Preoperative collapse* *(mm)* | 2.0 ± 0.9 | 1.6 ± 1.0 | 0.23 |
| Postoperative progression of collapse (yes/no)† *(no. of patients)* | 0/7 | 5/16 | 0.29 |
| Preoperative intact ratio* *(%)* | 7.3 ± 9.4 | 4.0 ± 5.7 | 0.54 |
| Postoperative intact ratio* *(%)* | 95.7 ± 7.9 | 60.5 ± 13.6 | 0.0002† |
| Femoral neck-shaft varus angle* *(deg)* | 10.0 ± 4.2 | 15.3 ± 8.2 | 0.17 |
| Shortening of limb length* *(mm)* | 11.1 ± 6.7 | 18.2 ± 8.5 | 0.047† |
| Uptake at collapsed lesion on SPECT/CT (increase/absence) *(no. of patients)* | 7/0 | 2/19 | <0.0001† |

*The values are given as the mean and the standard deviation. †Defined as ≥2 mm of collapse progression at the anteriorly rotated subchondral lesion. †Significant ($p < 0.05$).

rotational osteotomy to confirm that the medial femoral circumflex artery has been preserved intraoperatively. SPECT/CT was performed with use of a hybrid dual-head gamma camera with an inline CT scanner (Symbia T6; Siemens). SPECT data were acquired 4 hours after the patient was injected with 740 MBq of $^{99m}$Tc-hydroxymethylene diphosphate. The SPECT settings were as follows: low-energy, high-resolution collimators; 128 × 128 matrix; 140 kV ± a 10% energy window; and 72 ten-second steps per 360°. The CT settings were as follows: tube voltage of 130 kV, current-time product of 15 mAs, 2.5-mm slices, and 512 × 512 matrix. A 3-dimensional (3D) reconstruction technique was performed, and CT-based attenuation and scatter corrections were applied to all SPECT images.

SPECT/CT images were used to evaluate the collapsed lesion (the area around the subchondral fracture line within the femoral head) for an increase in, or the absence of, tracer uptake compared with the same area in the contralateral femoral head (Fig. 2). These findings were assessed independently by 2 experienced hip surgeons (K.S. and G.M.) without any knowledge of the patients' clinical outcomes. If the opinions of the 2 reviewers differed initially, a final decision was reached by consensus.

### *Statistical Analysis*

We compared the clinical backgrounds of the patients in both groups in terms of age at the time of surgery, sex, body mass index (BMI), the duration from the onset of pain to surgery, and the duration of postoperative follow-up. We then compared the 2 groups in terms of the HHS at each time point, the postoperative intact ratio, the degree of preoperative femoral head collapse, the rate of postoperative progression of collapse at the anteriorly rotated subchondral lesion, the femoral neck-shaft varus angle, the amount of limb-length shortening, and the rate of increased tracer uptake at the collapsed lesion on SPECT/CT images.

The numerical data were expressed as the mean and the standard deviation. Differences between the SIF and ON groups were examined with the Wilcoxon signed-rank test for continuous variables and the Fisher exact probability test for categorical variables. In each group, the preoperative and postoperative HHS values were compared with use of the paired t test. The level of significance was set at $p < 0.05$. Statistical analysis was performed with use of JMP statistical analysis software (version 11; SAS Institute).

## Results

In all 7 patients with SIF, intraoperative biopsy confirmed the typical histopathological findings of SIF, namely, thin, disconnected bone trabeculae; callus formation; reactive cartilage; and associated granulation tissue at the collapsed subchondral lesion[4,19].

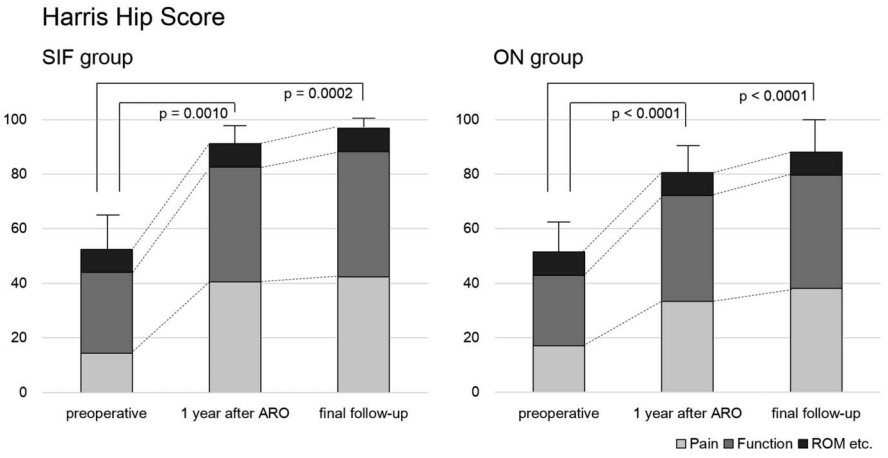


Fig. 3

Bar graphs showing the preoperative and postoperative HHS values for the SIF and ON groups. The error bars indicate the 95% confidence intervals. Postoperatively, the HHS improved significantly in both groups. ARO = anterior rotational osteotomy, and ROM = range of motion.

Fig. 4-A

Fig. 4-B

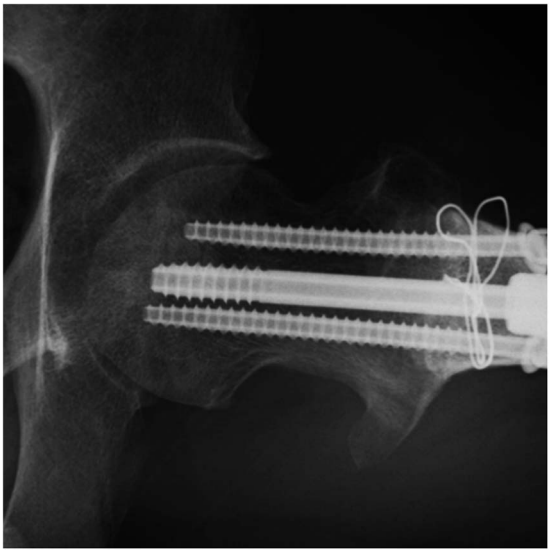

Fig. 4-C

**Figs. 4-A through 4-G** A 36-year-old man with SIF. **Fig. 4-A** Preoperative anteroposterior radiograph showing collapse of the left femoral head. The preoperative HHS was 30. **Figs. 4-B and 4-C** Anteroposterior and lateral radiographs made 4 weeks postoperatively.

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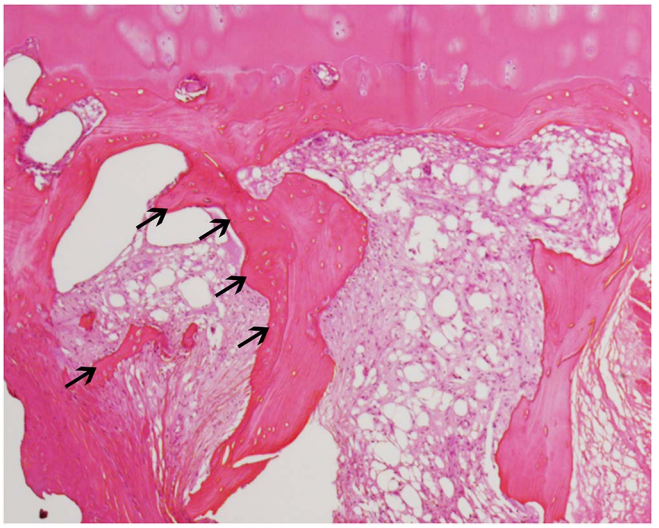

Fig. 4-D

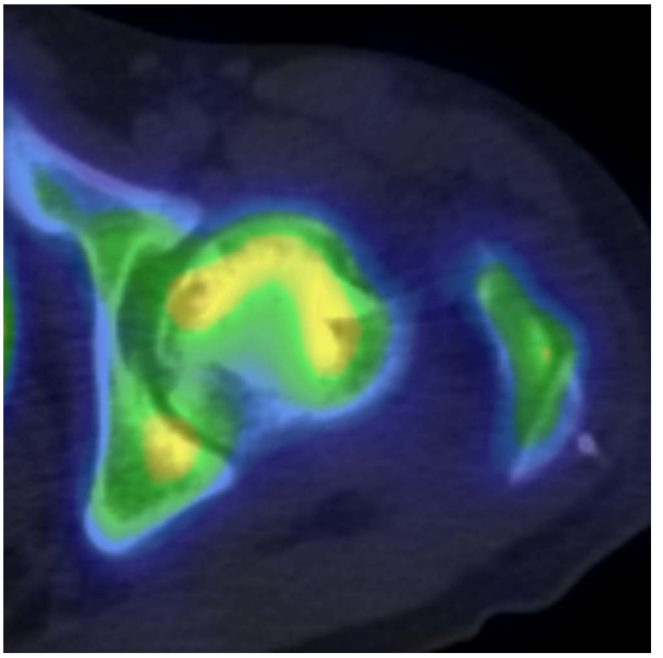

Fig. 4-E

**Fig. 4-D** Photomicrograph of a sample of subchondral bone, showing fracture callus formation (arrows) with associated granulation tissue (hematoxylin and eosin; ×40). **Fig. 4-E** SPECT/CT image made 5 weeks postoperatively, showing increased tracer uptake at the collapsed lesion.

Clinically, there were no significant differences between the SIF and ON groups in terms of age at the time of surgery, sex, BMI, the duration from the onset of pain to surgery, or the duration of postoperative follow-up (Table I). In addition, there were no significant differences between the 2 groups in terms of either the degree of preoperative femoral head collapse or the preoperative intact ratio (Table II). During the follow-up period, no patient in either group had postoperative complications, including infection or nonunion at the osteotomy site. Radiographic evidence of osseous union was observed 3 to 6 months after surgery.

The mean HHS in the SIF group improved significantly from 51.6 ± 11.7 preoperatively to 91.9 ± 7.1 at 1 year after surgery and 96.9 ± 3.8 at the time of the latest follow-up ($p = 0.0010$ and 0.0002, respectively) (Fig. 3). Likewise, the mean HHS in the ON group improved significantly from 52.4 ± 13.7 preoperatively to 80.7 ± 10.0 at 1 year after surgery and to 88.2 ± 12.6 at the time of the latest follow-up ($p < 0.0001$ for both). The HHS was significantly higher in the SIF group than in the ON group at 1 year after surgery ($p = 0.019$), but there was no significant difference between the groups at the time of the latest follow-up ($p = 0.10$).

The postoperative intact ratio was significantly higher in the SIF group than in the ON group (95.7% ± 7.9% compared with 60.5% ± 13.6%; $p = 0.0002$) (Table II). A postoperative intact ratio of >80% was achieved in all patients in the SIF group. In addition, the higher postoperative intact ratio was achieved in association with smaller femoral neck-shaft varus angles in the SIF group compared with the ON group (10.0° ± 4.2° compared with 15.3° ± 8.2°; $p = 0.17$). Consequently, there was significantly reduced limb-length shortening in the SIF group compared with the ON group (11.1 ± 6.7 compared with 18.2 ± 8.5 mm, $p = 0.047$). Radiographically, postoperative progression of collapse at the anteriorly rotated subchondral lesion was observed during the follow-up period in 5 patients (23.8%) in the ON group but in no patients in the SIF group (Figs. 4-A through 4-G).

Five weeks after surgery, SPECT/CT revealed that no patient in either group had a complete absence of tracer uptake in the proximal bone fragment, indicating that the medial femoral circumflex artery had been preserved intraoperatively. The collapsed lesion showed increased tracer uptake in all 7 patients in the SIF group (Table II). In contrast, the collapsed lesion showed no uptake in 19 (90.5%) of the 21 patients in the ON group. The rate of increased tracer uptake at the collapsed lesion in the SIF group was significantly higher than that in the ON group ($p < 0.0001$). The 2 reviewers were in complete agreement on all findings.

## Discussion

The current study assessed the clinical and radiographic results of anterior rotational osteotomy for the treatment of SIF as compared with ON. The postoperative intact ratio in the SIF group was significantly higher than that in the ON group. In addition, a postoperative intact ratio of >80% was achieved in all patients in the SIF group, which was likely related to the excellent results of anterior rotational osteotomy for SIF.

A sufficient postoperative intact ratio was achieved with smaller femoral neck-shaft varus angles in the SIF group compared with the ON group. Consequently, there was significantly less shortening of limb length in the SIF group than in the ON group. These results indicated that a sufficient

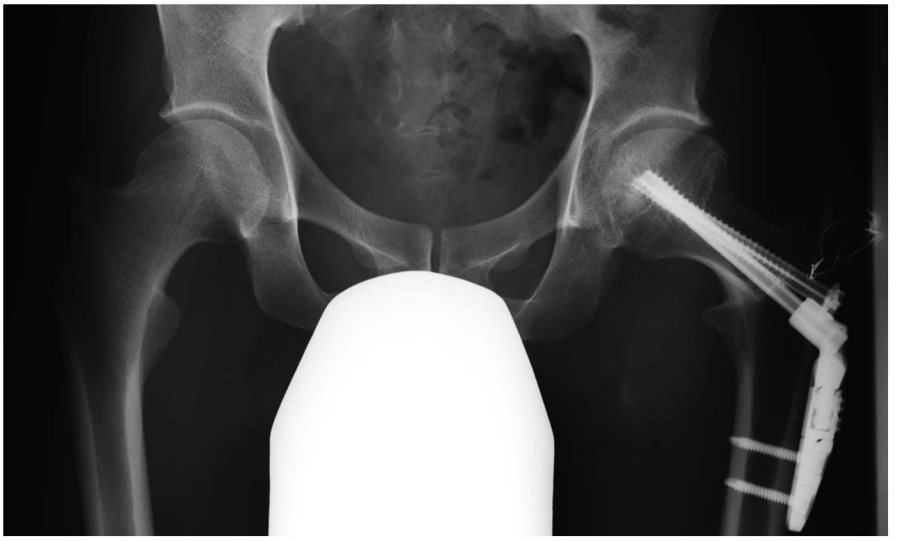

Fig. 4-F

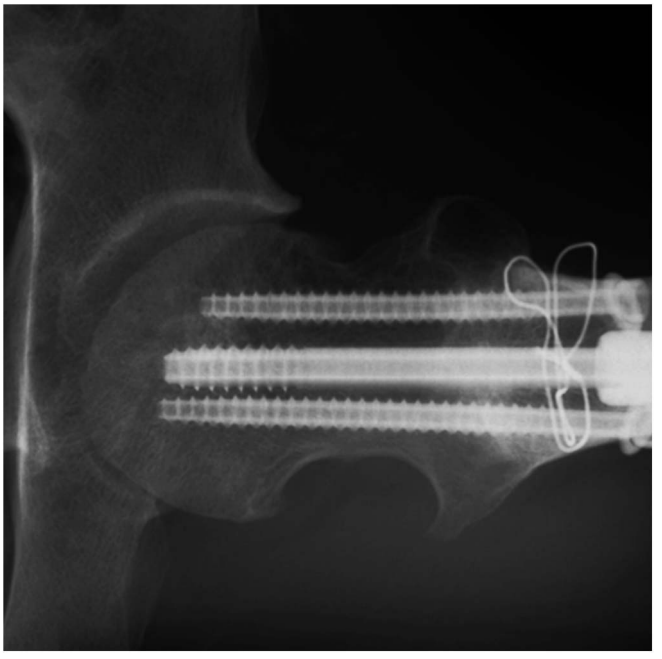

Fig. 4-G

**Figs. 4-F and 4-G** Anteroposterior and lateral radiographs made at the time of the latest follow-up (3.5 years after surgery). Progression of collapse at the anteriorly rotated subchondral lesion is not observed when this lateral radiograph is compared with the lateral radiograph made 4 weeks after surgery. The HHS at the time of the latest final follow-up was 100.

postoperative intact ratio tended to be obtained without the need for intentional varus realignment in the SIF group because the lesions that had to be transposed from the weight-bearing area were confined to the subchondral fractured area whereas those in the ON group affected not only this area but the entire necrotic bone region. One disadvantage of anterior rotational osteotomy is shortening of limb length on the treated side, which can cause a limp[26]. The more pronounced the shortening, the longer it would take for the patient to accommodate the limp, which might account for our finding that the HHS at 1 year after anterior rotational osteotomy was significantly higher in the SIF group than in the ON group.

In the present study, postoperative progression of collapse at the anteriorly rotated subchondral lesion was observed in none of the 7 patients with SIF but in 5 (23.8%) of the 21 patients with ON. The absence of progression of collapse at the anteriorly rotated subchondral lesion may also have been related to the excellent results that were observed in the SIF group. Five weeks postoperatively, SPECT/CT images showed that all 7 patients in the SIF group had increased tracer uptake

at the collapsed lesion, whereas 19 (90.5%) of 21 patients in the ON group had an absence of tracer uptake at the lesion. Given that SPECT/CT can accurately evaluate osteoblastic activity at lesion sites[27-30], these findings reflect the pathophysiological difference between the 2 conditions (fracture versus osteonecrosis). Therefore, we propose that the existence of osteoblastic activity at the collapsed lesion is associated with early repair of the lesion and no progression of collapse as the lesion has been transposed to the non-weight-bearing area.

Currently, anterior rotational osteotomy is not widely used outside Asian countries. A chief disadvantage of this procedure is the lengthy postoperative regimen. Appropriate surgical indications, a careful procedure, and a standardized postoperative regimen are essential to achieve successful results. Hence, anterior rotational osteotomy has limited use in countries where the medical service system and patient expectations do not allow for such a long-term postoperative regimen.

The present study had several limitations. The first limitation is the small number of SIF cases, resulting from the fact that SIF is relatively uncommon in young adults. However, we focused on unilateral cases in the present study in order to fairly compare the clinical and radiographic results of anterior rotational osteotomy for the treatment of SIF with those for ON. The second limitation is the short duration of follow-up (mean, 3.7 years). Additional studies with longer-term follow-up are required to fully characterize the long-term results of anterior rotational osteotomy for the treatment of SIF. The third limitation is the scoring system that was applied to the clinical assessment. In the present study, the clinical status was evaluated on the basis of the HHS only. Patient-reported outcome measures may be helpful to provide more timely information on the clinical outcomes. The fourth limitation is that we evaluated the postoperative changes on radiographs. Despite its greater radiation exposure and cost, CT is preferred for detecting subtle changes that are potentially important for long-term outcomes.

In conclusion, both the absence of postoperative progression of collapse and the achievement of a sufficient postoperative intact ratio without the need for marked varus realignment may have been associated with the favorable results that we observed after transtrochanteric anterior rotational osteotomy for the treatment of SIF in young adults. ■

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