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Original Article

Residual Femoral Deformity and Femoroacetabular Impingement after Intertrochanteric Osteotomy for Slipped Capital Femoral Epiphysis

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We retrospectively reviewed 29 hips in which intertrochanteric osteotomies were performed for severe slipped capital femoral epiphyses. Mean age at surgery: 12.6 years. Mean follow-up period: 6 years. At the final follow-up evaluation, one patient had coxalgia, and six hips showed a limited range of motion. A pistol-grip deformity was observed in 13 hips, osteoarthritis in two hips, and a bump existed in 19 hips on the latest radiographs. Gradual remodeling of the bumps was observed post-operatively in 22 hips. The mean α and β angles and offset α and β improved over time. The remodeling proceeded rapidly for 1 year post-surgery. We compared hips classified as β angles of ≥63° to <63° at the final follow-up evaluation, the mean β angle 1 year post-surgery, and the mean ratio of improvement of the β angle per year from 1 year post-surgery to the final follow up, which differed significantly. Nearly all of the patients who underwent intertrochanteric osteotomies had residual morphologic abnormalities, but few had clinical symptoms. The β angle 1 year post-surgery and the ratio of remodeling of the bump from 1 year post-surgery to the final follow-up can be regarded as a potential predictor of morphologic results after intertrochanteric osteotomy.

Key words: slipped capital femoral epiphyses, intertrochanteric osteotomy, residual femoral deformity, femoroacetabular impingement, bone remodeling

Slipped capital femoral epiphysis (SCFE) is one of the causes of osteoarthritis of the hip [1]. Several papers stated that deformity following SCFE leads to the development of cam-type impingement and subsequent osteoarthritis of the hip [2-5]. It is thus important to improve deformities due to slippage. The amount of deformity is influenced by the degree of slipping and the treatment method. *In situ* pinning and osteotomy are the standard methods for treating SCFE. *In situ* pinning has been shown to provide good long-term outcomes in cases of mild slippage [6,7], but *in situ* pinning cannot improve deformity of the femoral head, and it is therefore difficult to treat severe SCFE with *in situ* pinning.

Various osteotomies at the subcapital [8,9], basicervical [10], intertrochanteric [11], and subtrochanteric [12,13] levels have been described as realignment procedures in cases of moderate-to-severe slippage. At our institutions, Imhäuser [12] and three-dimensional (3D) osteotomies [13], which are classified as intertrochanteric osteotomies, have been performed in cases with a >30° posterior tilting angle (PTA). These procedures cannot resolve a deformity at the head-neck junction, suggesting the possibility of impingement between the

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acetabulum and the metaphysis in hip motion due to residual bone morphologic abnormalities. A direct corrective procedure (such as the Dunn method and the modified Dunn method) can result in anatomic restoration, but such procedures present a risk of avascular necrosis of the femoral head [14-16]. The superiority of interchanteric *versus* subcapital osteotomies for severe SCFE remains controversial. We therefore examined the presence of radiographic evidence of impingement and clinical symptoms in patients with SCFE who underwent an intertrochanteric osteotomy.

Materials and Methods

We retrospectively reviewed the medical records of 33 patients who underwent intertrochanteric osteotomies for SCFE at 2 institutions (Okayama University Hospital and Asahigawasou Rehabilitation and Medical Center) between 1981 and 2012. Our criteria for the treatment were based on the PTA. Each osteotomy was indicated for a PTA ≥ 30°. Of the 33 patients, 29 hips of 27 patients (24 boys and three girls) were analyzed (follow-up rate 87%). The type of onset was acute in one hip, acute on chronic in 15 hips, and chronic in 13 hips. At our institutions, 3D osteotomies [13] have been performed since 1999. An Imhäuser osteotomy [12] was performed on 23 hips (21 patients), and a 3D osteotomy [13] was performed on 6 hips (6 patients). Twenty-five patients were affected unilaterally and two patients were affected bilaterally. According to the Lorder classification [17], 18 hips were classified as stable and 11 were unstable at the initial presentation. The mean age of the patients at the time of surgery was 12.6 years (range 9-23 years), and the mean follow-up period was 6 years (range 2-11 years; Table 1).

The PTA was defined as a slipping angle of the epiphysis based on the long axis of the femoral shaft, and it was measured on pre- and post-operative

Table 1 Patient demographics

Patient	Gender	Side	Age at onset (years)	Age at osteotomy (years)	Follow-up period (years)	PTA before surgery (°)	PTA after surgery (°)	Classification of Loder [17]	Onset types	Types of osteotomy
1	Male	Right	9.1	9.2	11.3	50	20	stable	Chronic	3D
2	Female	Right	11.3	11.4	9.4	50	15	stable	Chronic	Imhäuser
3	Male	Left	10.8	11.1	4.7	50	25	stable	Acute-chronic	Imhäuser
4	Male	Left	11.8	12.5	6.4	65	25	stable	Acute-chronic	Imhäuser
5	Female	Right	9.3	10.0	8.6	60	5	stable	Chronic	3D
6	Male	Left	12.9	13.5	6.6	50	30	stable	Chronic	Imhäuser
7	Female	Right	10.9	11.7	2.3	65	10	unstable	Acute-chronic	Imhäuser
8	Male	Left	13.4	13.7	7.8	35	10	stable	Chronic	Imhäuser
9	Male	Right	8.5	9.1	9.6	60	27	stable	Chronic	Imhäuser
10	Male	Right	12.1	11.9	5.5	65	25	unstable	Acute-chronic	Imhäuser
11	Male	Left	14.8	15.0	8.3	57	22	stable	Acute-chronic	Imhäuser
12	Male	Left	22.8	25.1	3.2	45	5	stable	Chronic	Imhäuser
13	Male	Right	14.9	15.1	5.4	68	23	unstable	Acute-chronic	Imhäuser
14	Male	Right	8.6	8.7	6.3	45	10	unstable	Acute-chronic	Imhäuser
15	Male	Left	13.8	14.3	4.5	52	10	stable	Chronic	Imhäuser
16	Male	Right	12.8	14.4	4.4	55	25	stable	Chronic	Imhäuser
17	Male	Left	11.0	11.9	2.3	60	10	stable	Chronic	Imhäuser
18	Male	Left	12.1	12.5	2.4	70	25	unstable	Acute-chronic	Imhäuser
19	Male	Right	11.8	13.8	2.9	40	12	stable	Chronic	3D
20	Male	Left	10.8	11.1	4.3	40	5	stable	Chronic	Imhäuser
21	Male	Left	12.4	12.6	3.9	65	23	unstable	Acute-chronic	Imhäuser
22	Male	Left	12.5	14.4	10.4	47	15	unstable	Acute-chronic	3D
23	Male	Left	12.3	12.7	3.4	65	30	unstable	Acute-chronic	Imhäuser
24	Male	Left	10.8	11.3	6.7	50	20	stable	Chronic	3D
25	Male	Left	12.8	13.4	9.1	50	10	stable	Acute-chronic	3D
26	Male	Right	10.0	12.8	12.2	40	13	stable	Chronic	Imhäuser
27	Male	Left	11.9	12.1	9.3	55	25	unstable	Acute	Imhäuser
28	Male	Left	11.4	12.6	7.9	60	25	unstable	Acute-chronic	Imhäuser
29	Female	Left	10.2	11.3	5.3	55	20	unstable	Acute-chronic	Imhäuser

PTA indicates posterior tilting angle.

Lauenstein lateral radiographs with the thigh positioned parallel to the radiographic table. The Mose criteria [18], the presence of pistol-grip deformities, and early osteoarthritic changes (joint space narrowing) were evaluated on anteroposterior radiographs, and bony bumps were noted on lateral radiographs at the latest follow-up evaluation. An α angle [19] and offset α [20] (Fig. 1) were measured on lateral radiographs before the surgery, at 2 months and at 1 year after the surgery, and at the latest follow-up evaluation. The β angle (*i.e.*, the modified α angle) based on the axis of the parallel to the proximal long axis of the femoral shaft [21], and the newly defined offset β were measured (Fig. 2). We compared lateral radiographs 2 months after surgery and at the latest follow-up evaluation to assess the remodeling of the bony bump. The presence of coxalgia and a limited range of motion as clinical symptoms were assessed using the medical records at the latest follow-up evaluation.

Statistical analyses of the data were performed with the use of SPSS Statistics (ver. 22; IBM Japan, Tokyo, Japan). The Wilcoxon signed-rank test was used to evaluate the changes in α, β angle, and offset. The Mann-Whitney *U*-test was used to determine the differences between groups. Statistical significance was defined as a p-value <0.05. All study protocols were approved by the Institutional Review Board of Okayama University (approval no. 2243).

Results

The mean PTA improved significantly from 55° before surgery to 17° after surgery ($p<0.01$). At the latest follow-up evaluation, a pistol-grip deformity was observed in 13 hips (45%). According to the Mose criteria [18], there was a loss of sphericity <2 mm in 13 hips (45%), 2-4 mm in 14 hips (48%), and >4 mm in 2 hips (6%). Early osteoarthritic changes were observed in 2 hips (6%). The bony bump was observed in 19 hips (66%) on lateral radiographs.

The mean α and β angles were 109.9° and 95.2° before surgery, 96.1° and 56.4° at 2 months after surgery, 78.8° and 43.9° at 1 year after surgery, and 73.1° and 40.4° at the latest follow-up evaluation. The mean α angle 1 year after surgery was significantly lower than that observed 2 months after surgery ($p<0.01$), and the mean α angle at the latest follow-up evaluation was significantly lower 1 year after surgery ($p<0.05$). The mean β angle 1 year after surgery was significantly lower than that at 2 months after surgery ($p<0.01$); however, the mean β angle at the latest follow-up evaluation was not significantly lower than that at 1 year after surgery.

The mean offset α and β were −7.1 mm and −4.4 mm before surgery, −4.3 mm and 4.1 mm at 2 months after surgery, −1.0 mm and 6.7 mm at 1 year after surgery, and 1.9 mm and 7.5 mm at the latest follow-up evaluation. The mean offset α at 1 year after surgery was sig-

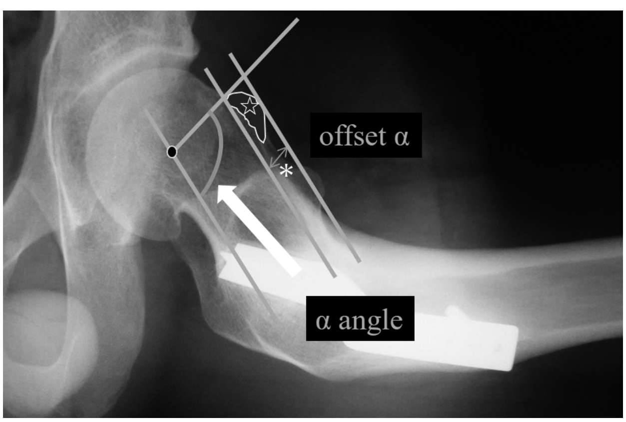


Fig. 1 Definition of the *α* angle (arrow). Nötzli *et al*. [19] advocated an angle between a line of the axis of the neck through the center of the femoral head and a line from the center through the end point of the subchondral surface and offset *α* (∗). Offset *α* was defined as the distance between a head and a bump (☆) using lines parallel to the axis of the femoral neck.

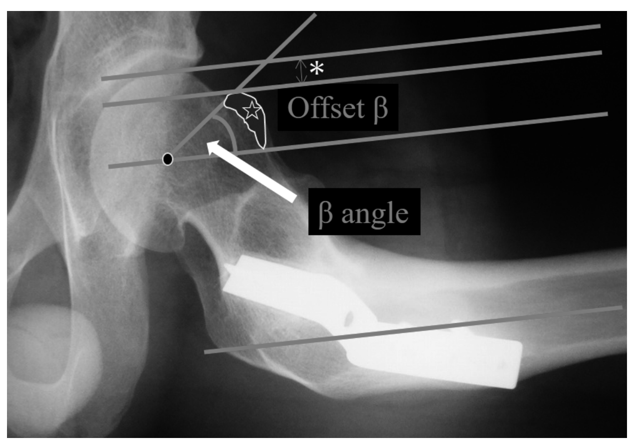


Fig. 2 Definition of the *β* angle (arrow). Kamegaya *et al*. [21] advocated an angle between a line parallel to the long axis of the femur through the center of the femoral head and a line from the center through the end point of the subchondral surface and offset *β* (∗). Offset *β* was defined as the distance between a head and a bump (☆) using lines parallel to the long axis of the femur.

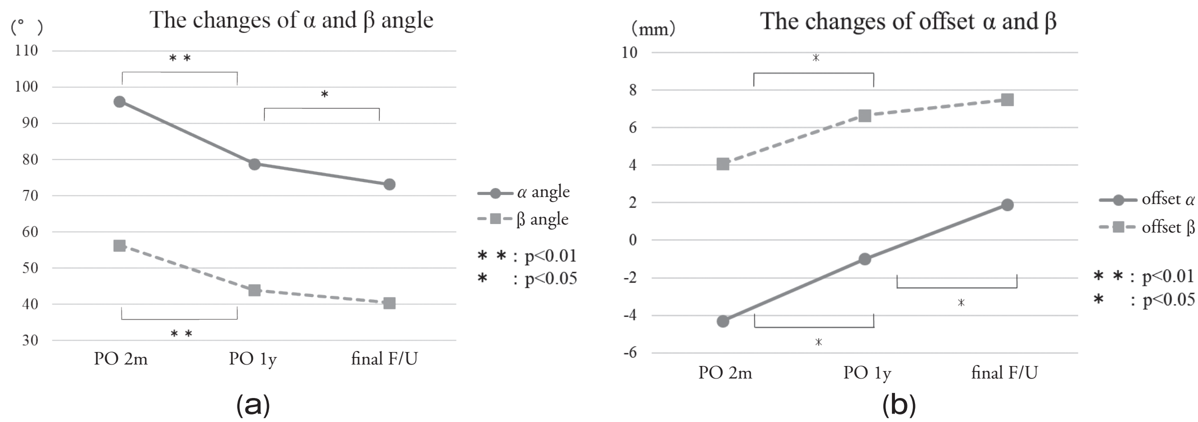


Fig. 3 Change in the mean α and β angles (**a**) and α and β offsets (**b**) at 2 months post-surgery, 1 year post-surgery, and at the final follow-up evaluation. The outcomes were analyzed using the Wilcoxon signed-rank test.

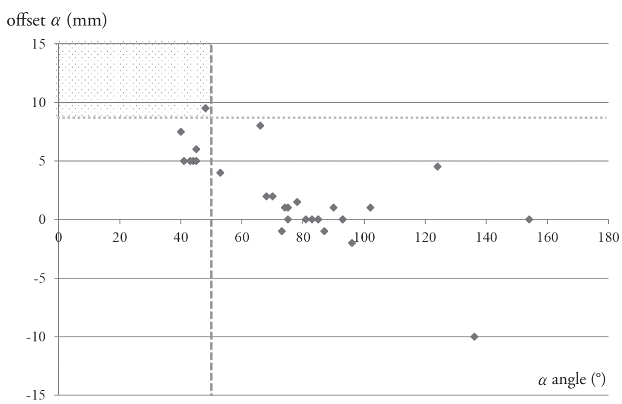


Fig. 4 The α angles and offset α values at the latest follow-up evaluation. The percentage of α angles $\leq 50°$ [20] was 31%, and that of an offset $\alpha \geq 8$ mm (dotted area) was 3% (one hip). Vertical dashed line indicates a 50° α angle, and the horizontal dashed line indicates an 8-mm offset α.

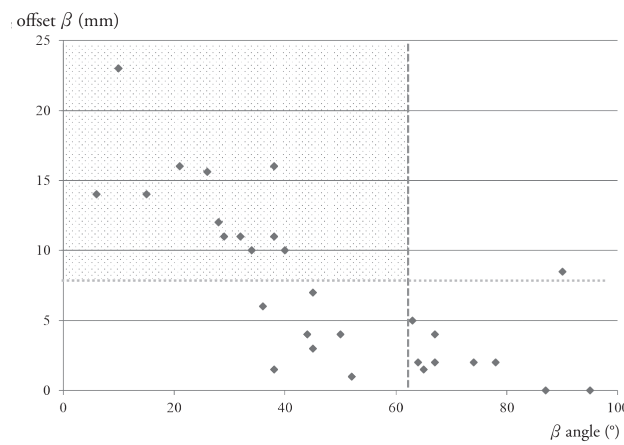


Fig. 5 The β angles and offset β at the latest follow-up evaluation. The percentage of β angles $\leq 63°$ (*i.e.*, the mean β angle in the patients with a negative Drehmann sign reported by Kamegaya *et al*. [21]) was 69%, and that of the offset $\beta \geq 8$ mm (dotted area) was 41%. Vertical dashed line indicates a 63° β angle, and the horizontal dashed line indicates an 8-mm offset β.

nificantly higher than that at 2 months after surgery ($p<0.05$), and the latest follow-up was significantly higher than that at 1 year after surgery ($p<0.05$). The mean offset β at 1 year after surgery was significantly higher than that at 2 months after surgery ($p<0.05$); however, the mean offset β at the latest follow-up evaluation was not significantly higher than that at 1 year after surgery (Fig. 3). Thus, the bony bump improved rapidly 1 year after surgery.

Tannast *et al*. [20] described that the radiographic signs of cam-type femoroacetabular impingement (FAI) are α angles ≤50° and offset α ≥8 mm. In our patient series, at the latest follow-up, α angles ≤50° were observed in 31% of the hips, and an offset α ≥8 mm was present in only one hip (3%; Fig. 4). Kamegaya *et al*. [22] reported that the mean β angles for all hips with a negative Drehmann sign was 63°. In the present patient population, β angles ≤63° occurred in 66% of the hips, and an offset β ≥8 mm occurred in 41% of the hips (Fig. 5).

Based on that finding, we divided the patients into two groups based on their β angles at the final follow-up evaluation: group A (β angle <63°, 19 hips) and group B (β angle ≥63°, 10 hips). We evaluated the β angles and the remodeling ratio of the bump and compared the findings between the groups. Two months after surgery, the mean β angle was 52.8° in group A and 62.3° in group B; this difference was not significant. One year after surgery, the mean β angle was 37.5° in group A and 58.4° in group B ($p < 0.05$; Fig. 6). At the final follow up, the mean β angle was 31.7° in group A and 71.4° in group B. The changes in β angles from 1 year after surgery to the latest follow-up evaluation were −5.8° in group A and 13.0° in group B ($p < 0.05$).

The mean ratio of remodeling per year from 1 year after surgery to the latest follow-up evaluation was −1.3°/year in group A and 4.0°/year in group B

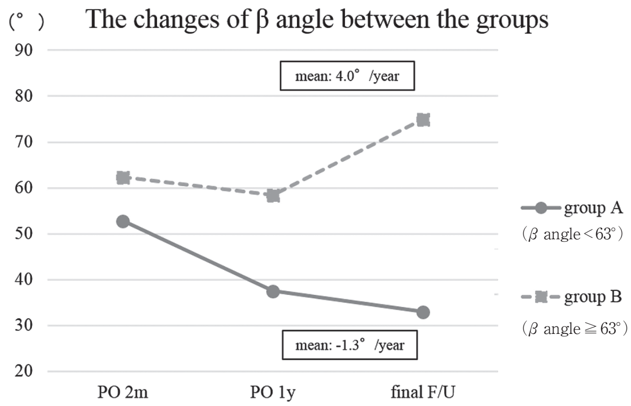


Fig. 6 We divided the patients into 2 groups based on their β angles at the final follow-up evaluation, as follows: group A (β angle <63°) and group B (β angle ≥63°). The changes in β angles comparing group A with group B. Two months after surgery, the mean β angle was 52.8° in group A and 62.2° in group B; this difference was not significant. At 1 year after surgery, the mean β angle was 37.5° in group A and 58.4° in group B ($p < 0.05$). The mean ratio of remodeling per year (*i.e.*, the increase in the β angle) from 1 year post-surgery to the latest follow-up evaluation, which was calculated using the increase in the β angle and the number of years that had passed, was −1.3°/year in group A and 4.0°/year in group B ($p < 0.05$).

($p < 0.05$; Table 2). In the comparison of the lateral radiographs obtained 2 months post-surgery with the latest radiographs, the remodeling of a bump was observed in 22 hips (76%), not observed in 5 hips (17%), and unknown in 2 hips (7%). With respect to clinical symptoms, at the latest follow-up evaluation one patient (3.4%) had coxalgia, and a limited range of motion (ROM) was observed in 6 patients (20%). The mean α angle of the patients who had clinical symptoms was 77.3°, and the mean β angle was 49.2°. The mean α angle of the patients who had no clinical symptoms was 72.1°, and the mean β angle was 47.3°. The mean α and β angles of the patients who had clinical symptoms were higher than those of the patients with no symptoms. However, there was no significant difference in the mean α and β angles between these 2 groups.

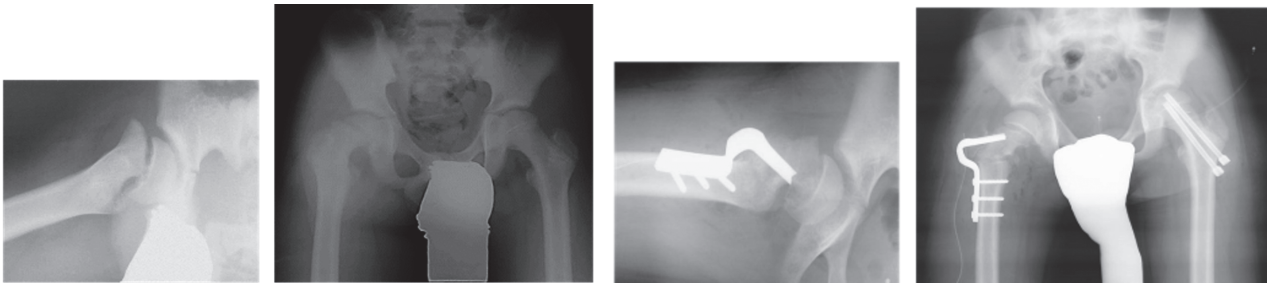
Case Presentation

A 12-year-old boy had an unstable (acute) slip of the right hip. An Imhäuser osteotomy was performed on the right side, and *in situ* pinning was performed on the left side. The PTA improved from 55° to 25° after surgery (Fig. 7). Two months after surgery, the α and β angles were 123° and 86°, respectively. The bump was gradually remodeled on lateral radiographs until 8 months after surgery. One year post-surgery, the patient's physis had closed. An arthrogram was performed at the time of implant removal. Impingement of the labrum against the femoral bump was shown on lateral views (Fig. 8). At the latest follow-up evaluation, when the patient was 22 years old, he had no clinical symptoms. There was a morphologic abnormality according to the measurement on a lateral radiograph (the α angle was 82° and the β angle was 70°; Fig. 9).

Table 2

Variables (β angle)	Group A (n=19)	Group B (n=10)	*p*-value
2 months after the surgery (°)	52.8 (15–91)	62.3 (15–90)	0.31
1 year after the surgery (°)	37.5 (9–65)	58.4 (41–84)	0.032
Changes from 1 year to final follow-up (°)	−5.8 (−48–29)	13.0 (−6–26)	0.030
Ratio of improvement per year from 1 year to final follow-up (°/year)	−1.3 (−7–4)	4.0 (−0.5–12)	0.013

Values are expressed as the mean (range). Statistical analysis of the outcome was performed using the Mann-Whitney *U*-test.
This table compares the β angles and the remodeling ratio of the bump between the groups. Two months after surgery, there was no significant difference. At 1 year, the mean β angle was significantly different ($p < 0.05$). The changes in β angles and the mean ratio of remodeling per year from 1 year after surgery to the final follow-up evaluation were significantly different.

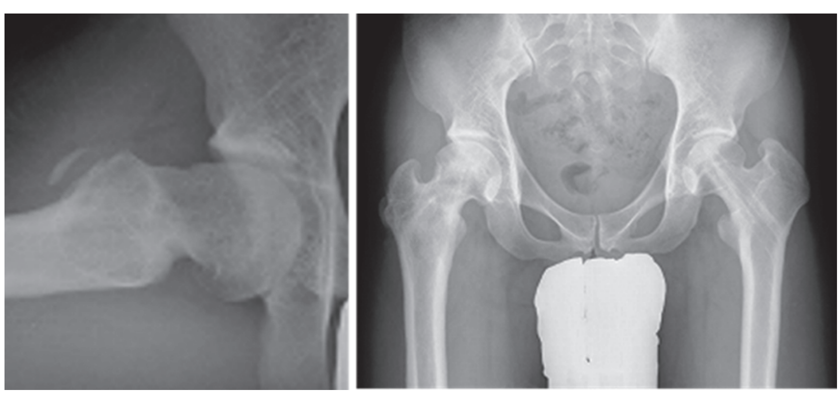


(a) (b) (c) (d)

Fig. 7 Lateral (a) and anteroposterior (b) radiographs before surgery. Lateral (c) and anteroposterior (d) radiographs after surgery. The PTA improved from 55° to 25° after surgery.

(a) (b) (c)

Fig. 8 Radiographs taken during the post-operative period. a, Lateral view at 2 months (the α and β angles were 123° and 86°); b, 8 months after the osteotomy; c, Arthrogram at the time of implant removal. The bump was gradually remodeled. One year after surgery, an arthrogram was performed and an implant was placed. The impingement of the labrum against the femoral bump is shown (the α and β angles were 84° and 76°).



(a) (b)

Fig. 9 The latest lateral (a) and anteroposterior (b) radiographs 9 years after surgery. The patient was 22 years old and had no clinical symptoms. There was a morphologic abnormality on the radiograph (the α angle was 82° and the β angle was 70°).

Discussion

In situ pinning was recommended for severe SCFE by the 2001 Instructional Course Lecture (American Academy of Orthopaedic Surgeons) [22] because *in situ* pinning is considered to be safer and associated with better long-term outcomes than intertrochanteric osteotomies. However, the problem of femoroacetabular impingement is widely known as a cause of early hip osteoarthritis. Thus, a direct corrective procedure with surgical dislocation (which is more invasive to joints than intertrochanteric osteotomies) and an osteochondroplasty have been recommended in recent years [22-24]. A modified Dunn procedure [9] can be expected to restore a near-normal anatomic configuration post-operatively, even in cases of severe SCFE. Ziebarth *et al.* [9] reported the outcomes of 40 patients treated with a modified Dunn procedure at 2 institutions. Specifically, patients were followed for 2 years and 4 months (range 1-3 years), and no chondrolysis or avascular necrosis was noted. In addition, the slip angles were corrected to a range of 4-8°, and the mean α angle was 40.6°. Slongo *et al.* [25], at one of these same institutions, reported that 21 of 23 patients had excellent outcomes by a modified Dunn procedure; however, one patient developed severe osteoarthritis and another developed avascular necrosis.

An intertrochanteric osteotomy is considered to have a relatively low incidence of complications of avascular necrosis of the femoral head, but it cannot restore the deformity to normal morphology—in contrast with the procedures that correct the slipped epiphysis directly. Some studies have reported good long-term results after an Imhäuser osteotomy for severe SCFE [26, 27]. Saisu *et al.* [28] described the outcomes of 32 SCFE patients treated with an intertrochanteric osteotomy with a mean follow-up of 5 years (range 2-9 years). In their study, the β angle was reduced by an average of 39°, 8 patients (25%) had early osteoarthritis on radiographs, and the impingement sign was positive in 8 hips (25%); however, only 2 patients complained of pain or inconvenience in daily life at the latest follow-up evaluation.

In the present study, at the latest follow-up evaluation, a pistol-grip deformity was observed in 13 hips (45%), early osteoarthritic changes were observed in 2 hips (6%), the bony bump was observed in 19 hips (66%) on lateral radiographs, the remodeling of a bump was observed in 22 hips (76%), 1 patient (3.4%) had coxalgia, and a limited ROM was observed in 6 patients (20%). Our review of the anteroposterior and lateral radiographs revealed that morphologic abnormalities persisted in > 50% of the hips treated with an intertrochanteric osteotomy. The bony bump was very large immediately after the osteotomy, but gradual remodeling was observed in many hips. Surgical realignment and remodeling of the bony bump after intertrochanteric osteotomies contributed to the asymptomatic post-operative course in many patients. No severe complications, including avascular necrosis of femoral head, were observed. Our analysis thus revealed that in the short-term, intertrochanteric osteotomies showed good clinical results.

Residual femoral deformities (*i.e.*, pistol-grip deformity, bony bump) after SCFE are a precursor of the cam type of FAI and the development of joint degeneration [29]. Fraizl *et al.* [2] suggested that proximal femoral osteochondroplasty might avoid or delay the development of FAI, even after mild SCFE. Kamegaya *et al.* [21] advocated a modified α angle (*i.e.*, the β angle), and they reported that the mean β angles for all hips with a negative Drehmann sign was 63° at the latest follow-up evaluation, and that the Drehmann sign is highly valuable for clinically evaluating the existence of FAI and for following with observation or realignment to prevent early osteoarthritis.

In the present study, we evaluated the changes in the β angle between the groups (group A, β angle < 63° and group B, β angle ≥ 63°) at the latest follow-up. One year after surgery, the mean β angle was 37.5° in group A and 58.4° in group B ($p < 0.05$). The changes in β angles from 1 year after surgery to the latest follow-up evaluation were −5.8° in group A and 13.0° in group B ($p < 0.05$). Improvement in the β angle was observed 1 year after surgery. Based on a receiver operating characteristic curve analysis, we determined that the β angle at 1 year after surgery affected the final follow-up evaluation (β angle < 63°), with a cut-off value of 41°, 1.0 sensitivity, and 0.625 specificity; the area under the curve was 0.786. The β angles did not improve rapidly in the group A patients (mean, −1.3°/year) from 1 year after surgery. The β angles gradually worsened in the group B patients (mean, + 4.0°/year).

Basheer *et al.* [30] evaluated 18 SCFE patients who underwent arthroscopic treatment, and they reported that an increase in the time from slip to surgery resulted in poorer functional outcomes both before and after surgery. They recommended that patients with symptomatic FAI following SCFE should be treated promptly to prevent progression to irreversible chondrolabral degeneration. Based on our data, patients in whom the β angle was > 41° at 1 year post-surgery and gradually increased may need additional arthroscopic treatment.

The limitations of this study include its retrospective study design and the fact that the operations were not all performed by the same surgeon. In addition, the post-operative evaluation of the radiographs on the femoral side might have been affected by the limb position. A three-dimensional evaluation using computed tomography is needed for accurate evaluations. Here, there was no difference in the angle and offset between the patients who had symptoms and those who had no symptoms, because of the small sample size and the short-term follow-up. We need to continue assessing clinical symptoms and radiographic changes after intertrochanteric osteotomies in a corollary study.

In conclusion, nearly all of the patients who underwent intertrochanteric osteotomies had residual morphologic abnormalities on radiographs, even at the final follow-up evaluation, but few of the patients had clinical symptoms. Although intertrochanteric osteotomies for SCFE have limitations regarding the correction of morphologic abnormalities, we consider intertrochanteric osteotomies to be one of the useful treatments for severe SCFE because its use can avoid the severe risk of osteonecrosis. Our study also demonstrated that the β angle at 1 year after surgery and the ratio of remodeling of the bump can be regarded as potential predictors of morphologic results after intertrochanteric osteotomy in severe SCFE.

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