Journal of Southeast Asian Orthopaedics
ISSN 2821-9848 (Print)
ISSN 2821-9864 (Online)
https://doi.org/10.56929/jseaortho-2026-0310 https://jseaortho.org

Femoral Neck Growth and Remodeling After Screw Removal Following Slipped Capital Femoral Epiphysis

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Purpose: The primary objective of this study was to investigate the remodeling process of the femoral neck after screw removal in patients with slipped capital femoral epiphysis (SCFE).
Background: In situ screw fixation is widely used to stabilize SCFE and prevent its progression, often with the expectation that physeal closure will occur over time. However, concerns remain regarding the alteration of proximal femoral growth and morphology, and the potential for remodeling after elective screw removal is not well defined.
Methods: We retrospectively reviewed 40 patients (47 hips) diagnosed with SCFE, who underwent in situ screw fixation using two cancellous screws, followed by scheduled screw removal approximately one year later. The immediate postoperative radiographs were compared with those obtained at the time of physeal closure. Radiographic parameters, including articulotrochanteric distance (ATD) and lesser trochanter–articular distance (LTA), were analyzed to assess femoral neck morphology in terms of width, length, and angular changes.
Results: Radiographic comparisons between immediate postoperative and post-physeal closure evaluations revealed a statistically significant improvements in femoral neck length, width, and anglular remodeling.
Conclusions: SCFE treated with in situ screw fixation followed by screw removal facilitates femoral neck remodeling and contributes to hip restoration at skeletal maturity.

Keywords: Slipped capital femoral epiphysis, in situ screw fixation, screw removal, femoral neck remodeling, radiographic outcome

Slipped capital femoral epiphysis (SCFE) is one of the most common hip disorders in adolescents, with an incidence of approximately 10.8 per 100,000 children. It typically occurs during periods of rapid growth and is characterized by displacement of the capital femoral epiphysis relative to the femoral metaphysis at the proximal femoral physis. The primary treatment of SCFE typically involves surgical intervention. The most common surgical procedure is in situ screw fixation to stabilize the slipped femoral epiphysis and prevent further displacement[2,3]. Cannulated screws are typically retained in situ until physeal closure to maintain epiphyseal stability in SCFE[4].

Management of SCFE requires an individualized approach, considering patient-specific characteristics, slip severity, and surgeon experience, due to the absence of a clear consensus on

Article history:
Received: December 19, 2025 Revised: April 30, 2026
Accepted: May 19, 2026
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optimal treatment[5]. Regular follow-up and monitoring play a crucial role in evaluating the efficacy of the chosen treatment strategy and addressing potential complications. The optimal number of screws for in-situ fixation of SCFE remains controversial, and biomechanical studies have shown that although double-screw constructs offer increased stiffness, single-screw fixation is often preferred because of the lower risk of complications[5-7].

The decision to remove screws after in situ fixation of SCFE should be individualized, considering factors such as the duration of implant retention, risk of removal complications, and patient preference. Some studies have reported a removal failure rate of up to 18%, with prolonged implant retention identified as a significant predictor of difficult or failed screw removal[8,9]. In selected cases, open reduction techniques such as the modified Dunn procedure, have gained attention for their ability to restore the proximal femoral anatomy in moderate to severe SCFE while carefully preserving the femoral head blood supply[10-12].

We hypothesized that femoral neck remodeling may occur if the screws are removed before physeal closure. This study presents the results of femoral neck growth and remodeling after the screw removal following fixation for SCFE.

Previous studies have suggested that proximal femoral growth may continue after SCFE fixation when constructs minimize compressive forces across the physis[4,13-16]. For example, Guzzanti et al. utilized screws with threads primarily within the epiphysis, whereas Sailhan et al. reported outcomes using proximally threaded cannulated screws[5,13], both of which may function similarly to growth-friendly constructs by stabilizing the epiphysis without excessive physeal compression. In contrast, our technique employed standard cancellous screws; however, the threaded portion of the screw was deliberately positioned cross the physis such that the threads remained entirely within the epiphysis. Short-threaded screws were selected to minimize compressive forces across the physis while maintaining stable fixation. This configuration was intended to preserve the residual growth potential and allow continued femoral neck remodeling after elective screw removal. Therefore, rather than suggesting equivalence to free-gliding constructs, the present study aimed to evaluate radiographic remodeling observed after screw removal in patients treated with this fixation strategy.

MATERIALS AND METHODS

This retrospective study included 40 patients (47 hips) diagnosed with SCFE at our institute between 2008 and 2017. All the patients underwent in situ screw fixation.

An open Watson–Jones approach was used to allow direct visualization of the screw entry point, which is often relatively anterior, while minimizing the risk of injury to the retinacular vessels supplying the femoral head. The goal of this approach was to accurately identify the entry point and avoid vascular injury rather than to reduce the slipped epiphysis. Routine capsulotomy was not performed, and the joint capsule was preserved. Fixation was performed for in situ stabilization without manipulation of the slipped physis. Two cancellous screws were inserted under fluoroscopic guidance to confirm appropriate positioning.

The patients were classified according to slip chronicity (acute, chronic, or acute-on-chronic) and stability based on the Loder classification (stable vs. unstable).

Postoperative management included non-weight-bearing with crutches or a walker for approximately 4–6 weeks, combined with early initiation of hip range-of-motion exercises under physiotherapy guidance[17].

Follow-Up

All patients underwent radiographic evaluation immediately postoperative and again at physeal closure using anteroposterior (AP) and frog-leg lateral views. The radiographic evaluations were performed by an independent physician. Radiographic parameters included femoral neck width and length, neck-shaft angle, articulotrochanteric distance (ATD), lesser trochanter-to-articular surface distance (LTA), and slip severity according to the Southwick classification. We also collected data regarding age, sex, side, and slip severity. Complications such as avascular necrosis (AVN), chondrolysis, and progressive slipping were also noted.

Statistical Analysis

We employed Student's t-test to compare the immediate postoperative film with the film taken when the physis was closed in the affected part. A p-value ≤0.05 was considered statistically significant.

RESULTS

A total of 47 hips from 40 patients were included in this study. The mean age at the time of surgery was 12.2 years (range, 9–15 years). In our study, 28 patients were male (70%) and 12 were female (30%). Based on the Southwick angle, 4 hips (8.5%) were classified as mild slips, 26(55.3%) as moderate slips, and 17 (36.2%) as severe slips. Bilateral SCFE was identified in 7 patients (17.5%). The severity of slip was classified according to the Southwick angle. The Southwick slip angle classification is widely used to assess SCFE severity: mild (< 30°), moderate (30°–50°), and severe (> 50°)[18,19]. Regarding temporal classification, most patients present with chronic slips (87.2%), whereas acute (8.5%) and acute-on-chronic (4.3%) presentations were less common. According to the Loder classification, the majority of cases were stable (91.5%), with only four hips (8.5%) classified as unstable. Demographic data are shown in Table 1.

Table 1 Patient demographics and clinical characteristics.

Variable	Value
Demographic Data	
Male, n (%)	28 (70%)
Female, n (%)	12 (30%)
Age (years), mean (range)	12.2 (9.0–15.0)
Weight (kg), mean (range)	64.3 (40.0–84.0)
BMI (kg/m²), mean (range)	25.1 (20.2–37.3)
Slip type	
Chronic	41 (87.2%)
Acute	4 (8.5%)
Acute on top chronic	2 (4.3%)
Stability (Loder classification)	
Stable	43 (91.5%)
Unstable	4 (8.5%)
Slip severity (Southwick classification)	
Mild	
Moderate	26 (55.3%)
Severe	17 (36.2%)

Values are presented as number (percentage) or mean (range). Slip severity was classified according to the Southwick angle, and stability was defined based on the Loder classification.

Fixation was performed using two 16-mm short-threaded cancellous screws. The screws were inserted perpendicular to the physis rather than centrally within the femoral neck, with the threaded portion traversing the physis and engaging the epiphysis to provide stable fixation and adequate purchase.

The screws were removed approximately 18 months after insertion. No intraoperative or immediate postoperative complications were encountered, and screw removal was successfully performed in all cases.

No cases of chondrolysis or progressive slipping were observed in this study. Avascular necrosis (AVN) was identified in 5 of 47 hips, resulting in an overall AVN rate of 10.6%. All AVN cases occurred in the severe-slip subgroup. Among the 17 hips classified as severe slips, 5 developed AVN, corresponding to an AVN rate of 29.4% in this subgroup. The AVN rate in our cohort was considerably lower than that reported in previous studies, where the incidence has been documented to be as high as 50% in patients with unstable or severely displaced SCFE[20].

Radiographic Findings

Radiographic evaluation demonstrated measurable and statistically significant remodeling of the proximal femur after screw removal in patients with SCFE. Radiographic parameters obtained during the immediate postoperative period were compared with those obtained at physeal closure.

The lesser trochanter–articular distance (LTA) increased steadily from a postoperative average of 92.95 mm to 96.67 mm at physeal closure, indicating a significant gain in the anatomical height of the femoral neck ($p = 0.0023$). Although the articulotrochanteric distance (ATD) also increased modestly from 25.63 mm to 26.96 mm, this change did not reach statistical significance ($p = 0.2557$).

The neck width showed a marked increase from 37.37 mm immediately after surgery to 44.07 mm by growth plate closure, reflecting substantial lateral expansion of the femoral neck ($p < 0.001$). Similarly, neck growth, measured longitudinally, increased significantly from 88.39 mm to 92.09 mm ($p = 0.0103$), suggesting continued elongation during growth phase.

Finally, the neck-shaft angle (NSA) improved significantly from 130.49° to 134.0°, reflecting favorable angular remodeling toward normal alignment ($p = 0.0043$). This angular correction supports the concept that, with sufficient remaining growth and the absence of hardware obstruction, the femoral neck can remodel toward a more anatomical configuration.

These findings collectively suggest that, after removal of the in situ screws, the femoral neck continues to remodel in both length and geometry during the growth phase, with statistically significant improvements in most radiographic parameters.

All radiographic parameters, including the lesser trochanter–articular distance (LTA), articulartrochanteric distance (ATD), femoral neck width, neck length, and neck–shaft angle, are summarized in Table 2 across three time points: preoperative, postoperative, and physeal closure. Statistical analysis revealed significant changes in most parameters over time, particularly between the postoperative and physeal closure stages. Notably, all variables showed statistically significant improvements ($p < 0.05$), except for ATD, which did not reach statistical significance. Radiographic parameters and p-value comparisons are shown in Table 2.

Table 2 Radiographic Parameters and P-value Comparison**.**

Parameter	Preop	Postop	Physeal closure	P-value
LTA	91.04	92.95	96.67	0.0023
ATD	24.12	25.63	26.96	0.2557
Neck width	35.71	37.37	44.07	< 0.001
Neck growth	85.59	88.39	92.09	0.0103
Neck-shaft angle	129.26	130.49	134.0	0.0043

As illustrated in Figure 1, radiographic measurements were performed on anteroposterior hip radiographs using standardized anatomical landmarks. Figures 2 and 3 demonstrate gradual improvement in the neck–shaft angle and other radiographic remodeling parameters from the immediate postoperative period to physeal closure. Figures 4 and 5 show a representative case treated using the open-insertion technique, which allows direct visualization of the screw entry point to avoid vascular injury. The fixation was performed using two cancellous screws. Figures 6 demonstrate the remodeling of the femoral neck following screw removal and subsequent physeal closure, indicating the capacity for anatomical restoration after growth was completed.

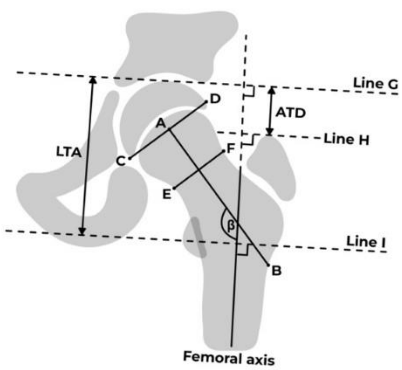

Fig. 1 Radiographic measurement techniques of the proximal femur.

Neck-Shaft Angle Progression

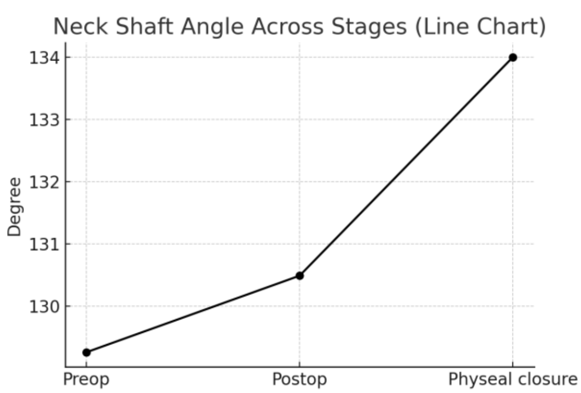

Fig. 2 The line chart shows the progression of the Neck-Shaft Angle in degrees across the three stages: preoperative (preoperative), Immediate Postoperative (postoperative), and Physeal Closure.

Postoperative radiographic parameters were measured using immediate postoperative radiographs obtained after screw fixation. No intentional reduction of the slipped epiphysis was performed as the procedure was conducted for in situ stabilization. However, positional changes may occur during patient positioning on the fracture table or limb manipulation during the surgical setup, which may account for the differences observed between the preoperative and immediate postoperative measurements.

Radiographic Comparison

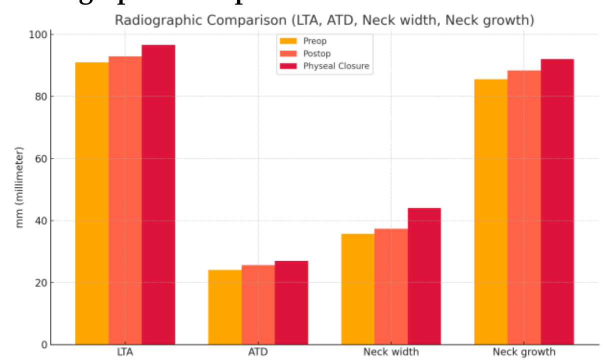

Fig. 3 Bar chart illustrating the mean radiographic values (in millimeters) across different stages: Preoperative, Postoperative, and Physeal Closure.

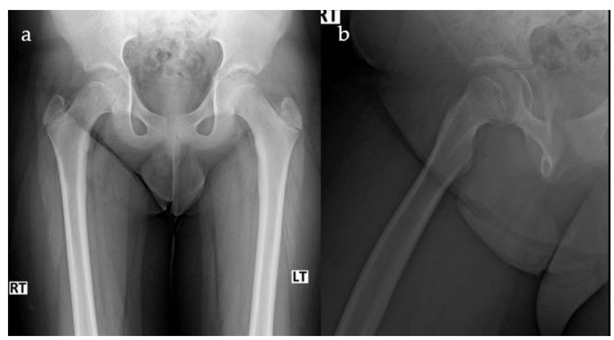

Fig. 4 Preoperative radiograph of an 11-year-old boy diagnosed with a right-sided SCFE.

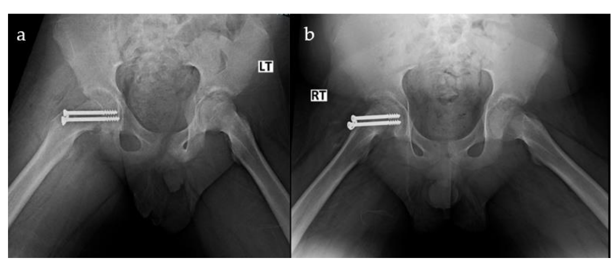

Fig. 5 Immediate postoperative radiographs following in situ fixation of right-sided SCFE in an 11-year-old boy using two cancellous screws. An open-insertion technique was used to carefully determine the entry points and avoid injury to the retinacular vessels.

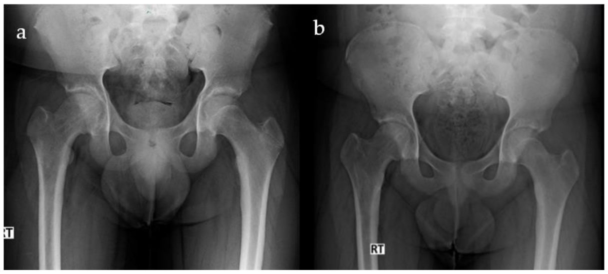

Fig. 6 Follow-up radiographs one month after screw removal and physeal closure showing notable remodeling of the femoral neck and improvement in morphology.

Schematic illustration demonstrating the measurement of lesser trochanter–articular distance (LTA), articulotrochanteric distance (ATD), femoral neck growth, femoral neck width, and neck-shaft angle (β) in relation to the femoral axis. Reference lines (G, H, and I) were used to standardize vertical measurements. (Illustration created by Papob Ruangdetch, MD, with permission.)

These results suggest that, after screw removal, femoral neck remodeling continued until physeal closure, with statistically significant changes in the angle, width, and length of the femoral neck.

DISCUSSION

In our study, significant improvements in the femoral neck length, width, and angulation were observed after removal. This aligns with the findings of Sailhan et al.,(4) who demonstrated that proximally threaded screws facilitated continued growth and remodeling of the proximal femur. Proximally threaded cannulated screws have been shown to allow continued femoral neck growth while providing sufficient epiphyseal stabilization. This design minimizes compressive forces across the physis and may contribute to improved remodeling outcomes(21).

The relatively low incidence of AVN in our cohort supports the use of open-insertion technique. This technique provides direct visualization and may help protect the retinacular vessels during screw insertion, potentially reducing the vascular injury associated with severe slips(22). Our open-insertion technique was employed to allow direct visualization of the screw entry point, which typically lies more anteriorly and poses a risk of injuring the retinacular vessels supplying the femoral head. No attempt was made to reduce the slipped epiphysis, and the procedure was performed without manipulation of the displaced physis. This study aimed to evaluate the ability of the femoral neck for continued growth and remodeling in patients with SCFE treated with in situ screw fixation. Additionally, we explored the effect of removing all screws to encourage the remodeling process. Notably, all unstable slips in this cohort were associated with higher Southwick severity grades, which is consistent with previous studies identifying instability as a key risk factor for avascular necrosis.

Currently, various surgical techniques and implants are used to treat SCFE. Some involve open reduction, whereas others employ in situ screw fixation, K-wires, simple screws, or proximally threaded cannulated screws with. In our opinion, the use of an open approach to prevent further damage to the vessels and inserting two standard cancellous screws, followed by their removal, can facilitate growth and remodeling in the affected hip. This hypothesis is supported by previous studies. For example, Guzzanti et al. observed that fixation using proximal screws preserved physeal growth and leads to remodeling(14). Similarly, Sailhan et al. reported significant improvements in the femoral neck morphology with continued growth after fixation using a single proximally threaded screw(4,14). These findings align with our results, reinforcing the concept that controlled fixation with subsequent removal may help restore the proximal femoral anatomy in SCFE.

Our findings support the remodeling potential of the proximal femur after screw removal in patients with SCFE. Similar to previous reports, particularly those by Sleth et al., we observed statistically significant improvements in neck-shaft angle (NSA), ATD, and neck width after physeal closure(21), suggesting that the femoral neck continues to remodel after implant removal, particularly during the growth phase(16). Our findings support the concept that the femoral neck continues to remodel after screw removal, particularly in younger patients during the growth phase. Similarly, Morash K et al. reported that the use of free-gliding screws (FG screws) in SCFE allowed femoral neck growth and remodeling by enabling telescoping of the screw as the femoral neck lengthened[22]. This technique was shown to prevent complications such as coxa breva and demonstrated the greatest remodeling effect in mild slips, further highlighting the importance of early diagnosis and growth-friendly fixation techniques[22].

Biomechanical studies have demonstrated that two-screw fixation provides greater mechanical stability than single-screw fixation in SCFE models. However, single-screw fixation is often preferred because of its simplicity and lower risk of complications, particularly in stable slips[6,7]. In our study, no screw-related complications were observed, further supporting the safety of this technique.

It is important to acknowledge that the remodeling observed in this study may not be exclusively attributable to screw removal. Adolescents with residual growth potential may demonstrate continued femoral neck remodeling as part of the natural growth process. Therefore, the improvements in radiographic parameters observed at the physeal closure likely represent a combination of physiological growth and the absence of hardware constraints. Screw removal may facilitate this remodeling process by eliminating potential mechanical restrictions; however, natural growth remains an important contributing factor.

In patients with SCFE treated with in situ screw fixation, continued femoral neck remodeling was observed until physeal closure. These changes likely reflect a combination of natural growth and absence of hardware constraints following screw removal. Timely removal of fixation may facilitate anatomical remodeling in patients with remaining growth potential.

The mechanism underlying femoral neck remodeling after screw removal remains unclear. Our study does not suggest that physeal growth is completely arrested, but that the screw remains in situ and resumes only after implant removal. Rather, we hypothesized that screw removal may reduce mechanical constraints across the proximal femoral physis and surrounding structures, thereby allowing continued remodeling during the remaining growth period.

Because radiographic measurements at the exact time of screw removal were not consistently available in our retrospective dataset, we were unable to directly evaluate the changes occurring between the time of fixation and screw removal. Therefore, we could not determine whether remodeling occurred during the fixation period, after screw removal, or as part of the natural growth process. This limitation should be considered when interpreting the observed radiographic changes.

Limitations and Strengths

This study had several limitations. First, its retrospective design may have affected data consistency, as some radiographic images were not obtained in a true anteroposterior or frog-leg lateral view, potentially influencing the accuracy of the angular and linear measurements.

Second, radiographic measurements were performed by a single independent observer without assessment of inter-observer or intra-observer reliability, which may introduce measurement variability and potential bias, particularly for angular parameters such as the neck–shaft angle.

Third, no subgroup analysis comparing radiographic remodeling between male and female patients was performed. Differences in skeletal maturity between sexes may influence the remodeling potential, as males typically reach skeletal maturity later than females.

Fourth, this study primarily focused on radiographic parameters. Clinical outcomes such as range of motion, pain scores, and functional assessments at skeletal maturity were not consistently available owing to the retrospective nature of the study. Therefore, whether the observed radiographic improvements translate into meaningful functional benefits remains unclear.

CONCLUSIONS

Finally, femoroacetabular impingement (FAI), including CAM deformities and alpha angle measurements, has not been systematically evaluated. Future studies incorporating both clinical outcomes and detailed morphological assessments of the femoral head–neck junction would provide further insights into the long-term implications of femoral neck remodeling after screw removal.

Despite these limitations, this study had several strengths. It included a relatively large cohort of patients with SCFE and evaluated a treatment strategy that has been less commonly reported. The combination of an open-insertion approach to minimize vascular injury and planned screw removal demonstrated continued femoral neck remodeling, which may contribute to reducing the risk of avascular necrosis (AVN) and improving anatomical restoration.

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