

A Novel Classification System for Slipped Capital Femoral Epiphysis Based on the Radiographic Relationship of the Epiphyseal Tubercle and the Metaphyseal Socket

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Background: Recent studies have suggested that the epiphyseal tubercle serves as a fulcrum for rotation in slipped capital femoral epiphysis (SCFE). However, radiographic evidence of the rotational mechanism is limited. In this study, we describe a novel radiographic staging system for SCFE based on the anatomic relationship between the epiphyseal tubercle and the metaphyseal socket.

Methods: We reviewed the cases of 469 patients with SCFE who were treated at our institution between 2000 and 2017. SCFE was classified according to our proposed staging system using the preoperative lateral radiograph. Normal hips were considered to be Stage 0. In Stage 1, the tubercle is concentric within its metaphyseal socket, which is enlarged and may present peritubercle radiolucency. In Stage 2, there is evidence of eccentricity of the tubercle, which remains in contact with the posterior wall of the socket. In Stage 3, the tubercle and metaphyseal lucency reach the posterior cortex of the femoral neck. A complete dislodgment of the tubercle from the metaphysis is present in Stage 4. Intra- and interobserver agreement, and correlations between the staging system and the traditional classifications of severity, stability, and chronicity, were estimated.

Results: The distribution by stage was as follows: 2% of the hips were classified as Stage 0, 19% were Stage 1, 48% were Stage 2, 15% were Stage 3, and 16% were Stage 4. The staging system had excellent intraobserver ($\kappa = 0.89$ [95% confidence interval (CI) = 0.83 to 0.96]) and interobserver agreement ($\kappa = 0.87$ [95% CI = 0.72 to 1.00]). There was a high correlation between the staging system and SCFE severity as assessed by the Southwick angle ($r = 0.77$ [95% CI = 0.73 to 0.82]; $p < 0.001$). There was a moderate correlation between the staging system and the Loder classification of stability ($r = 0.55$ [95% CI = 0.48 to 0.62]; $p < 0.001$) and a negligible correlation with the classification of chronicity ($r = 0.19$ [95% CI = 0.10 to 0.28]; $p < 0.001$).

Conclusions: The proposed staging system for SCFE is highly reliable and correlates well with the severity of SCFE based on the degree of displacement, with moderate correlation shown for stability. This new staging system helps in understanding the rotational mechanism of SCFE, warranting further investigation to determine its clinical application.

Clinical Relevance: The novel classification has the potential for the identification of hips that demonstrate subtle SCFE or are at pre-slip stage, or those at risk for osteonecrosis of the femoral head, failure of fixation, or slip progression.

Slipped capital femoral epiphysis (SCFE) has traditionally been described as a slip of the capital femoral epiphysis over the metaphysis¹. However, for the epiphysis to merely glide over the metaphysis, it would require the physal surface to be spherical and homogeneously smooth. In contrast, the growth-plate surface anatomy is irregular with multiple interfaces, called mammillary processes, that contribute to physal stability²⁻⁷. The epiphyseal tubercle is a

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beak-like projection eccentrically located at the posterosuperior quadrant of the epiphysis, in close relation with the corresponding metaphyseal socket⁷⁻⁹. The tubercle is a key-stone stabilizer of the epiphysis and may play an important role in the pathogenesis of SCFE^{6,10-12}. The relative instability associated with SCFE may generate abnormal focal mechanical stress concentrated around the tubercle and its metaphyseal socket¹³. Bone reaction around the epiphyseal tubercle with adjacent metaphyseal bone resorption could occur, enlarging the metaphyseal socket, leading to growing epiphyseal instability and mechanical failure¹³. The authors of previous studies proposed a rotational mechanism for SCFE, whereby the rotation occurs through the eccentrically located epiphyseal tubercle, which serves as a fulcrum^{10,11}. However, radiographic evidence of the rotational mechanism is limited.

Our purposes were to describe a novel staging system for classifying the progression of SCFE based on the radiographic relationship of the epiphyseal tubercle and its metaphyseal socket and to determine its intra- and interobserver reliability. We also sought to investigate the correlation of the staging system with traditional classifications according to slip severity¹⁴, stability¹⁵, and chronicity¹⁶.

Materials and Methods

This retrospective study received institutional review board approval.

We identified 754 patients with the diagnosis of SCFE at our institution between 2000 and 2017, on the basis of the criteria of the presence of hip pain and surgical treatment by in situ pinning or femoral realignment. We excluded 261 patients because radiographs from the initial presentation were unavailable, 13 patients because the technical quality of the radiographs was inadequate, 9 patients with a closing growth plate at the time of the initial evaluation, and 2 patients who had undergone prior surgery for a femoral neck fracture. The final cohort included 469 patients with available preoperative anteroposterior pelvic and frog-leg lateral radiographs from initial presentation. The mean age (and standard deviation) was 12.5 ± 1.7 years (range, 8 to 18 years), 58% (270 of 469) of the cohort was male, and the median body mass index percentile was 97 (interquartile range, 92 to 99). Among the unilateral SCFE cases, the left hip was more often affected (53%; 249 of 469); 10% (45 of 469) of the cases were bilateral. SCFE severity was classified on the basis of the degree of displacement according to the Southwick angle¹⁴: mild ($<30^\circ$); moderate (30° to 60°), or severe ($>60^\circ$), as measured on frog-leg lateral radiographs. SCFE was classified as “unstable” if the patient had such severe pain that walking was not possible, even with crutches, regardless of the duration of the symptoms (criteria of Loder et al.)¹⁵. Finally, SCFE was classified as “chronic” if symptoms were present for ≥ 3 weeks, “acute” if present < 3 weeks, or “acute on chronic” if there were ≥ 3 weeks of symptoms with acute exacerbation¹⁶ (Table I).

Lateral radiographs consisted of a Lauenstein frog-leg view (supine positioning, hip flexion of approximately 45° and

TABLE I Demographic, Clinical, and Radiographic Characteristics of the Cohort of Patients with SCFE*

Characteristic	Value
Age at slip (yr)	12.5 ± 1.7
Male sex	270 (58%)
SCFE laterality	
Right	175 (37%)
Left	249 (53%)
Bilateral	45 (10%)
BMI percentile group (n = 337)†	
Obese (≥ 95 th)	227 (67%)
Overweight (≥ 85 th and < 95 th)	50 (15%)
Healthy weight (< 85 th)	60 (18%)
Duration of symptoms	
Chronic	251 (54%)
Acute on chronic	81 (17%)
Acute	137 (29%)
SCFE stability	
Stable	358 (76%)
Unstable	111 (24%)
SCFE severity	
Mild	154 (33%)
Moderate	204 (43%)
Severe	111 (24%)
Southwick angle (affected side)‡	$43.1^\circ \pm 20.7^\circ$
Positive Klein sign (affected side)‡	400 (85%)

*N = 469. The values are given as the number and percentage, with the exception of age and Southwick angle, which are given as the mean and standard deviation. †BMI = body mass index. ‡In bilateral cases, only the most severe SCFE side was considered.

abduction of approximately 45° , knees flexed to about 90° with both feet placed together)¹⁷, or cross-table lateral view for painful, unstable SCFE. The epiphyseal tubercle was identified as the bone prominence located at the second-most posterior quadrant of the physeal surface of the capital epiphysis on the lateral radiograph¹³, with the exception of 2 cases with an unstable slip that had only the anteroposterior view. A staging system based on the radiographic relationship of the epiphyseal tubercle and its respective metaphyseal socket (Fig. 1) was developed. Stage 0 corresponds to the normal relationship between the epiphyseal tubercle and its socket (Fig. 2). In Stage 1, the epiphyseal tubercle is concentric within its metaphyseal socket, but the socket is enlarged and there is radiographic lucency surrounding the tubercle: the peritubercle lucency sign¹³ (Figs. 3-A and 3-B). Alternatively, the entire growth plate may be wider than that of the contralateral hip (Fig. 3-C). Stage 2 corresponds to an evident eccentricity of the tubercle, which remains in contact with the posterior wall of the metaphyseal socket (Fig. 4-A). Depending on the chronicity, sclerosis may be observed surrounding the epiphyseal tubercle (Fig. 4-B). In

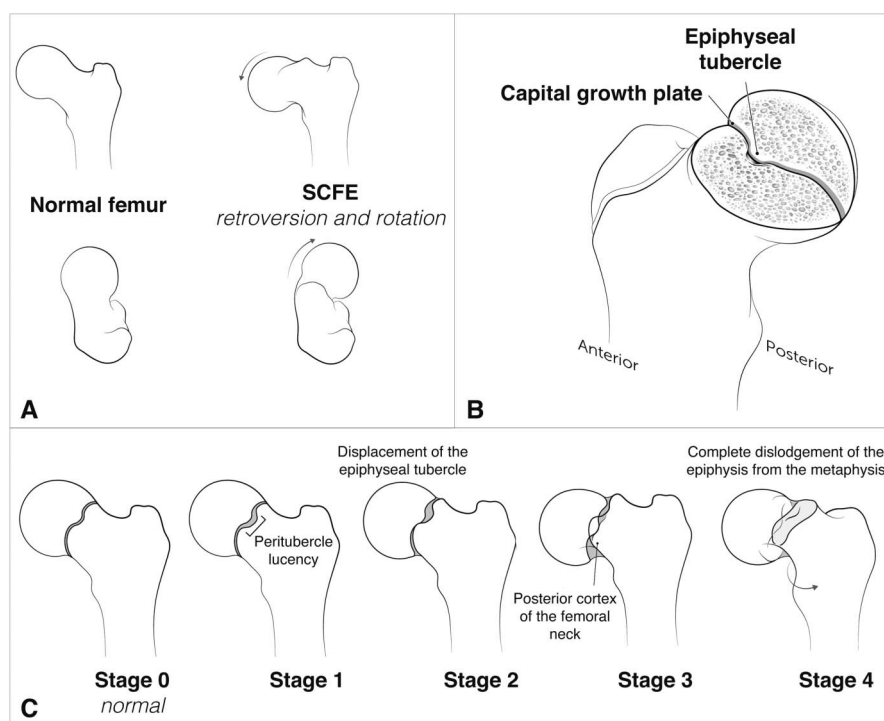


Fig. 1

Fig. 1-A Slipped capital femoral epiphysis (SCFE) with a rotational mechanism of deformity, characterized by retroversion and rotation of the capital epiphysis. **Fig. 1-B** The epiphyseal tubercle is a bone prominence located at the superoposterior quadrant of the physal surface of the capital epiphysis, fitting into a metaphyseal socket. **Fig. 1-C** The staging system for the rotational mechanism of SCFE is based on the relationship of the epiphyseal tubercle and its corresponding metaphyseal socket. Stage 0 corresponds to a normal radiographic aspect. In Stage 1, the tubercle is concentric within its metaphyseal socket, which is enlarged and may present the peritubercle lucency sign or global physal widening. In Stage 2, there is an evident eccentricity of the tubercle, which is in contact with the posterior wall of the socket. In Stage 3, the peritubercle lucency advances posteriorly and the epiphyseal tubercle is entrapped at the posterior cortex. In Stage 4, there is complete dislodgement of the tubercle, which is outside the metaphysis.

Stage 3, the epiphyseal tubercle and the metaphyseal socket resorption reach the posterior cortex of the femoral neck (Fig. 5). In Stage 4, there is complete dislodgement of the tubercle from the metaphyseal socket within an acute (Figs. 6-A and 6-B) or chronic setting (Fig. 6-C).

Statistical Analysis

Patient and SCFE characteristics were summarized as the number and percentage, or the mean and standard deviation. For demographic and correlation analysis, we included in the analysis only the affected hip in cases of unilateral SCFE, or the most affected hip in bilateral cases, as defined by the Southwick angle. Only preoperative radiographs from the onset of SCFE were assessed, to enable a blinded approach by the observers, who were not aware of subsequent treatment. For reliability, power analysis indicated that, in order to test for a kappa (κ) coefficient of at least 0.80 using a 1-sided test with a 0.10 margin of error, we would require a minimum of 180 readings to achieve 80% power with alpha set to 5%. One observer (D.A.M., a pediatric orthopaedic surgeon with 10 years of practice, who was not involved with the patients' care) reviewed preoperative radiographs for all patients and assessed the classifications of

slip severity¹⁴, stability¹⁵, and chronicity¹⁶, and classified the stage according to the novel staging system. After a 2-month interval, the same observer performed a second blinded



Fig. 2

A right frog-leg lateral radiograph of a 12-year-old girl showing a normal aspect of the epiphyseal tubercle (black arrow) and its metaphyseal socket (white arrowheads), without physal widening, representing Stage 0 of the staging system based on epiphyseal tubercle anatomic positioning.

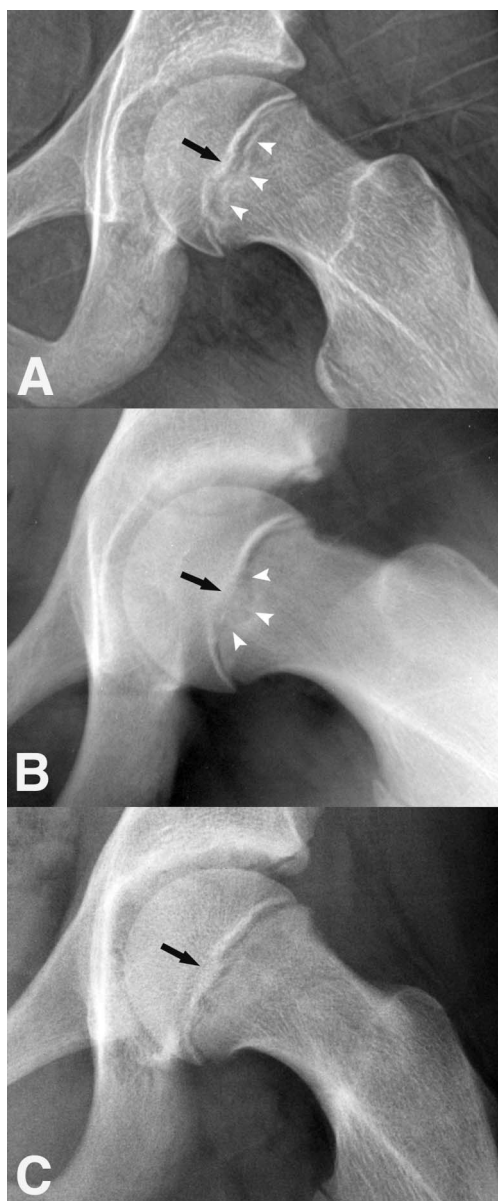


Fig. 3
 Examples of Stage-1 rotational deformity in slipped capital femoral epiphysis (SCFE). **Fig. 3-A** A Lauenstein frog-leg lateral radiograph of the proximal part of the left femur of a 12-year-old girl with mild, chronic, and stable SCFE. The epiphyseal tubercle (black arrow) is congruent with its metaphyseal socket, which presents a focal enlargement constituting the peritubercle lucency sign (white arrowheads), without evidence of global physeal widening. **Fig. 3-B** A Lauenstein frog-leg lateral radiograph of the proximal part of the left femur of a 14-year-old boy with mild, chronic, and stable SCFE. The epiphyseal tubercle (black arrow) is congruent with its metaphyseal socket. The peritubercle lucency sign (white arrowheads) is evident, along with global physeal widening. **Fig. 3-C** A Lauenstein frog-leg lateral radiograph of the proximal part of the left femur of a 16-year-old boy with mild, chronic, and stable SCFE. A global physeal widening is observed, although a peritubercle lucency is not clearly observed around the epiphyseal tubercle (black arrow).

assessment of all hips using the staging system, in order to evaluate the intraobserver agreement. A second observer (S.B., a pediatric musculoskeletal radiologist with 15 years of practice) read a random sample of the radiographs, created using an electronic random number generator, for 87 patients (174 hips) in order to evaluate the interobserver agreement. For both intra- and interobserver agreement, a blinded approach was applied among readings. Intra- and

interobserver agreement was assessed using the Cohen κ ¹⁸ with quadratic weights along with 95% confidence intervals (CIs). A κ value of 0.61 to 0.80 indicated substantial reliability, and a value of 0.81 to 1.00, excellent reliability¹⁹. The correlations between the new staging system and SCFE chronicity, severity, and stability were assessed by Spearman rank correlation analysis or the Cochran-Armitage test for trend. A correlation coefficient of 0.0 to 0.3 was considered a

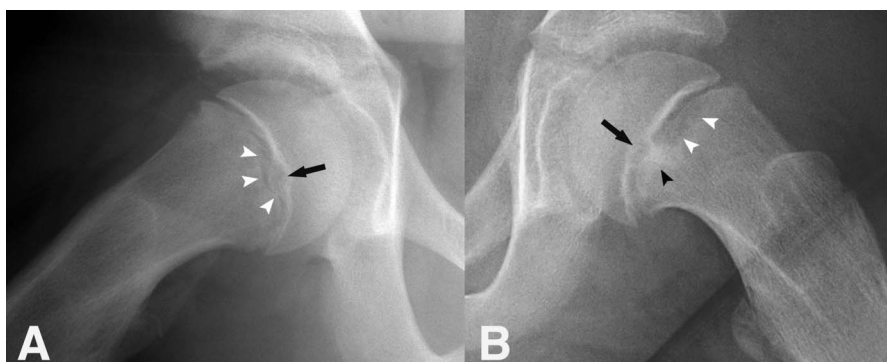


Fig. 4
Examples of Stage-2 rotational deformity in slipped capital femoral epiphysis (SCFE). **Fig. 4-A** A Lauenstein frog-leg lateral radiograph of the proximal part of the right femur of a 14-year-old boy with mild, chronic, and stable SCFE. The epiphyseal tubercle (black arrow) is displaced and in contact with the posterior limit of the metaphyseal socket (white arrowheads). **Fig. 4-B** A Lauenstein frog-leg lateral radiograph of the proximal part of the left femur of an 11-year-old boy with moderate, acute-on-chronic, and stable SCFE. The epiphyseal tubercle (black arrow) is pressing against the posterior wall of the metaphyseal socket, where sclerosis is observed (black arrowhead). The metaphyseal socket is enlarged and visually empty (white arrowheads).

negligible correlation; >0.3 to 0.5 was considered a low correlation; >0.5 to 0.7 , moderate; >0.7 to 0.9 , high; and >0.9 to 1.0 , very high²⁰. All tests were 2-sided and p values of <0.05 were considered significant.

Results

According to the novel staging system, 9 (2%) of the 469 hips treated for SCFE had a normal relationship between the epiphyseal tubercle and its socket (Stage 0). The classification was Stage 1 for 88 (19%) of the hips, Stage 2 for 227 (48%) of the hips, Stage 3 for 69 (15%), and Stage 4 for 76 (16%) of the hips (Table II). The mean age of those at Stage 0 was smaller than at Stage 3 (11.5 ± 1.5 years compared with 13.1 ± 2.0 years; $p = 0.017$).

Excellent intra- and interobserver agreement was observed for the assessment of all hips ($\kappa = 0.89$ [95% CI = 0.83 to 0.96],

and $\kappa = 0.87$ [95% CI = 0.72 to 1.00], respectively) and for the assessment of 1 affected hip per patient ($\kappa = 0.88$ [95% CI = 0.85 to 0.90], and $\kappa = 0.86$ [95% CI = 0.74 to 0.97], respectively). Excellent agreement was also observed for the intraobserver assessment of a random selection of the right or left hip of each patient ($\kappa = 0.89$ [95% CI = 0.80 to 0.98]), and excellent interobserver agreement was observed for the assessment of a random sample of 87 hips by a second reviewer ($\kappa = 0.88$ [95% CI = 0.67 to 1.09]) (Table III).

The novel epiphyseal tubercle staging system had a high correlation with the traditional classification of SCFE severity using the Southwick angle¹⁴ ($r = 0.77$ [95% CI = 0.73 to 0.82]; $p < 0.001$). For the 97 hips at Stage 0 or 1, 78 (80%) were classified as mild according to Southwick¹⁴, and none was considered severe. For hips at Stage 4, 96% were classified as severe. The correlation between the epiphyseal tubercle staging system

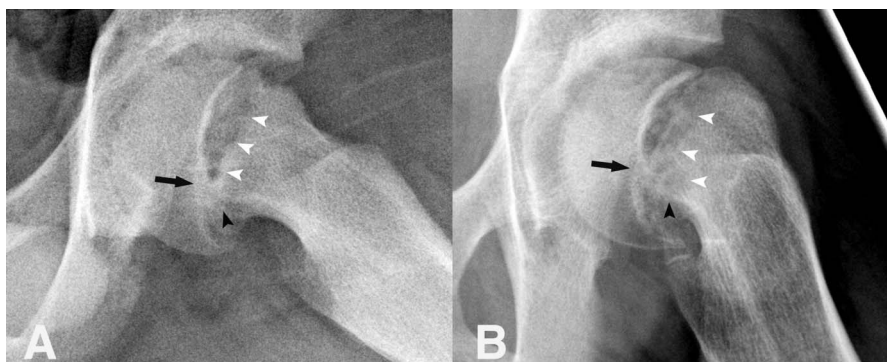


Fig. 5
Examples of Stage-3 rotational deformity in slipped capital femoral epiphysis (SCFE). **Fig. 5-A** A Lauenstein frog-leg lateral radiograph of the proximal part of the left femur of a 14-year-old boy with moderate, chronic, and stable SCFE. The epiphyseal tubercle (black arrow) is displaced and in contact with the posterior cortex of the femoral neck (black arrowhead). The metaphyseal lucency (white arrowheads) is expanded posteriorly. **Fig. 5-B** A Lauenstein frog-leg lateral radiograph of the proximal part of the left femur of an 11-year-old boy with severe, acute-on-chronic, and unstable SCFE. The epiphyseal tubercle (black arrow) is in contact with the posterior cortex of the femoral neck (black arrowhead). The metaphyseal socket is enlarged and visually empty, and the radiolucency is heading posteriorly (white arrowheads), suggesting bone resorption of the posterior cortex. The presence of clinical instability may suggest a transition between Stage 3 and 4.

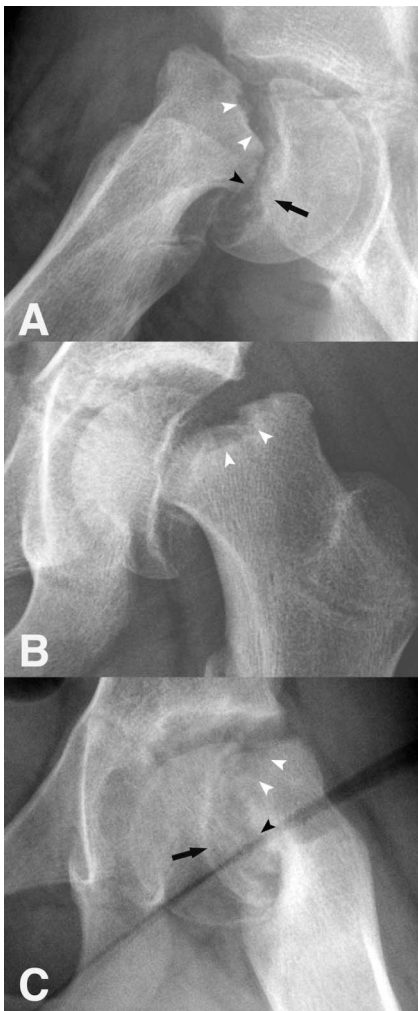


Fig. 6
Examples of Stage-4 rotational deformity in slipped capital femoral epiphysis (SCFE). **Fig. 6-A** A Lauenstein frog-leg lateral radiograph of the proximal part of the right femur of a 12-year-old boy with acute, unstable, and severe SCFE. The epiphyseal tubercle (black arrow) is completely dislodged from the physal surface of the metaphysis, surpassing the limit of the posterior cortex corner of the femoral neck (black arrowhead). The metaphyseal socket (white arrowheads) is visually empty, without signs of bone resorption. **Fig. 6-B** An anteroposterior radiograph of the proximal part of the left femur of an 11-year-old girl with acute, unstable, and severe SCFE. Because of the positioning of the capital epiphysis, the epiphyseal tubercle is not completely identifiable. However, there is a clear dislodgment of the capital epiphysis from the metaphysis. The metaphyseal socket (white arrowheads) is visually empty. **Fig. 6-C** A Lauenstein frog-leg lateral radiograph of the proximal part of the left femur of a 10-year-old girl with severe, chronic, and stable SCFE. Observed is an extensive posterior callus between the epiphyseal tubercle area (black arrow) and the posterior cortex of the remodeling femoral neck (black arrowhead), allowing for a stable setting of SCFE. Metaphyseal lucency is observed around the socket. Although the tubercle is not clearly seen inside the callus, the tubercle area is unequivocally displaced from the physal surface of the metaphysis.

and the Loder classification¹⁵ of stability was moderate ($r = 0.55$ [95% CI = 0.48 to 0.62]; $p < 0.001$). More than 90% of the hips at Stages 0 and 1 were stable, while >80% of the hips at Stage 4 were unstable. There was also a correlation between the staging system and the chronicity of SCFE¹⁶; however, the correlation was found to be negligible ($r = 0.19$ [95% CI = 0.10 to 0.28]; $p < 0.001$) (Table IV).

Discussion

In this study, we proposed a novel staging system to grade the progression of SCFE on the basis of the relationship of the epiphyseal tubercle and its respective metaphyseal socket on lateral radiographs. We identified 5 stages of tubercle-metaphysis relationship in patients with SCFE, from the normal anatomic relationship to complete dislodgment of the tubercle from the metaphyseal socket. The staging system had excellent inter- and intraobserver reliability, a high correlation with the traditional classification of SCFE severity, and a moderate correlation with the classification of SCFE stability.

Our proposed staging system is based on the rationale of the rotational mechanism of SCFE previously suggested by Tayton¹⁰ and Liu et al.¹¹. Shearing forces surpassing the stability of the growth plate may lead the metaphysis to start to rotate on the epiphyseal tubercle as a fulcrum, developing an extension and retroversion deformity¹¹. This initial rotation corresponds to Stage 1, where radiolucency is observed around the tubercle without evident displacement (Figs. 3-A and 3-B), resembling a pre-slip status. The stability of the epiphysis provided by the tubercle, the surrounding thick periosteum, and the perichondral ring and by interdigitations or ridges from the epiphysis into the metaphysis, allow for the gradual progression observed in stable SCFE^{2,4,21-23}. In Stage 2, the tubercle is eccentrically located in proximity to the posterior aspect of the corresponding metaphyseal socket (Fig. 4-A). Depending possibly on the chronicity, mechanical behavior, and osseous reaction, sclerosis may be observed around the tubercle (Fig. 4-B). As the deformity progresses, the metaphyseal

TABLE II Distribution of the Hips Affected with SCFE*

	No.	%
Epiphyseal tubercle stage		
Stage 0	9	2%
Stage 1	88	19%
Stage 2	227	48%
Stage 3	69	15%
Stage 4	76	16%
Presence of sclerosis	130	28%

*According to the staging of rotational displacement based on the epiphyseal tubercle classification. A total of 469 patients were evaluated, and only the affected side (unilateral SCFE) or the most affected hip (bilateral SCFE) was considered in the analysis.

TABLE III Intraobserver and Interobserver Agreement of the Epiphyseal Tubercle Staging System for the Rotational Mechanism of SCFE*

Agreement	No.	κ	95% CI
Both hips			
Intraobserver	938	0.89	0.83, 0.96
Interobserver	174	0.87	0.72, 1.00
Affected hip			
Intraobserver	469	0.88	0.85, 0.90
Interobserver	87	0.86	0.74, 0.97
Random hip			
Intraobserver	469	0.89	0.80, 0.98
Interobserver	87	0.88	0.67, 1.09

* κ = Cohen weighted kappa coefficient, and CI = confidence interval.

socket enlarges, and the epiphyseal tubercle starts to lose contact with the adjacent bone, pressing against the posterior wall. Contact with the posterior cortex of the femoral neck

remains during Stage 3 (Fig. 5). In Stage 4, there is further progression, and the epiphyseal tubercle completely dislodges from the metaphyseal socket, resembling an unstable SCFE (Figs. 6-A and 6-B).

Our staging system provides a complete and detailed description of the relationship between the tubercle and the metaphyseal socket compared with the dichotomous (engaged versus completely dislodged) definition previously described^{8,9,11}. Potential clinical implications for the treatment of SCFE are worth exploring with further investigation. It is possible that the deformity is rotational^{10,11}, and an initial subtle displacement would not be recognized using the Klein method, the Southwick angle, or slip displacement¹³. Micro-instability around the tubercle, contributing to a loss in the “docking” characteristics, could be recognized early at Stages 1 and 2 if the peritubercle lucency sign is present, helping in timely diagnosis. Stable SCFE is traditionally treated by percutaneous fixation using a single cannulated screw²⁴, which would provide additional stability to the epiphyseal tubercle that is still engaged^{8,9}. Although the failure of screw fixation or slip progression after stable SCFE pinning is a rare event, with incidence around 2% to 4%, the position of the screw is the main risk factor for failure²⁴⁻²⁶. If the screw is placed

TABLE IV Patient and SCFE Characteristics According to the Epiphyseal Tubercle Stage of Rotational Deformity*

	Tubercle Stage					P Value
	0 (N = 9)	1 (N = 88)	2 (N = 227)	3 (N = 69)	4 (N = 76)	
Age at slip (yr)	11.5 ± 1.5	12.2 ± 1.6	12.5 ± 1.7	13.1 ± 2.0	12.3 ± 1.6	0.007†
Male sex	6 (67%)	52 (59%)	140 (62%)	37 (54%)	35 (46%)	0.16
BMI percentile group (n = 337)‡						0.018
Obese (≥95th)	5 (56%)	47 (75%)	120 (73%)	23 (52%)	32 (57%)	
Overweight (≥85th and <95th)	1 (11%)	5 (8%)	20 (12%)	14 (32%)	10 (18%)	
Healthy weight (≤85th)	3 (33%)	11 (17%)	25 (15%)	7 (16%)	14 (25%)	
Laterality						0.14
Right	5 (56%)	38 (43%)	85 (37%)	25 (36%)	22 (29%)	
Left	4 (44%)	38 (43%)	124 (55%)	32 (46%)	51 (67%)	
Bilateral	0 (0%)	12 (14%)	18 (8%)	12 (17%)	3 (4%)	
Severity						<0.001
Mild	8 (89%)	70 (80%)	76 (33%)	0 (0%)	0 (0%)	
Moderate	1 (11%)	18 (20%)	145 (64%)	37 (54%)	3 (4%)	
Severe	0 (0%)	0 (0%)	6 (3%)	32 (46%)	73 (96%)	
Stability						<0.001
Stable	9 (100%)	83 (94%)	207 (91%)	45 (65%)	14 (18%)	
Unstable	0 (0%)	5 (6%)	20 (9%)	24 (35%)	62 (82%)	
Duration of symptoms						<0.001
Chronic	4 (44%)	56 (64%)	142 (63%)	39 (57%)	10 (13%)	
Acute on chronic	2 (22%)	4 (5%)	24 (11%)	20 (29%)	31 (41%)	
Acute	3 (33%)	28 (32%)	61 (27%)	10 (14%)	35 (46%)	

*The values are given as the number and within-column relative percentage according to the tubercle stage, with the exception of age, which is given as the mean and standard deviation. †The mean age of patients at Stage 0 differed significantly from that of patients at Stage 3 (1-way analysis of variance [ANOVA], Bonferroni post-test, p = 0.017). ‡BMI = body mass index.

through the tubercle, the epiphysis would have only 1 eccentric and robust point of fixation and could still rotate^{8,10,11}. Theoretically, the position of the screw in relation to the epiphyseal tubercle would be more relevant for younger children as the epiphyseal tubercle decreases in size with growth during adolescence⁷. The stability provided by the epiphyseal tubercle may be critical in Stages 0, 1, and 2, when the tubercle is well engaged in the metaphyseal socket (Figs. 2, 3, and 4). However, it is unlikely that the epiphyseal tubercle provides substantial stability at the end of Stage 3, when the metaphyseal socket enlarges, and the tubercle starts to lose its relationship with the metaphysis (Fig. 5-B). In Stage 4, the tubercle is completely dislodged, and unless a well-established callus is present (Fig. 6-C), the SCFE would be unstable. In unstable SCFE, improved biomechanical resistance to failure has been suggested with 2-screw fixation instead of the use of a single screw²⁷⁻²⁹. It is possible that acute-on-chronic slips may be at risk to present progressive slippage after pinning²⁶, which might correspond to Stage 3, when the tubercle starts to disengage from the metaphyseal socket. On the basis of the loss of contact, with a lack of stability provided by the tubercle, it is possible that Stage-3 slips should be treated as Stage 4 to improve the biomechanical rotational resistance and reduce the risk of screw failure or slip progression.

Liu et al.^{9,11} showed that the vascular foramina from the deep branches of the superior epiphyseal vessels were located directly peripheral to the epiphyseal tubercle. They hypothesized that in stable SCFE, the epiphyseal tubercle is engaged, protecting the superior epiphyseal vessels. On the contrary, a dislodgment of the tubercle in unstable SCFE, corresponding to Stage 4 of the novel staging system, could lead to displacement of the vessels and the potential risk for osteonecrosis of the femoral head. We observed a moderate correlation between the staging system and the classification of hips as stable or unstable according to the Loder criteria¹⁵. Further investigation as to whether the novel staging system can be predictive of osteonecrosis in the clinical setting is warranted.

There were limitations to the current study. First, although we used a blinded and independent approach for imaging interpretation, the observers were aware of the diagnosis, which may have generated observer bias. Second, the study involved a large cohort of patients from an extensive period. There may have been variations within the radiographic protocol and hip positioning, or even variants of SCFE, such as valgus slip. Also, a potential bias may have been present because of the exclusion of a substantial number of patients with unavailable initial radiographs. Third, advanced-imaging evidence of the rotational mechanism of SCFE is limited, and we caution that radiographs do not provide a complete understanding of a complex tridimensional deformity. The radiographic identification of the epiphyseal tubercle depends on femoral positioning, and although the frog-leg incidence provided a reliable option, the best incidence for visualizing the tubercle needs to be determined. Fourth, the image quality in the general population of patients with SCFE may be poor, which may have a negative effect on the identification of the

peritubercle lucency. Although the hip is painful in SCFE, the range of motion may be wide in pre-slip or subtle SCFE, characterized by Stages 1 and 2, and patients may flex and abduct the hip to achieve a good-quality frog-leg lateral view. Therefore, it was possible to visualize the relationship between the tubercle and metaphysis in initial SCFE, and the peritubercle radiolucency. On the contrary, when a deformity is present, the frog-leg radiograph is painful and range of motion is limited, but the extent of peritubercle lucency is usually increased, allowing for the assessment or estimation of tubercle positioning but not allowing for the perfect assessment of epiphyseal displacement by the Southwick angle. Fifth, some hips classified as Stage 0 may have been prophylactically treated in consideration of other risk factors for SCFE progression; we cannot exclude the likelihood of false negatives for the staging system. Lastly, the staging system may have little value for late, chronic SCFE with advanced remodeling of the posterior callus and nearly closed growth plate, since the tubercle is possibly included into the callus. Nevertheless, our study brings new evidence supporting the theory of the rotational mechanism and stimulates further imaging investigation with advanced methods such as magnetic resonance imaging (MRI), computed tomography (CT), 3-dimensional computer modeling, and finite element analysis. Prospective clinical studies involving other centers are necessary to validate this staging system for the rotational mechanism.

In summary, we reviewed the radiographs from 469 patients with SCFE and propose a novel staging system on the basis of the relationship between the epiphyseal tubercle and the corresponding metaphyseal socket on lateral radiographs. The staging system was found to have excellent inter- and intraobserver reliability. Moreover, it correlated well with previous classifications systems for SCFE severity and stability. This staging system may have relevant clinical implications, including the identification of hips that demonstrate subtle SCFE or are at pre-slip stage, or those at risk for osteonecrosis of the femoral head, failure of fixation, or slip progression. However, clinical studies are necessary to establish whether this novel staging system would increase value for the management of patients with SCFE. The staging system provides a radiographic pattern based on the rationale of the rotational mechanism that may benefit future research about the pathogenesis of SCFE. ■

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