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Subcapital Correction Osteotomy for Malunited Slipped Capital Femoral Epiphysis

Lucas A. Anderson, MD, Jeremy Gililland, MD, Christopher Pelt, MD, and Christopher L. Peters, MD

University of Utah, Department of Orthopaedic Surgery

Abstract

Background—Slipped capital femoral epiphysis (SCFE), causing posterior and inferior displacement and retroversion of the femoral head, is a well-recognized etiology for femoroacetabular impingement (FAI) and can lead to premature arthritis in the young adult. The treatment of malunited SCFE remains controversial. Surgical dislocation and subcapital correction osteotomy (SCO) has been described as a powerful method to correct the proximal femoral deformity.

Methods—Between January 2003 and January 2010, 11 patients (12 hips) with closed femoral physes and symptomatic FAI from malunited SCFE were treated with surgical dislocation and SCO. We performed a retrospective review of patient histories, physical exams, operative findings, and pre and postoperative anteroposterior (AP) and groin lateral (GLat) radiographs. Mean follow-up was 61 months.

Results—There were 4 female and 7 male patients with an average age of 15 years at the time of SCO. On the AP radiograph the mean inferior femoral head displacement (AP epiphyseal-neck angle) was significantly improved (-26° to -6° , $p<0.001$). On the groin lateral radiograph the mean posterior femoral head displacement (Lateral epiphyseal-neck angle) was significantly improved (-45° to -3° , $p<0.001$). The mean alpha angle was also significantly improved on both views (AP: 85° to 56° , $P<0.001$; GLat: 85° to 46° , $p<0.001$). Operative findings included one femoral osteochondral defect, 8 Outerbridge grade 3-4 acetabular cartilage lesions, and 10 labral lesions. Significant improvement of the mean Harris hip score (HHS) was seen at latest follow-up (54 to 77, $p=0.016$). Complications occurred in 4 of the 12 cases with AVN in two patients, a worse postoperative HHS in one patient, and failure of fixation treated successfully with revision open reduction internal fixation in one patient.

Conclusions—Subcapital correction osteotomy as an adjunct to surgical dislocation and osteochondroplasty can be used to correct the deformity of the proximal femur associated with malunited SCFE. Normalization of proximal femoral anatomy may postpone progression to severe osteoarthritis and thus delay the need for arthroplasty in this young patient population. However, surgeons and patients should be aware that the risks of this procedure in this population are significant.

Corresponding author: Christopher L. Peters MD Department of Orthopaedic Surgery, University of Utah School of Medicine, 590 Wakara Way, Salt Lake City, UT 84108, USA Chris.Peters@hsc.utah.edu Fax: 801-587-7100 Phone: 801-587-5448.

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INTRODUCTION

Slipped capital femoral epiphysis (SCFE), a condition of early adolescence wherein the femoral epiphysis “slips” off of the proximal femoral neck, often leads to posteroinferior displacement and retroversion of the femoral head relative the femoral neck. In the absence of significant remodeling, this resulting deformity causes reduced range of motion and severe femoroacetabular impingement (FAI)[33]. The FAI associated with SCFE leads to cartilage injury and premature arthritis in the young adult[1, 24, 32]. In addition, severely malunited capital epiphyses can be associated with functional limitations during gait and hip range of motion. Subcapital realignment has been described by Ziebarth et al. and Slongo et. al as a safe and effective treatment for acute and subacute SCFE in patients with open proximal femoral physes[43, 46]. It is felt that early deformity correction may prevent some of the long-term sequelae of SCFE.

The optimal management of malunited SCFE is less clear. Most patients present after having undergone previous in situ stabilization and have undergone some amount of proximal femoral remodeling. Current late treatment options include total hip arthroplasty, resurfacing arthroplasty, surgical dislocation and osteochondroplasty (SDO), arthroscopic osteochondroplasty, intertrochanteric repositioning osteotomy, and arthrodesis. Although, subcapital realignment has been described as a safe and effective treatment in patients with an open proximal femoral physis, there is little data regarding this technique for patients with closed physes and a malunited SCFE.

The purpose of our study was to report on the clinical and radiographic outcomes of a series of patients with closed proximal femoral physes and symptomatic FAI secondary to SCFE treated at our institution with subcapital correction osteotomy (SCO) of the femoral neck via the open surgical dislocation approach.

PATIENTS AND METHODS

Between January 2003 and January 2010, 11 consecutive patients with SCFE were treated with 12 subcapital correction osteotomies via surgical dislocation. Surgeries were performed by a single surgeon (CLP) who has performed more than 150 surgical dislocations since 2004; the only cases of avascular necrosis were found in this subseries of subcapital correction osteotomies. In this series there were 4 female and 7 male patients, with an average age of 15 years old (range 12 to 19 year-old) at time of surgery. Five of the affected hips were right hips, while 7 were left hips. (Table 1) After institutional board review approval for this retrospective review, prospectively collected clinical data, including presenting medical history, preoperative and postoperative Harris Hip Scores, operative findings and interventions and preoperative and postoperative radiographic findings were reviewed. Nine of the hips had prior pinning in situ of their SCFE and in these cases, the time from prior pinning to SCO was recorded. Two of the patients had not had any prior intervention for their unrecognized SCFE and in these patients the time from onset of hip pain to SCO was recorded. One patient had a recognized SCFE that was treated non-operatively with limited weight bearing and in this patient, the time from SCFE to SCO was recorded. The indication for surgery in this group of patients was pain interfering with activities daily living and severe functional limitation usually manifested by substantial external rotation contracture of the affected limb with limited hip flexion. (Fig. 1)

Preoperative and postoperative digital radiographs were evaluated in a digital environment (iSite PACS; Philips Healthcare, Andover, Massachusetts) by two readers (JG, LA). Radiographic measurements and findings were determined by consensus. Radiographs were evaluated for the degree of femoral head displacement and angulation using anteroposterior

(AP) and groin-lateral radiographs. (Figure 2) On the AP radiograph, neck/shaft angle, AP alpha angle, and a measurement of AP neck-epiphyseal angle were measured[37]. Additionally, the AP film was used to measure the relative trochanteric position to the center of the femoral head using the described center-trochanteric distance[38] (CTD, indicates the effective height of the greater trochanter), and a novel measurement of the lateral offset of the greater trochanter, which we call center-trochanteric offset (CTO). (Figure 3) On the groin-lateral radiograph, the alpha angle and the neck-epiphyseal angle, were measured[9, 15, 36]. (Figure 4) We elected to use the neck-epiphyseal angle rather than the previously described shaft-epiphyseal angle of Southwick as the neck-epiphyseal angle more directly measures the degree of slip with reference to the femoral neck. Additionally, the neck-epiphyseal angle does not require comparison to the contralateral hip, which may not be normal either. Postoperative measurements were performed on latest available followup radiographs.

Surgical dislocation and subcapital correction osteotomy technique

A lateral skin incision was carried through the subcutaneous fat and through the fascia lata using sharp dissection. The vastus lateralis was sharply elevated off the anterior proximal femur. The interval posteriorly between the medius and the posterior edge of the trochanter was developed. A trochanteric osteotomy was performed using a $\frac{3}{4}$ inch oscillating saw and completed with a straight osteotome. The gluteus minimus and medius were left attached to the superior aspect of the trochanteric fragment and the vastus lateralis remained attached to the inferolateral aspect as described by Ganz et al[21]. A Wagner retractor was placed over the anterior rim of the acetabulum to facilitate exposure. The interval between the piriformis and the short external rotators was left intact. With external rotation of the hip, the entire anterior hip capsule extending from the piriformis posteriorly to the anterior-inferior portion of the hip capsule was exposed.

A Z-shaped capsulotomy was then performed and sutures were placed in the flap corners. After transecting the ligamentum teres, the femoral head was dislocated without difficulty.

The hip was inspected and areas of labral and/or cartilage damage were recorded in a prospective database. Hyaline cartilage was recorded according to an adapted Outerbridge grading scale with grade 0 being normal, grade 1 having softening, grade 2 having fissuring, grade 3 having partial thickness cartilage loss and fragmentation, and grade 4 having areas of full thickness cartilage loss[39]. Damaged acetabular cartilage was debrided back to stable cartilage and full thickness cartilage lesions were treated with resection of the acetabular rim back to normal cartilage. A burr was used to create a bleeding cancellous bed along the extra-articular acetabular rim allowing for reattachment of the labrum via suture anchors[18]. If the labrum was not repairable, then the area of degenerative labrum was excised.

Attention was then turned to the femoral side. A second trochanteric osteotomy was then performed to facilitate development of an extended retinacular flap. The posterior oblique trochanteric osteotomy from the remaining stable greater trochanter allowed reflection of the short external rotators including the piriformis from the posterior proximal femur. A freer elevator was used to elevate the periosteum containing the retinacular vessels and the terminal branches of the medial femoral circumflex along the postero-lateral femoral neck[46]. This created an extended retinacular flap or vascular pedicle, which allowed circumferential exposure of the femoral neck. (Figure 5a)

Once circumferential exposure of the femoral neck was obtained, an osteotome was used to osteotomize the femoral head-neck junction through the remodeled physeal scar. (Figure 5b) The femoral head was then repositioned to recreate adequate anteversion and neck-shaft

angle. (Figure 5c) A pin was placed in retrograde fashion through the fovea and out the lateral cortex. The hip was then reduced and the femoral head position was evaluated under two plane image fluoroscopy prior to placement of three 4.5mm to 7.3mm screws from the lateral cortex into the head for definitive fixation. The largest screw size allowable based on available space in the neck was used. A burr and a rongeur were used to further contour the anterior femoral head-neck junction after corrective osteotomy had been performed to address the often-present metaphyseal remodeling of the neck. The remaining posterior trochanter wafer was debrided with a rongeur[46]. The remaining trochanteric bed was contoured with a burr to accept the trochanteric flip osteotomy. Depending on the height of the greater trochanter relative to the newly repositioned femoral head, a greater trochanteric distalization was performed in some cases. The first trochanteric osteotomy was fixed with two 3.5mm or 4.5mm bicortical screws depending upon size and gender of patient. The posterior soft tissue sleeve was kept intact and protected throughout the procedure. The anterior hip capsule was repaired prior to layered closure. Our postoperative protocol included fifty percent weight-bearing with crutches for six weeks, after which, physical therapy was utilized to address abductor weakness and range of motion restriction.

Data were analyzed by an independent statistician using commercially available software (STATA Version 11, College Station, TX). Student's t test was used for comparing the preoperative and postoperative continuous variables of Harris Hip Score and radiographic measurements.

RESULTS

Of the 9 hips that had prior pinning in situ of the SCFE, the average time from prior pinning to SCO was 29 months (range 4-73). Of the 2 patients that had not had any prior intervention for their unrecognized SCFE, the time from onset of hip pain to SCO was found to be 9 months in one patient and 13 months in another. In the one patient with recognized SCFE treated non-operatively with limited weight bearing, the time from SCFE to SCO was 2 months. (Table 1)

Findings at the time of surgical dislocation and subcapital osteotomy included the following: Ten of the twelve hips had acetabular hyaline cartilage lesions. Two of these were full thickness delamination lesions and were associated with labral tears. Both of these lesions were addressed by further labral takedown, resection of acetabular rim back to stable cartilage, and advancement and refixation of the labrum via suture anchors. The remaining 8 hips with acetabular cartilage lesions of varying thickness all had resection of the acetabular rim back to normal cartilage with 4 requiring resection of degenerative labrum and 4 requiring labral repair with suture anchors. One hip had a discrete labral detachment not associated with an acetabular cartilage lesion. This was a small enough lesion that no repair was performed. Three hips had labral tears associated with acetabular cartilage lesions and all 3 of these were repaired after appropriate acetabuloplasty had been performed. Labral degeneration was found in 4 hips, 3 of which were debrided, and 1 of which was repairable. A calcified labrum was found in 1 hip that was then debrided. A small isolated labral tear without significant acetabular cartilage damage was found in 1 hip and this was treated with simply debridement of the labral tear and did not warrant repair. (Table 2) The average estimated blood loss was 496 milliliters (range 250-700ml; standard deviation 148). All femoral heads had evidence of bleeding following the reduction and fixation.

All presenting radiographs demonstrated varying degrees of coxa vara and femoral retroversion (inferior and posterior translation of head on the femoral neck) with resulting relative prominence of the greater trochanter. As would be expected, the mean neck-shaft angle and mean CTO did not change significantly after SCO. After SCO, the CTD did

improve significantly by 11 millimeters on average ($p=0.003$). The alpha angle measured on AP and groin-lateral radiographs significantly improved by 29 degrees and 39 degrees respectively after SCO ($p<0.001$ for both). The AP neck-epiphyseal angle improved significantly from a mean of 26 degrees of varus to mean 6 degrees of varus after SCO ($p<0.001$). The neck-epiphyseal angle on groin-lateral radiograph also improved significantly from a mean 45 degrees of posterior tilt to a mean 3 degrees of posterior tilt after SCO ($p<0.001$). At final follow-up, the degree of radiographic osteoarthritis as measured by Tönnis grade had increased significantly from a mean grade of 0.8 pre-operatively to 1.3 post-operatively ($p=0.002$). (Table 3)

There were several significant perioperative complications in four out of the twelve cases (25%). Three patients met our criteria for failure as defined as worsening of symptoms or conversion to total hip arthroplasty. One patient had an early postoperative infection that was treated with incision and debridement. This patient did go on to successful healing, but was one of our failures as she had a very poor outcome with worse hip pain and function after surgery than before surgery. Two hips developed the radiographic appearance of avascular necrosis postoperatively and underwent total hip arthroplasty at 5 months and 26 months respectively. (Figure 6) One patient had failure of fixation requiring revision of the osteotomy position and hardware revision from 4.5 to 7.3mm screws. After revision, this patient went on to heal the osteotomy and was doing well at his 4-year post-operative visit.

There was a mean follow-up of 61 months (range 6 to 104 months). One hip underwent THA at 6 months, while all other hips had follow-up of 24 months or longer. When all patients were included in the clinical analysis (including the pre-arthroplasty HHS of the two patients who developed AVN) average HHS improved from 54 preoperatively to 77 postoperatively ($p=0.016$). (Table 3) When the patients who had the complication of AVN were excluded (postoperative HHS of 33 and 50), the average Harris hip scores improved from a mean of 55 preoperatively (range 40-71) to 84 postoperatively (range 52-100, $p=0.004$) One hip underwent THA at 6 months, while all other hips had follow-up of 24 months or longer. Additionally, average hip range of motion for the group improved from an average preoperative flexion of 75 degrees to 94 degrees postoperatively (STDEV 7 degrees, $p<0.05$) and internal rotation from -35 to 12.5 degrees (STDEV 9 degrees, $p<0.05$).

DISCUSSION

The proximal femoral morphological abnormalities characteristic of SCFE are a well-known cause of femoroacetabular impingement (FAI)[6, 22, 25]. The pistol grip deformity resulting from retroversion of head and varus deformity causes a decreased head/neck offset and varus deformity[40]. This deformity causes abutment of the head-neck junction within the acetabulum, which frequently leads to intra-articular chondrolabral damage[1, 30, 43]. Our study supports this concept as 83% had labral lesions and 67% had significant acetabular hyaline cartilage damage greater Outerbridge grade 2. (Table 2) It has been shown that unless these acetabular lesions are addressed, osteoarthritis may progress rapidly[18]. Ziebarth et. al found more chondrolabral lesions to not be associated with slip angle severity but rather with stable SCFE and longer symptom duration (6 months versus 1 month)[46].

The treatment approach to the patient with symptomatic FAI secondary to malunited SCFE remains controversial. There are advocates of various methods from watchful waiting[8, 13] to those who advocate for surgical intervention, which has traditionally been focused on one or more of the following: intertrochanteric osteotomy, surgical dislocation and osteochondroplasty, arthrodesis, and THA. Several groups have demonstrated clinical improvement with intertrochanteric osteotomy and base of neck, extracapsular osteotomies[15, 44].

Intertrochanteric osteotomy, while having less risk of osteonecrosis and chondrolysis, partially corrects the proximal femoral deformity by creating an additional deformity distally[15]. This not only alters normal hip biomechanics but has other consequences such as making future total joint arthroplasty more difficult. Rab showed with 3D computational modeling that significant metaphyseal deformities are associated with remodeled SCFE and are a significant cause of impingement[40]. These metaphyseal deformities are not directly addressed by peritrochanteric redirection osteotomies whether intertrochanteric, subtrochanteric or basicervical in nature. While Rab demonstrated that extracapsular osteotomies can eliminate metaphyseal impingement in his computational model, the complex multiplanar correction required is difficult to determine preoperatively and accomplish surgically. Mausen et. al did not find that intertrochanteric osteotomies reduced development of osteoarthritis in hips with more significant deformities and thus recommended that they be reserved for hips with flexion contractures[35].

Surgical dislocation with osteochondroplasty alone can be used to improve the head-neck offset and address chondrolabral lesions. Leunig et. al advocated for simultaneous in situ pinning and osteochondroplasty of the head-neck junction to improve offset in mild SCFE deformities[31]. However, this does not address the limb-length deficit, retroversion, and varus deformities of more moderate to severe SCFE deformities.

Due to the limitations of the above treatments for the late sequelae of SCFE, when possible, we have utilized a subcapital osteotomy to correct both the varus and retroversion deformity of the proximal femur in patients with closed physes. To our knowledge, the use of a subcapital osteotomy to correct SCFE deformities in hips with closed physes has not been reported on in the literature. Numerous studies have discussed the use of subcapital cuneiform osteotomies to correct SCFE deformities in skeletally immature patients[19, 20, 26, 34]. These earlier series demonstrated clinical efficacy with high complication rates, with rates of AVN and chondrolysis approaching 30% and 40% respectively in one large series. However, more recent series utilizing the surgical dislocation technique described by Ganz have demonstrated minimal risk of AVN and chondrolysis and similar clinical improvement in skeletally immature patients.

Ziebarth et al. reported on 40 patients with acute or subacute SCFE who had undergone a modified Dunn osteotomy[46]. No osteonecrosis or failures were noted, though one patient had impingement from incomplete reduction and another developed heterotrophic ossification, both which were successfully addressed with revision surgery. Slongo et. al also reported on open reduction through the open physis in SCFE hips[43]. Their series included 23 hips with either acute or subacute slips, 20 of which had satisfactory postoperative clinical and radiographic outcomes. They reported two failures: one hip developed early symptomatic osteonecrosis after having no bleeding of the head at the time of surgery prior to reduction and fixation, while the second hip was found to have a large delamination lesion of the acetabulum during surgery and went on to develop radiographic findings of early severe osteoarthritis. Huber et. al similarly had excellent clinical results with near anatomic correction in 30 hips treated with a subcapital osteotomy via a surgical dislocation[27]. 93% of these patients had HHS greater than 95 at mean followup of 3.8 years with only one case of AVN occurring.

In contrast to previous studies, we present our experience with a subcapital femoral osteotomy for chronic slips in the setting of a closed physis. We have found a higher rate of AVN (2/12 hips, 17%) in our series of SCO for SCFE deformities in these skeletally mature hips. This higher rate of AVN could be due to intrinsic factors to the delayed treatment. Remodeling of the posterior head-neck junction occurs along with adhesions between the posterior vasculature and the epiphyseal scar. This makes mobilizing the vascular pedicle all

the more precarious. Additionally, remodeled callus is often present along the epiphyseal scar and must be debrided posteriorly to remove tension on these structures[19, 43]. Frequently the soft-tissue structures are very contracted posteriorly due to the SCFE deformity (varus and retroverted). Therefore, placing the head back on the neck places these shortened structures on stretch, risking the blood supply to the head. Of our two failures secondary to AVN, one had the highest pre-operative AP neck-epiphyseal angle (42 degrees of varus slip), while the other had the highest pre-operative lateral neck-epiphyseal angle (70 degrees of posterior slip). Placing the head back on the neck in these cases may have caused excessive stretch to the vasculature, potentially leading to the AVN. All the above factors may play a role in the higher rates of AVN in our series of SCO used to address chronic SCFE deformities when compared to acute reductions of SCFE deformities in hips with open physes.

In addition to the reorienting procedure of the femoral epiphysis, we also elected to address the acetabular sided sequelae. Our preference for treating chondrolabral injuries associated with SCFE deformities, was cartilage lesion debridement, labral takedown, rim resection, and labral advancement rather than microfracture or debridement alone[17, 18]. Preoperative advanced imaging including magnetic resonance arthrography has been helpful in our practice to evaluate the condition of the acetabular and femoral cartilage[2]. Anecdotally, several patients who we were planning on performing hip preservation surgery for SCFE have been found to have significant cartilage loss on preoperative magnetic resonance imaging despite maintained joint space on plain radiographs and thus were treated with total joint arthroplasty. In our small series, postoperative HHS did not correlate with the presence of acetabular rim cartilage lesions, possibly indicating that the lesions were appropriately addressed. However, all three of our failures did have large, full thickness acetabular chondral lesions.

The retroversion and varus deformities associated with SCFE not only contribute to FAI but also play a role in a reduction of the abductor lever arm. This leads to a deficiency of abductor strength, contributing to the often limp, exercise induced fatigue, and lateral based pain associated with SCFE. More recently, it has been shown that an elevated greater trochanter to femoral head center relationship caused by either a relative overgrown trochanter, low head (coxa plana), or a varus femoral neck is associated with progression of osteoarthritis in hips with pistol grip deformity[3]. We measured our pre and postoperative CTD and found a significant improvement from the mean pre-operative center of the head being 8mm inferior to the tip of the trochanter to a mean post-operative position of 3mm superior to the tip of the trochanter.

Our study has several limitations. This is a retrospective series of a small number of patients with limited clinical and radiographic followup. A limitation of the technique described is the rate and severity of complications. One of the most devastating complications is AVN; when it occurs the options are limited to total hip arthroplasty, a solution that is undesired in this population due to the young age, activity level and subsequent propensity for future revision surgeries.

Young skeletally mature patients with symptomatic FAI secondary to SCFE deformities often have significant functional limitations and severe clinical symptoms, while unfortunately having limited treatment options. Subcapital osteotomy, while potentially improving hip biomechanics and hip outcomes, does carry a significant risk of major complications. Preoperative counseling in this population should include a thorough discussion of these risks and encourage realistic expectations.

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Figure 1. Photograph demonstrating preoperative external rotation contracture of the left hip prior to subcapital corrective osteotomy. After surgery the patient was able to internally rotate past neutral both in hip extension and flexion.

Figure 2.
Pre and postoperative anteroposterior and groin lateral radiographs demonstrating improved position of the femoral head on the neck with corresponding improved head/neck offset and neck-epiphyseal angle.

Figure 3. Preoperative anteroposterior radiograph demonstrating a skeletally mature hip with a pistol grip deformity consistent with a history of SCFE. Technique for measuring center-trochanteric distance (CTD) and center-trochanteric offset (CTO) are labeled.

Figure 4. Preoperative groin lateral radiograph demonstrating a hip with a SCFE deformity with posterior displacement and retroversion of the femoral head. Technique for measuring the neck-epiphyseal angle (NEA) is demonstrated.

Figure 5.
Intraoperative photographs of subcapital correction osteotomy of the femur.

Fig. 5a. Intraoperative photograph demonstrating SCFE deformity prior to osteotomy.
Fig. 5b. Intraoperative photograph demonstrating elevation and preservation of the vascular pedicle to the femoral head after osteotomy of the subcapital femoral neck.
Fig. 5c. Intraoperative photograph demonstrating the femoral head reduced to an anatomic position on the neck prior to preliminary k-wires fixation. Remodeled callus, distal neck, and/or a wafer of posterior trochanter is removed when the vascular pedicle is stretched or impinged.

Figure 6. Postoperative anteroposterior pelvis radiograph of one of the two hips that went on to avascular necrosis and subsequent total hip arthroplasty within one year of the subcapital correction osteotomy.

Table 1

Demographic Data (n=12 Hips in 11 Patients)

	Finding
Age at time of operation (years) *	15 (2)
Body Mass Index *	30 (4)
Gender (M/F)	7/4
Affected Hip (R/L)	5/7
Prior Bilateral Pinning in Situ	6
Prior Unilateral Pinning in Situ	3
Time from Pinning to Osteotomy (months) *	29 (26)
No Prior Pinning **	3

* Data presented as Mean with Standard Deviation in parenthesis.

** 2 patients presented with unrecognized chronic severe SCFE, one patient presented 9 months after onset of hip pain and the second patient presented 13 months after onset of an antalgic limp. 1 patient presented 2 months after a recognized SCFE that was treated non-operatively with limited weight bearing.

Table 2

Intra-Operative Findings (n=12 Hips)

Intraoperative Finding	#Hips	Intervention
Acetabular Cartilage Damage		
None	2	N/A
OB I	2	Acetabuloplasty
OB II	0	N/A
OB III	3	Acetabuloplasty
OB IV	3	Acetabuloplasty
Delamination	2	Acetabuloplasty
Labral Damage		
None	2	Labrum taken down for Acetabuloplasty followed by Repair - 2
Degeneration	4	Resected Labrum – 3 Labrum taken down for Acetabuloplasty followed by Repair – 1
Calcification	1	Resected Labrum
Tear	5	No Repair Necessary – 2 Acetabuloplasty followed by Repair – 3

OB: Outerbridge cartilage lesion grading system

Table 3

Clinical and Radiographic Measures (n = 12 Hips with mean follow-up of 39 months)

	Pre-Operative	Post-Operative	p-value
AP Radiographic Measures			
Neck Shaft Angle (degrees)	138 (129.9 to 145.7)	136 (133.0 to 139.1)	0.681
Center-Trochanter Distance (mm) (+ = Superior, - = Inferior)	-8 (-14.7 to -0.6)	3 (-2.8 to 7.8)	0.003
Center-Trochanter Offset (mm)	50 (45.6 to 53.9)	51 (48.1 to 54.6)	0.325
AP Alpha Angle (degrees)	85 (79.1 to 90.1)	56 (51.2 to 60.7)	<0.001
AP Neck Epiphyseal Angle (degrees) (+ = Valgus, - = Varus)	-26 (-32.2 to -19.8)	-6 (-10.6 to -1.4)	<0.001
Groin-Lateral Radiographic Measures			
Alpha Angle (degrees)	85 (77.1 to 92.4)	46 (41.9 to 49.8)	<0.001
Neck Epiphyseal Angle (degrees) (+ = Anterior, - = Posterior)	-45 (-53.9 to -36.8)	-3 (-7.9 to 2.3)	<0.001
Tönnis Grade	0.8 (0.5-1.0)	1.3 (1.0-1.6)	0.002
Harris Hip Score	54 (47.9 to 60.7)	77 (64.1 to 89.6)	0.016
Clinical Range of Motion			
Flexion (degrees)	75 (70.7 to 78.5)	94 (88.0 to 100.3)	<0.001
Internal Rotation (degrees)	-35 (-47.7 to -22.3)	13 (7.2 to 17.8)	<0.001

All Data presented as Means with 95% Confidence Intervals in parentheses.