Original Clinical Article

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

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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

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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[1,2] and *in situ* fixation has been the traditional standard of care.[3,4] Although associated with acceptable safety and prognosis, recent literature highlights its failure to provide symptomatic relief and to stop the progressive hip osteoarthritis (OA).[2]

The recently introduced concept of femoroacetabular impingement (FAI)[5] and subsequent studies revealed considerable evidence of articular cartilage and labral injury in hips with SCFE,[2,4] which ultimately lead to degenerative changes and OA. This made it mandatory to attempt to restore the anatomy of the proximal femur.[6,7]

The typical slip is multiplanar and results in coxa vara, retroversion[8] and extension deformity as the femoral head (FH) displaces posteroinferiorly in relation to the femoral neck. The exposed anterolateral neck metaphysis forms an osseous bump, which impinges against the acetabular rim.[5,9] 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

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external rotation deformity and out-toeing gait.[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.[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.[12] In moderate and severe slips (lateral slip angle > 30°),[13] the relative prominence of the neck metaphysis, rather than the degree of slip was emphasized as being the major cause of impingement.[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.[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.[7] However, the procedure has high reported osteonecrosis (ON) rates (up to 26%) regardless of physeal closure.[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,[18] emphasized that the presence of open physis offers a clear cleavage plane for safe subcapital realignment, with minimal ON risk. These studies recommended an intertrochanteric osteotomy (ITO) in slips with closed physis.[18-20]

In 1966, Imhauser described a triplane osteotomy[21], realigning the head onto the shaft by creating valgus, flexion and derotation. A number of trials[22-26] 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 physis. 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 physis, conducted during the period from 1st January 2013 to 31st 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 *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)[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;[13] articulo-trochanteric distance (ATD);[28] and Nötzli's alpha angle.[16] The AP and lateral slip angles were measured according to Southwick's method:[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.[13] Accordingly, ten slips were classified as moderate (slip angle between 30° and 50°) and 13 were classified as severe (slip angle > 50°). The physis 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[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.[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 physeal plate remained unfused underwent simultaneous *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.[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. The

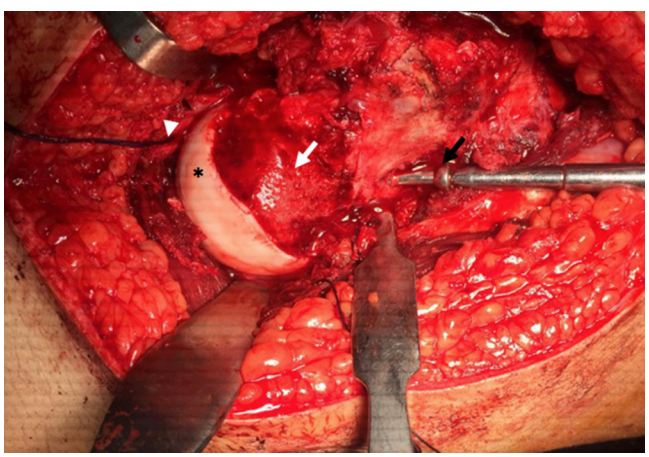

Fig. 1 Osteochondroplasty and simultaneous pinning through surgical hip dislocation. Femoral head cartilage with trimmed border (asterix), anterior capsular flap tagged with suture (white arrowhead), the head-neck junction after osteochondroplasty and restoring the head-neck offset (white arrow), *in situ* screw fixation (black arrow).

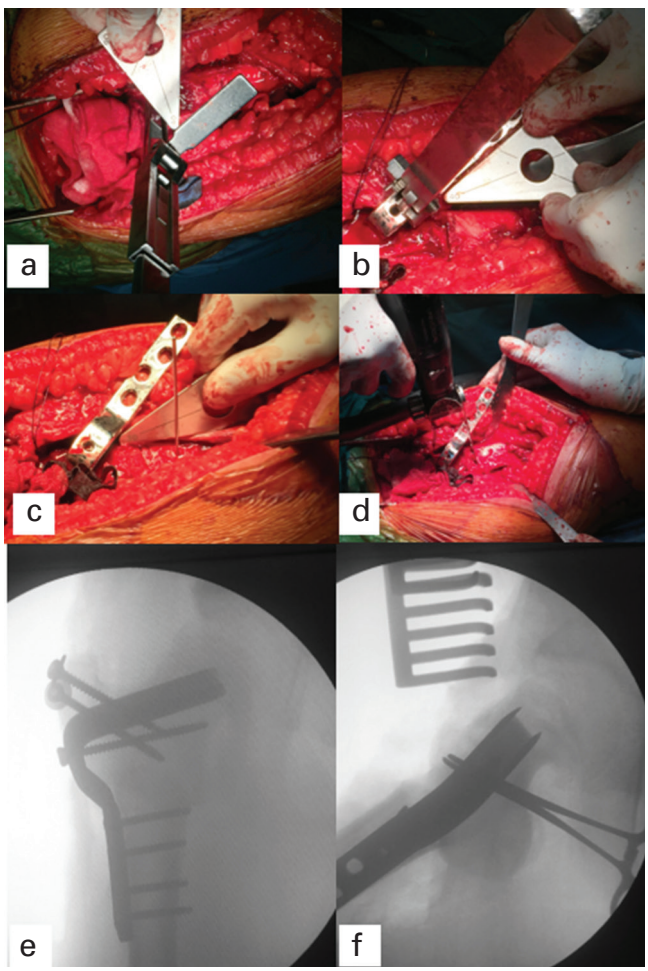

Fig. 2 a) Imhauser osteotomy in slipped capital femoral epiphysis through surgical hip dislocation approach; **b)** the seating chisel is inclined in the lateral view to achieve the amount of desired flexion, which corresponds to the bone-plate angle; **c)** in the frontal plane, the bone-plate angle 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.

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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 23.26 mm ($p < 0.001$), 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 (%)				
Negative	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*)		

*paired *t*-test
**McNemar test

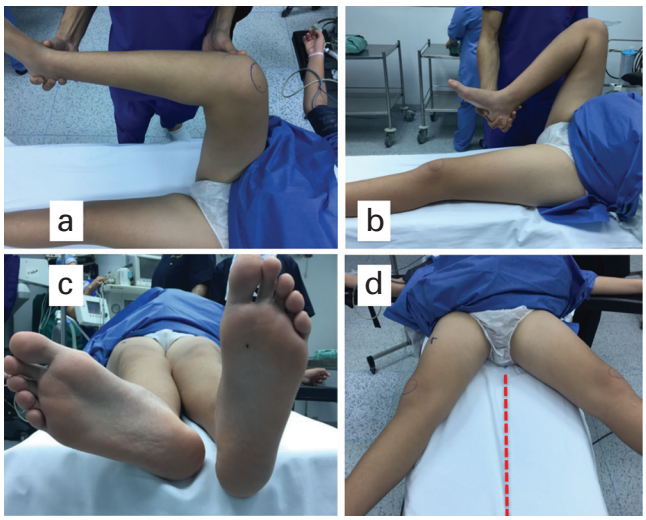

Fig. 3 Preoperative photographs of a 14-year-old child with moderate slip of the right hip, and a partially closed physis: **a)** limited internal rotation; **b)** limited flexion; **c)** fixed external rotation deformity; **d)** limited abduction.

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.

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. 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.

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Table 2 Improvements in the radiographic parameters

	Preoperative mean (SD; range)	Postoperative mean (SD; 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 (3.53; 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

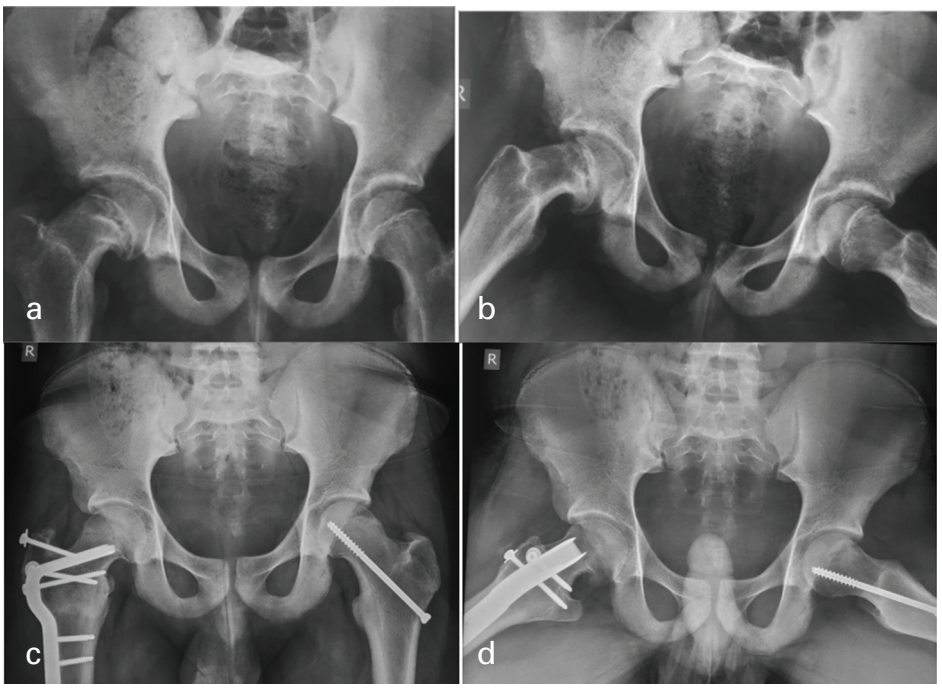

Fig. 5 **a)** and **b)** Right hip slipped capital femoral epiphysis, preoperatively; **c)** and **d)** postoperative radiographs after osteochondroplasty, union of Imhauser and trochanteric flip osteotomies, and physeal closure.

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

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

*Pearson correlation coefficient

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[18-20] 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 4 Summary of similar studies

Study	Number of patients	Mean follow-up (mths)	Procedures	Osteonecrosis rate, n (%)	Other complications, n (%)
Rebello et al[20]	8	41	ITO/OCP		
	5		ITO alone	1 (*7.6*)	
Spencer et al[41]	13	12	OCP alone	0 (*0*)	1 sensory superficial peroneal nerve palsy (*5.2*)
	6		ITO/OCP		
Erickson et al[44]	19	61	ITO/OCP pinning	0 (*0*)	1 instrumentation failure (*5.2*) 1 osteotomy nonunion (*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

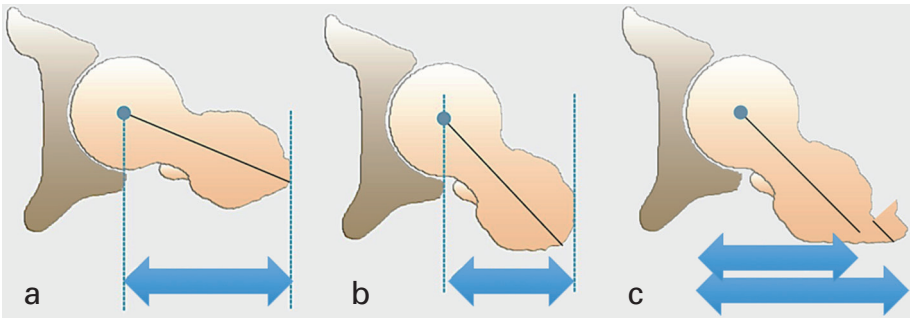

Fig. 6 An illustration of the abductor lever arm dysfunction in slipped capital femoral epiphysis (SCFE): **a)** normally oriented femoral head (FH) with wide horizontal offset of the greater trochanter **b)** reduced offset in SCFE due to FH retroversion, resulting in reduced abductor lever arm ratio 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.

angle > 30°), where the impingement is mainly because of the severe deformity and to a lesser extent due to the metaphyseal bump.[14] 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.[36] 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.[22-24] 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[19] and described in a number of studies,[3,14,37,38] can address both sources of impingement typical of moderate and severe slips. The comparative study by Bali et al[37] 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

of only one report[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.[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 retroversion and reduced abductor lever arm, frequently the cause of abductor insufficiency in SCFE, and a proposed mechanism for the accelerated OA.[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.[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,[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[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.[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[4] 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[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[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,[41,43,44] 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[2] .In a similar series by Dodds et al,[9] the alpha angle was the most reliable predictor of symptomatic impingement, and they did not find a clinically significant correlation between the initial slip angle and the development of symptomatic FAI.

The recent work by Gala et al[45] highlighted the importance 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 deformity 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 correction 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[18] 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 extensively with the acetabulum.[46] The work by Mamisch et al[14] highlighted that in moderate to severe slips, an ITO may improve the ROM, but those patients may need an additional 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 impingement, 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;[44] 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 preoperative 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 multiple 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 preoperative radial sequence MRI to determine the affected portions 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 posterior 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[39,47] were not found to alter neither 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, precluding 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.

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COMPLIANCE WITH ETHICAL STANDARDS

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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.

ETHICAL STATEMENT

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study was approved by our institution's Ethical Committee of Scientific Research.

Informed consent: Informed consent was obtained from all individual participants included in the study. All parents consented to and were informed that data concerning this study would be submitted for publication.

ICMJE CONFLICT OF INTEREST STATEMENT

None declared.

AUTHOR CONTRIBUTIONS

MMB: Conceived and designed the study, Particularly involved in literature search, One of main operating surgeons, Drafted the manuscript, Involved in decision making, Patients follow-up, Functional evaluation, analysis and interpretation of data, Reviewed the final manuscript critically for important intellectual content, Approved the final version and is responsible for the content.

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MAM: Conceived and designed the study, Particularly involved in literature search, One of main operating surgeons, Drafted the manuscript, Conceived and designed the study, Particularly involved in literature search, Involved in decision making, Patients follow-up, Functional evaluation, analysis and interpretation of data, Reviewed the final manuscript critically for important intellectual content, Approved the final version and is responsible for the content.

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