Combined Imhauser osteotomy and osteochondroplasty in slipped capital femoral epiphysis through surgical hip dislocation approach

Mostafa M. Baraka
Hany M. Hefny
Mootaz F. Thakeb
Tamer A. Fayyad
Haytham Abdelazim
Mamdouh H. Hefny
Mahmoud A. Mahran

Abstract

Purpose Treatment of moderate to severe stable slipped capital femoral epiphysis (SCFE) remains a challenging problem. Open reduction by modified Dunn procedure carries a considerable risk of osteonecrosis (ON). Imhauser osteotomy is capable of realigning the deformity without the risk of ON, but the remaining metaphyseal bump is implicated with significant chondro-labral lesions and accelerated osteoarthritis. We conducted this study to evaluate the efficacy and safety of Imhauser osteotomy combined with osteochondroplasty (OCP) through the surgical hip dislocation (SHD) approach.

Methods A prospective series of 23 patients with moderate-severe stable SCFE underwent Imhauser osteotomy and OCP through SHD. The mean age was 14.4 years (13 to 20) and the mean follow-up period was 45 months (24 to 66). The outcome measures included clinical and radiological parameters and Harris hip score (HHS) was used as a functional score.

Results The mean HHS improved significantly from 65.39 to 93.3. The limb length discrepancy improved by a mean of 1.72 cm. The mean flexion and abduction arcs showed a significant improvement (mean increase of 37.5° and 18.5°, respectively). The mean internal rotation demonstrated the most significant improvement (mean increase of 38.5°).

All the radiographic parameters improved significantly, including anterior and lateral slip angles (mean improvement 37.52° and 44.37°, respectively). The mean alpha angle decreased by 39.19°. The articulo-trochanteric distance significantly increased to a mean of 23.26 mm. No cases of ON or chondrolysis were identified.

Conclusion Combined Imhauser osteotomy and OCP through the surgical dislocation approach provide a comprehensive and safe management of moderate to severe stable SCFE.

Level of evidence: IV

Keywords: slipped capital femoral epiphysis; hip preservation; Imhauser osteotomy; surgical hip dislocation; hip impingement

Introduction

Slipped capital femoral epiphysis (SCFE) remains the most common adolescent hip disorder and in situ fixation has been the traditional standard of care. Although associated with acceptable safety and prognosis, recent literature highlights its failure to provide symptomatic relief and to stop the progressive hip osteoarthritis (OA). The recently introduced concept of femoroacetabular impingement (FAI) and subsequent studies revealed considerable evidence of articular cartilage and labral injury in hips with SCFE, which ultimately lead to degenerative changes and OA. This made it mandatory to attempt to restore the anatomy of the proximal femur.

The typical slip is multiplanar and results in coxa vara, retroversion and extension deformity as the femoral head (FH) displaces posteriorinferiorly in relation to the femoral neck. The exposed anterolateral neck metaphysis forms an osseous bump, which impinges against the acetabular rim. The retroversion presents clinically as decreased internal rotation and the metaphyseal bump may further result in complete loss of internal rotation or even a fixed...
external rotation deformity and out-toeing gait.\textsuperscript{10} Pincer-type FAI is also associated with SCFE and results from acetabular retroversion. The cause of acetabular retroversion remains controversial, whether primary and predisposes to slips or a secondary remodelling in hips that already developed SCFE.\textsuperscript{3,11}

Two factors have been attributed to impingement and premature OA in SCFE; the abnormal head-neck offset and the mal-oriented FH cartilage.\textsuperscript{12} In moderate and severe slips (lateral slip angle > 30\degree),\textsuperscript{13} the relative prominence of the neck metaphysis, rather than the degree of slip was emphasized as being the major cause of impegmement.\textsuperscript{14,15} In addition, the metaphyseal prominence, as determined by the alpha angle, has been reported to be the most significant predictor of symptomatic FAI and development of OA.\textsuperscript{2,9,16} These data illustrate the importance of osteochondroplasty (OCP) to restore the proximal femoral anatomy in slips with a significant metaphyseal prominence.

The recently introduced modified Dunn procedure theoretically provides the best surgical option by anatomical restoration with no residual impingement.\textsuperscript{7} However, the procedure has high reported osteonecrosis (ON) rates (up to 26\%) regardless of physeal closure.\textsuperscript{17} Many of the conducted studies did not highlight the difference between slips with open and slips with closed physes. Few studies, in agreement with the original report by Dunn,\textsuperscript{18} emphasized that the presence of open physs offers a clear cleavage plane for safe subcapital realignment, with minimal ON risk. These studies recommended an intertrochanteric osteotomy (ITO) in slips with closed physs.\textsuperscript{18-20}

In 1966, Imhauser described a triplane osteotomy,\textsuperscript{21} realigning the head onto the shaft by creating valgus, flexion and derotation. A number of trials\textsuperscript{12-26} evaluated this procedure and have shown a good clinical outcome, delayed onset of OA and fewer rates of chondrolysis and ON. However, ITO alone is incapable of completely restoring the proximal femoral anatomy in presence of a large metaphyseal bump in moderate and severe slips.

Utilizing the surgical hip dislocation (SHD) approach for combined ITO and OCP is infrequently discussed in the literature. The approach provides optimum visualization of the proximal femoral deformity and allows the metaphyseal prominence as well as associated intraarticular chondro-labral lesions to be simultaneously addressed.

The current study evaluates the efficacy and safety of combined Imhauser osteotomy and OCP performed through SHD approach in hips with chronic slips with closed or partially closed physs. We hypothesize that Imhauser osteotomy and OCP via SHD approach would provide comprehensive management; offering optimum visualization for OCP, management of associated chondro-labral disease, acetabular retroversion and Imhauser osteotomy as well as restoring the biomechanics of hip abductors.

### Patients and methods

This prospective case series included 23 patients (23 hips) with chronic SCFE and closed or partially closed physs, conducted during the period from 1\textsuperscript{st} January 2013 to 31\textsuperscript{st} March 2017. The study included 14 male and nine female patients. The mean age was 14.4 years (13 to 20). The right side was affected in ten patients and the left side in 13. In all, 11 patients had previous \textit{in situ} pinning. The minimum period from pinning to the index procedure was six months. The mean follow-up was 45 months (24 to 66). No patients in this series were lost in the follow-up. Institutional review board approval was obtained prior to conducting the study.

The preoperative clinical evaluation focused on history, physical examination and Harris hip score (HHS)\textsuperscript{27} was used as a functional score. The range of clinical features included groin pain with or without ipsilateral referred knee pain, limited range of movement (ROM), limp, interference with daily activities and out-toeing. Notably all patients in this series had a positive anterior impingement test and a positive Drehmann’s sign; obligatory external rotation with hip flexion.

Standard anteroposterior (AP) and frog-lateral radiographs of the pelvis and both hip joints were obtained. The radiographic parameters included AP and lateral slip angles;\textsuperscript{13} articulo-trochanteric distance (ATD);\textsuperscript{28} and Nötzli’s alpha angle.\textsuperscript{14} The AP and lateral slip angles were measured according to Southwick’s method;\textsuperscript{13} the first line is drawn across the base of the epiphysis, connecting it to the superior and inferior margins. A second line is drawn perpendicular to the first line. A third line is drawn representing the anatomical axis of the proximal femur. The angle formed between the second and the third line is measured. Similarly, the angle is measured on the opposite side and the difference between both sides in the AP and frog-lateral views constitutes the AP and lateral slip angles, respectively. The ATD was determined by measuring the vertical distance between the tip of the greater trochanter (GT) to the highest point of the FH. The alpha angle was determined on frog-lateral radiographs by measuring the angle between a line connecting the centre of the long axis of the femoral neck and the centre of the FH, and a line from the centre of the FH to the point on the anterolateral head-neck junction where the FH loses sphericity.

Severity of the slip was classified based on the lateral slip angle measured on frog-lateral radiographs.\textsuperscript{13} Accordingly, ten slips were classified as moderate (slip angle between 30\degree and 50\degree) and 13 were classified as severe (slip angle > 50\degree). The physs was closed in 15 patients and partially closed in eight patients. The acetabular version, state of physeal closure and the anatomy of the metaphyseal bump were further delineated by computed tomography.
The inclusion criteria included moderate to severe stable SCFE (slip angle > 30°) with closed or partially closed physis and no or minor hip OA (Grade 0 or 1 according to Tönnis classification\textsuperscript{29}). Unstable slips and those with open physis were excluded. According to a preset algorithm, those cases are preferably managed by the modified Dunn procedure. Mild slips were excluded as well as hips with already developed secondary OA (Grade 2 or more according to Tönnis classification), ON or chondrolysis. Surgical technique: surgical dislocation and OCP

The patient is positioned in the lateral position and the ipsilateral leg is draped free. In all cases, surgical dislocation approach was done as described by Ganz et al.\textsuperscript{30} Special attention was made to separate the gluteus minimus tendon insertion from the trochanteric flip to ease later GT transfer. The FH and acetabular cartilage were examined for chondral lesions and labral pathologies. The OCP was performed using a 1-cm curved osteotome and high-speed burr to trim the aspherical portion of the FH and recontour the head-neck offset. Care was taken to limit the extent of OCP to one-third of the femoral neck width to avoid the risk of femoral neck fracture. Three hips had chondro-labral separation that required repair. FH chondral flap tears were found in nine patients and were debrided. Slips with partially closing physis in which a large part of the physseal plate remained unfused underwent simultaneous \textit{in situ} fixation using a single 7.3-mm cannulated screw (Fig. 1).

Surgical technique: ITO

The hip was then relocated and an Imhauser osteotomy was performed to produce the desired amount of valgus, flexion and derotation. The amount of valgus and flexion was predetermined preoperatively by measuring the head-shaft angle difference according to Southwick.\textsuperscript{13} Two guide wires were inserted in the neck region, inclined in the AP and lateral views to achieve the desired amounts of valgus and flexion, respectively. The seating chisel was inserted along the guide wires, and a four-hole 90° double-angled blade plate was applied. Osteotomy was then performed as a single transverse cut, approximately 1.5 cm to 2 cm below the entry of the seating chisel, using a large oscillating saw. The blade plates offered significant rigidity and a closing-wedge osteotomy was not performed to avoid unnecessary limb shortening (Fig. 2). The shaft was approximated to the plate by a plate-holding clamp to achieve valgus and flexion components.

![Fig. 1 Osteochondroplasty and simultaneous pinning through surgical hip dislocation. Femoral head cartilage with trimmed border (asterisk), anterior capsular flap tagged with suture (white arrowhead), the head-neck junction after osteochondroplasty and restoring the head-neck offset (white arrow), \textit{in situ} screw fixation (black arrow).](image)

![Fig. 2 a) Imhauser osteotomy in slipped capital femoral epiphysis through surgical hip dislocation approach; b) the seating chisel is inclined in the lateral view to achieve the amount of desired flexion, which corresponds to the bone-plate angle; c) in the frontal plane, the bone-plate angle corresponds to the amount of valgus correction; d) a single transverse cut is performed by a power saw; e) and f) the final corrected head-shaft alignment.](image)
distal portion of the shaft was internally rotated based on preoperative examination to fairly produce equal amounts of hip internal and external rotation.

**Surgical technique: trochanteric transfer**

The capsular flaps were closed without tension using interrupted absorbable suture. The gluteus minimus tendon was repaired to the trochanteric base with the hip placed into moderate abduction. The GT fragment was advanced laterally and distally until the superior tip of the trochanter was located at the same horizontal level as the centre of the FH and its position confirmed under fluoroscopy. Trochanteric fixation was performed using two 4.5-mm cortical screws with washers. Special attention was made to transfer the GT fragment into a distal and a more anterior position to lateralize the abductor insertion and hence improve the abductor lever arm. The trochanteric fragment was seated anteriorly and slightly proximal to the prominence of the blade plate. In some cases, a high-speed burr was used to create a more flattened bone bed along the lateral surface of the proximal femur for stable positioning of the transferred GT.

**Postoperative management**

Patients were placed on a continuous passive motion (CPM) machine in the first three to five days, adjusted to achieve passive hip flexion of 90°, at a rate of two cycles per minute. During the first six weeks, toe-touch weight-bearing was allowed with precautions that prevented adduction and external rotation. Radiographs were repeated at six weeks to determine union of the trochanteric and intertrochanteric osteotomies. During the sixth to 12th week interval patients were instructed to gradually advance to full weight-bearing at 12 weeks under physical therapy guidance. Stationary bike exercise was introduced after six weeks in all patients.

All patients were re-evaluated at six-month intervals till the latest follow-up. This included clinical and functional assessment using the HHS and goniometric ROM measurements. Pre- and postoperative values were compared for each case. Plain radiographs at the final follow-up included assessment of viability of the FH, union of trochanteric and intertrochanteric osteotomies, together with measurements of the anterior and lateral slip angles, alpha angle and the ATD.

Results were analyzed using the Statistical Package for Social Science (SPSS 20, IBM corp. Armonk, New York, USA). Analytical statistics, the paired t-test and McNemar test were used to assess the statistical significance. Correlation analysis (Pearson’s method) was used to assess the strength of association between two quantitative variables.

**Results**

**Clinical parameters**

The mean preoperative HHS improved from 65.39 ± 7.64 to 93.3 ± 3.23 at the latest follow-up (p < 0.001). The mean limb length discrepancy (LLD) improved from 1.99 cm ± 0.48 to 0.27 cm ± 0.37. The percentage of patients with a positive anterior impingement and Trendelenburg test have improved significantly (Table 1). The mean ROM improved in all the measured directions (Figs 3 and 4). The mean flexion arc increased from 83° (45° to 93°) to 120.5° (95° to 135°), the mean abduction arc increased from 24.5° (20° to 37°) to 43° (38° to 47°), and the mean internal rotation increased from -2° (-15° to 5°) to 36.5° (25° to 45°). The mean flexion and abduction arcs showed a significant improvement (mean improvement 37.5° and 18.5°; p = 0.021 and p = 0.002, respectively). The mean internal rotation range demonstrated the most significant improvement of all the measured arcs of movement (mean increase of 38.5°; p < 0.001).

**Radiographic parameters**

All the radiographic parameters of hip morphology improved significantly after the procedure (Table 2). Mean improvement in the AP slip angle was 37.52°, the mean lateral slip angle improved by 44.37°. The mean alpha angle improvement was 39.19°. The ATD significantly increased to a mean of 38.5°; p = 0.001, reflecting a mean distalization of the GT of 11.3 mm (Fig. 5). Patients in this series have shown a statistically significant correlation between the preoperative HHS and

| Table 1 | Improvements in the clinical parameters and Harris hip score (HHS) |
|----------|---------------------------------------------------------------|
|          | Preoperative | Postoperative | p-value | Significant |
| Mean HHS (sd; range) | 65.39 (7.64; 52 to 78) | 93.3 (3.23; 87 to 99) | < 0.001* | Yes |
| Mean limb length discrepancy (cm) (sd; range) | 1.99 (0.48; 0.75 to 2.5) | 0.27 (0.37; 0 to 1.5) | < 0.001* | Yes |
| Anterior impingement test (%) | 0 (0) | 20 (86.96) | < 0.001** | Yes |
| Positive | 23 (100) | 3 (13.04) |        |        |
| Trendelenburg test |              |                  |        |        |
| Negative | 4 (17.39) | 21 (91.3) | < 0.001** | Yes |
| Positive | 19 (82.61) | 2 (8.7) |        |        |

*p paired t-test
**McNemar test
Complications

One patient had failure of instrumentation that occurred two weeks after the procedure, with backing-out of the blade plate, requiring revision of fixation. This was thought to be due to poor bone quality secondary to vitamin D deficiency and non-compliance with weight-bearing restrictions. This patient healed uneventfully and had a good HHS of 87 points at the final follow-up. No cases of ON, chondrolysis or OA progression were identified at the latest follow-up.

Discussion

The surgical dislocation approach has been recently adopted as the primary means of treatment for symptomatic residual deformities in adolescent hips.\(^4,20\) This approach simultaneously allows for assessment and treatment of intraarticular FAI and related chondro-labral pathology. The extraarticular deformity remains a major component of SCFE,\(^31-35\) including trochanteric overgrowth, reduced abductor lever arm and limb shortening, all of which have to be simultaneously addressed to optimize the surgical outcome.

Our data demonstrated that utilizing the SHD approach for combined Imhauser osteotomy and OCP

![Fig. 3 Preoperative photographs of a 14-year-old child with moderate slip of the right hip, and a partially closed physis: (a) limited internal rotation; (b) limited flexion; (c) fixed external rotation deformity; (d) limited abduction.](image1)

the preoperative alpha angle (\(p = 0.022\)) (Table 3). The lateral slip angle less significantly correlated with the functional score, reflecting the relative importance of the alpha angle to predict symptomatic impingement in patients with SCFE.

![Fig. 4 Two-year postoperative photographs of the same patient in Figure 3: (a) flexion; (b) symmetrical abduction; (c) abduction against gravity; (d) internal rotation in hip flexion; (e) symmetrical internal rotation in hip extension.](image2)
OSTEOTOMY AND OSTEOCHONDROPLASTY IN SCFE

has significantly improved the clinical and radiographic parameters in SCFE. In the current study, SHD approach allowed optimum assessment and treatment of the intraarticular lesions; labral tears, acetabular and femoral chondral lesions, and retrieval of loose bodies.

According to previous reports and in the authors’ own experience, performing a subcapital osteotomy (modified Dunn procedure) in those slips with a closed or partially closed physis is associated with a high rate of ON and should be avoided. In those patients, the more distal ITO is considered a safer procedure. Although our approach utilizes SHD, the key steps are quite different from the modified Dunn procedure. Slips with closed or partially closed physis have been shown to have difficulty in raising a retinacular flap and in mobilization of the epiphysis. Our procedure utilizes the surgical dislocation approach for the safer distal osteotomy at the intertrochanteric level, and benefits from the optimal visualization for OCP and management of the chondro-labral lesions. Thus, the procedure has proven capability of restoring the anatomy of the proximal femur, significantly improving the radiographic indices, with a low rate of complications compared with the modified Dunn procedure, and most importantly no cases of ON. This is found to be consistent with previous similar studies (Table 4).

The mode of impingement was found to be different between mild slips on one side, and moderate to severe slips on the other side. Mild slips (lateral slip angle < 30°) impinge by the osseous bump of the exposed femoral neck metaphysis; hence a simple OCP could relieve the impingement process. This is why our study population included only moderate to severe slips (lateral slip

Table 2 Improvements in the radiographic parameters

| Parameter                                | Preoperative mean (μ; range) | Postoperative mean (μ; range) | p-value* | Significant |
|------------------------------------------|------------------------------|-------------------------------|----------|-------------|
| Anteroposterior slip angle (°)           | 47.39 (7.19; 38 to 60.5)     | 9.87 (6.92; 0 to 30)          | < 0.001  | Yes         |
| Lateral slip angle (°)                   | 57.07 (14.15; 38 to 80)      | 12.7 (7.82; 5 to 27.5)        | < 0.001  | Yes         |
| Alpha angle (°)                          | 91.26 (10.28; 70.5 to 110)   | 52.07 (3.33; 47 to 60.5)      | < 0.001  | Yes         |
| Articulo-trochanteric distance (mm) **   | 11.96 (2.76; 1 to 14.5)      | 23.26 (5.29; 16 to 32)        | < 0.001  | Yes         |

*paired t-test
**measured as the vertical distance from the tip of the greater trochanter to the top of the femoral head

Table 3 Correlation of Harris hip score (HHS) with the alpha angle and the lateral slip angle

| Preoperative HHS | Preoperative lateral slip angle | Preoperative alpha angle |
|------------------|-------------------------------|--------------------------|
| R*               | p-value*                      | Significant              |
|                  | -0.133                        | 0.545                    | No          |
|                  | -0.476                        | 0.022                    | Yes         |

*Pearson correlation coefficient

Fig. 5 a) and b) Right hip slipped capital femoral epiphysis, preoperatively; c) and d) postoperative radiographs after osteochondroplasty, union of Imhauser and trochanteric flip osteotomies, and physeal closure.
angle > 30°), where the impingement is mainly because of the severe deformity and to a lesser extent due to the metaphyseal bump. These were the target of our study, where the extraarticular osteotomy and the intraarticular OCP could be perfectly combined. In addition, the SHD approach allowed concurrent management of the intraarticular disease notorious of this group.

A valgus flexion derotation osteotomy was performed, basically an Imhauser-type osteotomy performed through the SHD approach. Both valgus and flexion components realign the varus and extension deformities that occur in a typical slip. The valgus component of the osteotomy was determined preoperatively based on the head-shaft angle difference in the AP view as some slips have only a mild varus deformity, while others may have an excessive varus deformity with severe inferior head tilt to a degree that the neck metaphysis becomes articulating with the acetabular dome and results in significant limb shortening and abductor weakness. The valgus component reorients the articular surface of the FH back with the acetabular dome, relieves impingement further by laterally rotating the neck bump away from the lateral acetabular rim, corrects limb shortening by aligning the neck more vertically and improves the abductor muscle tension by lowering the bed for subsequent GT advancement.

The amount of flexion was also determined preoperatively based on the head-shaft angle difference in the frog-lateral view. This series included 13 patients with severe slips with lateral slip angles as high as 80°. However, the maximum amount of flexion used was 60° to avoid excessive shortening. Our technique also avoided wedge resection to avoid unnecessary limb shortening and instead, a single transverse osteotomy was done. The blade plate is a fixed-angle device that offers sufficient rigidity and perfect bone coaptation at the osteotomy was not mandatory. The above technical steps might be reflected in our results as the mean LLD significantly improved by 1.72 cm (p < 0.001) and the percentage of patients with a positive Trendelenburg test improved significantly (Table 1).

The Imhauser osteotomy has a long-standing history in the literature, and has proven to be a safe, effective and a reproducible realignment procedure. More recently employed is the modified Imhauser osteotomy, where the ITO is coupled with an OCP, both performed through an anterolateral approach. This technique, as originally proposed by Dunn and described in a number of studies, can address both sources of impingement typical of moderate and severe slips. The comparative study by Bali et al demonstrated a statistically significant improvement in the combined ITO/OCP group compared with the isolated ITO group.

The most recently employed is the Imhauser-type osteotomy, performed through the SHD approach, the same technique we utilized. However, this procedure was infrequently discussed in the literature, and we were aware

---

**Table 4** Summary of similar studies

| Study         | Number of patients | Mean follow-up (mths) | Procedures             | Osteonecrosis rate, n (%) | Other complications, n (%) |
|---------------|--------------------|-----------------------|------------------------|---------------------------|----------------------------|
| Rebello et al19 | 8                  | 41                    | ITO/OCP                | 1 (7.6)                  | 1 sensory superficial peroneal nerve palsy (5.2) |
|               | 5                  |                       | ITO alone              |                          |                            |
| Spencer et al14 | 13                 | 12                    | OCP alone              | 0 (0)                    | 1 instrumentation failure (5.2) |
|               | 6                  |                       | ITO/OCP pinning        |                          | 1 instrumentation failure (5.2) |
| Erickson et al37 | 19                | 61                    | ITO/OCP                | 0 (0)                    | 1 instrumentation failure (5.2) |
| Current study  | 23                 | 45                    | ITO/OCP GT transfer    | 0 (0)                    | 1 instrumentation failure (4.3) |

ITO, intertrochanteric osteotomy; OCP, osteochondroplasty; GT, greater trochanter.

---

Fig. 6 An illustration of the abductor lever arm dysfunction in slipped capital femoral epiphysis (SCFE): a) normally oriented femoral head (FH) with wide horizontal offset of the greater trochanter b) reduced offset in SCFE due to FH retroversion, resulting in reduced abductor lever arm ratio and abductor insufficiency; c) advancing the trochanteric flip to increase the abductor lever arm. The trochanteric flip is advanced anteriorly to the lateral-most point on the trochanteric base.
of only one report\textsuperscript{20} of this procedure at the start of our study.

The SHD approach was found to be beneficial in many aspects. First, it provided good visualization of the proximal femur, metaphyseal bump and the lesser trochanter, allowing protection of the main trunk of the medial femoral circumflex artery during an ITO. Second, it allowed a dynamic impingement test to be performed to decide the adequacy of OCP. Third, it allowed inspection and treatment of the various chondro-labral pathologies deemed responsible for persistent symptoms after an osteotomy. Fourth, the SHD approach provided good visualization of the bump with optimal alpha angle correction, a measurement we found to correlate significantly with the symptoms and development of OA, consistent with previous reports.\textsuperscript{9,38} Fifth, the lateral position during surgery facilitated soft-tissue retraction as the vast majority of children with SCFE are obese.

Furthermore, we found a valuable part of this approach was utilizing the trochanteric flip osteotomy to distalize the trochanteric flip in line with the FH centre, and to advance its attachment to a more anterior position (Fig. 6). This was found not only to restore the abductor muscle tension, but can also compensate for the fixed head retro-version and reduced abductor lever arm, frequently the cause of abductor insufficiency in SCFE, and a proposed mechanism for the accelerated OA.\textsuperscript{39} Corrective osteotomies when performed below the level of the GT will leave the abductor muscles in a mechanical dysfunction due to fixed retroversion of the FH. Advancing the insertion of the GT to a more anterior position is thought to restore the mechanical relationship of the GT and the abductor muscles.

We found this technical tip to have significant effect on the outcome, regarding the postoperative limp and Trendelenburg test in our series. It was previously emphasized that the short lever arm created by the coxa vara was less important than the posterior displacement of the GT created by the retroversion.\textsuperscript{40} We utilized these data to modify the attachment of the GT, which has yielded encouraging clinical results.

In the series by Rebello et al,\textsuperscript{20} eight patients underwent combined ITO/OCP via SHD, of which one developed ON. However, they did not illustrate the advantages provided by this approach on the hip biomechanics, and their results did not relate to alpha angle correction. Their report, however, included the conclusion that combined ITO/OCP could decrease the amount of correction needed from the ITO thus minimizing the resultant proximal femoral deformity and facilitating future total hip arthroplasty.

Spencer et al\textsuperscript{41} evaluated the outcomes of 19 patients with healed slips who underwent SHD for either OCP alone (13 patients) or combined OCP/ITO (six patients). After an average follow-up of 12 months, no cases developed ON and clinical improvement was reported to be higher among patients in the combined group. Patients with chondral flaps were reported to have less improvement. In their combined OCP/ITO group, OCP was performed first and they performed ITO only if there was residual impingement on intraoperative examination. This policy is different from ours and from previous biomechanical reports.\textsuperscript{12,42} The role of osteoplasty in moderate to severe slips has been confined to ‘fine-tuning’ the residual FAI, and there are many concerns of over-resection leading to femoral neck fractures. Their technique also illustrated the fixation of the trochanteric flip to its anatomical position, with no reference to the biomechanical importance of the anterior and/or distal advancement we adopted in our study.

Similarly, Sink et al\textsuperscript{43} performed ITO in 25 of the 39 hips in their series that comprised mild, moderate and severe SCFE. They recommended Imhauser ITO if at least 90° of hip flexion and some internal rotation could not be achieved after OCP. Although they reported improvement in hip function, outcome scores and ROM, they did not conclude which slip degree needed an Imhauser ITO.

McClincy and Bosch\textsuperscript{43} published a report of the surgical technique utilizing SHD for combined OCP/ITO. Their surgical technique included fixation of the GT to its original bed without reference to trochanteric advancement. Their technique, however, included a single cut osteotomy rather than a closing wedge to avoid unnecessary limb shortening, as they relied on the rigidity of the locking plate they used.

Erickson et al\textsuperscript{44} evaluated a retrospective series of 19 patients with moderate to severe slips who underwent the same procedure through SHD. Their series, however, included 13 patients who performed the procedure in a delayed fashion after a first-stage surgery of in situ pinning. Their results have demonstrated a similar improvement in the radiographic parameters. However, details of the clinical improvements in ROM, anterior impingement tests and improvement in gait pattern were not provided in their study. Trochanteric advancement or transfer procedure was not emphasized in their technique.

Although the SHD approach involves extensive dissection around the hip joint, postoperative rehabilitation is quite fast for the dimensions of the surgery. Fixation of the trochanteric flip by screws offers good stability and allows early mobilization. Our protocol is to mobilize the hip joint using a CPM machine on the same day of surgery and to encourage partial weight-bearing the next day. Surgeons who are not familiar with the surgical dislocation approach may be concerned about the risk of ON of the FH. However, in agreement with many previous reports,\textsuperscript{31,43,44} we found this approach to be safe and reliable. Wide exposure of the FH and neck makes this procedure safer than other approaches, which provide only limited exposure of...
the susceptible anatomical structures. Moreover, the FH
blood circulation can be monitored during the procedure.

A statistically significant correlation has been found
between the preoperative HHS and the preoperative alpha
angle, reflecting the relative importance of the alpha
angle rather than the lateral slip angle measurements to
predict symptomatic impingement in patients with SCFE.
In agreement with our results, the alpha angle was found
to be the most significant predictor of OA in a series of 121
patients by Castañeda et al. In a similar series by Dodds
et al, the alpha angle was the most reliable predictor of
symptomatic impingement, and they did not find a clini-
cally significant correlation between the initial slip angle
and the development of symptomatic FAI.

The recent work by Gala et al highlighted the impor-
tance of early correction of the alpha angle in hips with
symptomatic anterior impingement. They have found no
significant change in alpha angle measurements over 5.1-
year period in both groups of patients with a cam defor-
mity as well as those with a normal head-neck contour.
This further suggests that the remodeling potential of the
head-neck contour is minimal, and warrants early correc-
tion of the alpha angle before intraarticular damage/OA
occur. Their data also provides evidence of long-standing
results after surgical correction and that the recurrence of
cam deformity is highly unlikely.

The original work by Dunn recommended an ITO
with excising the neck bump in cases with moderate to
severe slips and closed physis. In moderate to severe slips,
OCP alone would lead to increased hip ROM but would
also allow for the thinner peripheral FH articular cartilage
and prominent metaphysis to articulate even more exten-
sively with the acetabulum. The work by Mamisch et al
highlighted that in moderate to severe slips, an ITO may
improve the ROM, but those patients may need an addi-
tional OCP to relieve the whole impingement process.

Our data demonstrated that combined ITO and OCP
through the SHD approach can provide comprehensive
management for the slip-related deformity and impinge-
ment, and is capable of restoring the proximal femoral
anatomy by reducing the alpha angle and slip angles to
near normal values. In addition, the associated chondral
lesions and labral tears can be simultaneously addressed.
Utilizing the trochanteric flip osteotomy for trochanteric
advancement improves the biomechanical function of hip
abductors. All these factors neutralize the forces within the
hip joint, reduce mechanical degradation and can prevent
or delay OA.

One patient in this series had instrumentation failure
that occurred two weeks after the procedure, requiring
revision of fixation. The patient presented with increased
pain with backing-out of the blade from the proximal
fragment noted on radiographs. Instrumentation failure
has been discussed in previous literature; the proposed
explanations are acute treatment in a hip with reduced
bone density, non-compliance with weight-bearing
restrictions and vitamin D deficiency with osteomalacia.
In addition to instrumentation failure, loss of some of the
flexion correction can occur as the blade easily rotates,
cutting through the soft bone of the proximal femoral
fragment during correction of the flexion. This can even
be observed intraoperatively. This is an important point
to consider in cases where hip osteopenia is marked on pre-
operative radiographs. As a more conservative approach
with fewer potential risks, the surgery can be delayed for
six months to ensure improved bone density and vitamin
D status, provided the physis is closed or in situ pinned.

The study limitations include the requirement for mul-
tiple procedures in a single hip and the lack of a control
group which makes it difficult to determine the relative
role of each part of the procedure. The use of preopera-
tive radial sequence MRI to determine the affected por-
tions of the FH and focal asphericity was not conducted
in this study. The authors relied on the patient-reported
complaints, the subjective assessment of anterior and pos-
terior impingement tests, plain radiographs, alpha angle
measurements and the 3D CT. In addition, routine MRI
arthrography was not routinely obtained to verify the
location and pathological type of chondro-labral tears.
Instead, the authors relied on the routine intraoperative
examination of the labrum, chondro-labral junctions and
articular cartilage. Additionally, advanced MRI techniques
conducted in similar trials were not found to alter nei-
ther the selection criteria for inclusion in the study nor the
outcome.

The Imhauser osteotomy realigns the proximal femur
by a more distal reverse-plane osteotomy, hence creating
an S-shaped deformity. Although our cases demonstrated
considerable remodelling of the proximal femur with
realignment of the medullary canal, further studies need
to be conducted to determine the impact on future hip
arthroplasty in case it is indicated. The follow-up period
in this series is relatively short. Hip preserving surgery,
in addition to improving the short-term clinical outcome,
must aim to extend the longevity of the hip joint, preclud-
ing the need for an arthroplasty or significantly delaying
its need. Longer term studies are needed to determine the
extended benefit of comprehensive deformity correction
in this population.

Received 18 February 2020; accepted after revision 17 April 2020.

COMPLIANCE WITH ETHICAL STANDARDS

FUNDING STATEMENT

No benefits in any form have been received or will be received from a commercial
party related directly or indirectly to the subject of this article.
OSTEOTOMY AND OSTEOCHONDROPLASTY IN SCFE

NEW AUTHORS

2. Castañeda P, Ponce C, Villareal G, Vidal C. The natural history of osteoarthritis after a slipped capital femoral epiphysis / the pistol grip deformity. J Pediatr Orthop 2013;33:576-582.
3. Hosalkar HS, Pandya NK, Bomar JD, Wenger DR. Hip impingement in slipped capital femoral epiphysis: a changing perspective. J Child Orthop 2012;6:161-172.
4. Sink EL, Zaltz I, Heare T, Dayton M. Acetabular cartilage and labral damage observed during surgical hip dislocation for stable slipped capital femoral epiphysis. J Pediatr Orthop 2010;30:26-30.
5. Ganz R, Parvizi J, Beck M, et al. Femoroacetabular impingement: a cause for osteoarthritis of the hip. Clin Orthop Relat Res 2003;417:112-120.
6. Sucato DJ, De La Rocha A. High-grade SCFE: the role of surgical hip dislocation and reduction. J Pediatr Orthop 2014;34:518-524.
7. Upasani VV, Matheney TH, Spencer SA, et al. Complications after modified Dunn osteotomy for the treatment of adolescent slipped capital femoral epiphysis. J Pediatr Orthop 2014;34:661-667.
8. Cooper AP, Salih S, Geddis C, et al. The oblique plane deformity in slipped capital femoral epiphysis. J Child Orthop 2014;8:121-127.
9. Dodds MK, McCormack D, Mulhall KJ. Femoroacetabular impingement after slipped capital femoral epiphysis: does slip severity predict clinical symptoms? J Pediatr Orthop 2009;29:535-539.
10. Lykissas MG, McCarthy JJ. Should all unstable slipped capital femoral epiphysis be treated open? J Pediatr Orthop 2013;33:S92-S98.
11. Sankar WN, Brighton BK, Kim Y-J, Millis MB. Acetabular morphology in slipped capital femoral epiphysis. J Pediatr Orthop 2011;31:254-258.
12. Abraham E, Gonzalez MH, Pratap S, et al. Clinical implications of anatomical wear characteristics in slipped capital femoral epiphysis and primary osteoarthritis. J Pediatr Orthop 2007;27:788-795.
13. Southwick WO. Osteotomy through the lesser trochanter for slipped capital femoral epiphysis. J Bone Joint Surg [Am] 1967;49-A:807-835.
14. Mamisch TC, Kim Y-J, Richolt JA, Millis MB, Kordelle J. Femoral morphology due to impingement influences the range of motion in slipped capital femoral epiphysis. Clin Orthop Relat Res 2009;467:692-698.
15. Chen A, Youderian A, Watkins S, Gourineni P. Arthroscopic femoral neck osteoplasty in slipped capital femoral epiphysis. Arthroscopy 2014;30:1229-1234.
16. Nötzli HP, Wyss TF, Stoecklin CH, et al. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. J Bone Joint Surg [Br] 2002;84-B:556-560.
17. Sankar WN, Vanderhave KL, Matheney T, Herrera-Soto JA, Karlen JW. The modified Dunn procedure for unstable slipped capital femoral epiphysis: a multicenter perspective. J Bone Joint Surg [Am] 2013;95:585-591.
18. Dunn DM. The treatment of adolescent slipping of the upper femoral epiphysis. J Bone Joint Surg [Br] 1964;46-B:621-629.
19. Ziebarth K, Leunig M, Slongo T, Kim Y-J, Ganz R. Slipped capital femoral epiphysis: relevant pathophysiologic findings with open surgery. Clin Orthop Relat Res 2013;471:2196-2192.
20. Rebello G, Spencer S, Millis MB, Kim Y-J. Surgical dislocation in the management of pediatric and adolescent hip deformity. Clin Orthop Relat Res 2009;467:724-731.
OSTEOTOMY AND OSTEOCHONDROPLASTY IN SCFE
Prevention of secondary coxarthrosis
The results of downgrading moderate and severe slipped
Bardakos NV.
Schai PA, Exner GU, Hänsch O.
A modified Imhäuser osteotomy: an
Surgical dislocation of the adult hip a
J Bone Joint Surg [Am]
2009;3:
Giles AE, Corneman NA, Bhachu S, et al.
Bone Joint J 2014;96-B:1195-1203.
Schai PA, Exner GU, Hänsch O. Prevention of secondary coxarthrosis
in slipped capital femoral epiphysis: a long-term follow-up study after corrective
intertrochanteric osteotomy. J Pediatr Orthop B 1996;5:133-143.
Anderson LA, Erickson JA, Severson EP, Peters CL. Sequelae
of Perthes disease: treatment with surgical hip dislocation and relative femoral neck
lengthening. J Pediatr Orthop 2010;30:753-766.
Kramer WG, Craig WA, Noel S. Compensating osteotomy at the base
of the femoral neck for slipped capital femoral epiphysis. J Bone Joint Surg [Am] 1976;58-
A:796-800.
Spencer S, Millis MB, Kim Y-J. Early results of treatment of hip impingement
syndrome in slipped capital femoral epiphysis and pistol grip deformity of the femoral head-
neck junction using the surgical dislocation technique. J Pediatr Orthop 2006;26:281-285.
Rab GT. The geometry of slipped capital femoral epiphysis: implications for
movement, impingement, and corrective osteotomy. J Pediatr Orthop 1994;14:419-424.
McClincy MP, Bosch PP. Combined surgical dislocation and proximal femoral
osteotomy for correction of SCFE-induced femoroacetabular impingement. Oper Tech Orthop
2013;23:140-145.
Erickson JB, Samora WP, Klingele KE. Treatment of chronic, stable slipped capital femoral epiphysis via surgical hip dislocation with combined
osteochondroplasty and Imhäuser osteotomy. J Child Orthop 2017;11:284-288.
Gaia L, Khanna V, Rakhra KS, Beaulé PE. Does the femoral
head/neck contour in the skeletally mature change over time? J Hip Preserv Surg 2016;3:
333-337.
Abraham E, Garst J, Barmada R. Treatment of moderate to severe
slipped capital femoral epiphysis with extracapsular base-of-neck osteotomy. J Pediatr
Orthop 1993;13:294-302.
Bardakos NV. Hip impingement: beyond femoroacetabular. J Hip Preserv Surg
2015;2:206-223.