

Probability analysis of sequential SCFE (PASS score)

Baruch Danino^{1,2,3}
 Satbir Singh¹
 Junxin Shi¹
 Jingzhen Yang¹
 Walter P. Samora^{1,4}
 Christopher A. Iobst^{1,4}
 Kevin E. Klingele^{1,4}

Abstract

Purpose: The study aimed to develop a scoring system based on clinical and radiological findings to predict the risk of a sequential slipped capital femoral epiphysis (SCFE).

Methods: Paediatric patients with unilateral SCFE and at least two years of radiographic follow-up were screened for inclusion. Medical records were reviewed for multiple variables including age, gender, body mass index (BMI), stability of SCFE, and time to sequential presentation. Radiographic analysis included triradiate physeal status, Risser staging, superior epiphyseal extension ratio (EER), posterior epiphyseal angle (PEA), posterior sloping angle (PSA) and slip severity.

Results: In total, 163 patients (88 male, 54%, 75 female, 46%) met inclusion criteria. Of those, 65 (40%) with a mean age of 11.9 ± 1.3 years developed sequential SCFE at a mean of 9.8 ± 6.4 months after the initial slip. Eight independent variables were statistically different ($p < 0.05$) between unilateral and sequential groups. Following multivariate analysis, Risser stage and triradiate status were no longer significant and did not influence the strength of the final model (overall area under the curve (AUC) = 0.954) and were consequently excluded. We developed the PASS score using three radiographic parameters using chosen cut-off values that were close to their maximized value and weighted the point value assigned to each parameter based on the strength of predictor.

Conclusion: A PASS score of three or higher predicts a high probability of sequential SCFE with 95% confidence and may warrant prophylactic screw fixation. PASS score calculation can

be used to predict a sequential SCFE and provide an objective method to determine the utility prophylactic screw fixation.

Level of Evidence: II

Cite this article: Danino B, Singh S, Shi J, Yang J, Samora WP, Iobst CA, Klingele KE. Probability analysis of sequential SCFE (PASS score). *J Child Orthop* 2020;14:387-396. DOI: 10.1302/1863-2548.14.200080

Keywords: slipped capital femoral epiphysis; posterior sloping angle; superior epiphyseal extension ratio; posterior epiphyseal angle

Introduction

Slipped capital femoral epiphysis (SCFE) is a common hip disorder seen in adolescents. The exact cause of SCFE is currently unknown but biomechanical factors in the setting of obesity or endocrine disorders have been implicated. SCFE typically presents with unilateral involvement. The management strategy for the contralateral hip at the time of presentation is controversial. Some authors recommend routine prophylactic insitu pinning based on a 25% to 80% reported risk of sequential involvement.¹⁻³ Others recommend close radiographic follow-up and observation since risks associated with prophylactic surgical treatment such as iatrogenic chondrolysis and avascular necrosis have been reported.⁴

Many parameters have been proposed as predictive factors for contralateral, sequential SCFE including: skeletal maturity,⁵ body mass index (BMI)⁶ and magnetic resonance imaging (MRI) pre-slip parameters.⁷ Femoral head/neck morphology, especially the posterior sloping of the epiphysis, has also been implicated.⁸⁻¹⁰ Previous studies have shown that the posterior sloping angle (PSA) of the physis on an axial radiograph is significantly higher in patients who progress to contralateral, sequential SCFE.^{11,12} Recent studies have shown that increasing capital femoral epiphyseal extension may confer physeal stability in the setting of SCFE, and that epiphyseal extension reflects an adaptive response to limit physeal stress and reduce the risk for progression to SCFE.¹³ Therefore, patients with relatively less epiphyseal extension, and consequently decreased physeal stability, would be at an increased risk for the development of sequential SCFE. However, there is controversy regarding the appropriate thresholds of each parameter that would promote prophylactic fixation.

The purpose of this study was to determine the diagnostic value of a scoring system based on clinical and radio-

¹ Nationwide Children's Hospital, Columbus, Ohio, USA

² The Department of Pediatric Orthopaedics, Dana Children's Hospital, Tel-Aviv Sourasky Medical Center, Israel

³ Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel

⁴ Department of Orthopaedics, The Ohio State University Wexner Medical Center, Columbus, Ohio, USA

Correspondence should be sent to Kevin Klingele, Department of Orthopedic Surgery, Nationwide Children's Hospital, 700 Children's Drive Suite A2630, Columbus, OH 43205-2696, USA.
 E-mail: Kevin.Klingele@nationwidechildrens.org

logical findings for predicting sequential hip involvement in patients with unilateral SCFE and to develop an evidence-based clinical decision-making algorithm for the optimal management strategy of the contralateral hip.

Materials and methods

After institutional review board approval, a retrospective study was performed of all patients with unilateral SCFE treated at a single paediatric centre between 1st January 2000 and 31st December 2018. Patients who underwent contralateral prophylactic screw fixation, those with bilateral involvement at presentation, those with metabolic or endocrine disorders, or those without available preoperative images were excluded. Minimum follow-up requirement was complete at the time of contralateral SCFE, contralateral physal closure or a follow-up of 24 months for patients with an open proximal femoral physis on their last radiograph. In total, 475 patients with a diagnosis of SCFE were identified between the years 2000 and 2018. Following exclusion criteria, 163 patients with unilateral SCFE were analysed: 65 patients (39.9%) developed contralateral, sequential SCFE and 98 (60.1%) remained unilateral (Fig. 1).

Medical records were reviewed for gender, age at initial surgery, laterality, time to sequential presentation, SCFE clinical stability (as classified by Loder et al¹⁴), height and weight. BMI percentile was calculated using the Centers for Disease Control and Prevention (CDC) website calculator¹⁵ and categorized according to the guidelines of the CDC:¹⁶ 5th to 85th percentile considered normal or healthy weight, 85th to 95th percentile as overweight and 95th percentile or greater as obese.

Radiographic assessment was performed via the picture and archiving communication system (PACS) (GE Medical Systems, Barrington, Illinois) by a fellowship trained,

paediatric orthopedic surgeon (BD) who was not clinically involved in patient care and blinded to the outcome of each hip. Measurements were repeated at approximately three months after the initial evaluation to test intra-rater reliability. Supine anteroposterior (AP) pelvic radiographs taken at initial presentation were available for all patients. Initial frog lateral pelvis radiographs – taken with the patient supine with both knees flexed at 45°, hips externally rotated and abducted 45° – were available for 149 (91%) of the 163 patients. The first postoperative frog lateral radiograph was used for the remaining 14 patients (9%).

On the AP view, the triradiate cartilage status was labelled as open (grade I – more than 2mm width, grade II – less than 2mm width) or closed (grade III) as defined in the modified Oxford bone age score.⁵ Risser stage was determined as described by Hacquebord and Leopold.¹⁷ Superior epiphyseal extension ratio (EER) of the uninvolved hip at time of unilateral SCFE presentation (Fig. 2a) was calculated. On the frog lateral view, the posterior epiphyseal angle (PEA) (Fig. 2b) was measured for the uninvolved hip. The posterior sloping angle (Fig. 2c) was measured on the affected hip (initial PSA) and unaffected hip (PSA). Southwick angle of the involved hip was calculated by subtraction of the PSA on the unaffected hip from that on the affected hip.

Comparisons were made between the unilateral SCFE and the sequential SCFE groups. Categorical variables, triradiate status and Risser stage were converted to binary classifiers. Specifically, grade I and II triradiate were labelled 'open' and grade III 'closed'. Risser stage was split into 0 and stages 1 to 4. Univariate analysis was performed using independent samples T test and Mann-Whitney U test for continuous variables. Chi-square test of proportions was used for categorical variables. The continuous variables were individually analysed via Receiver Operator

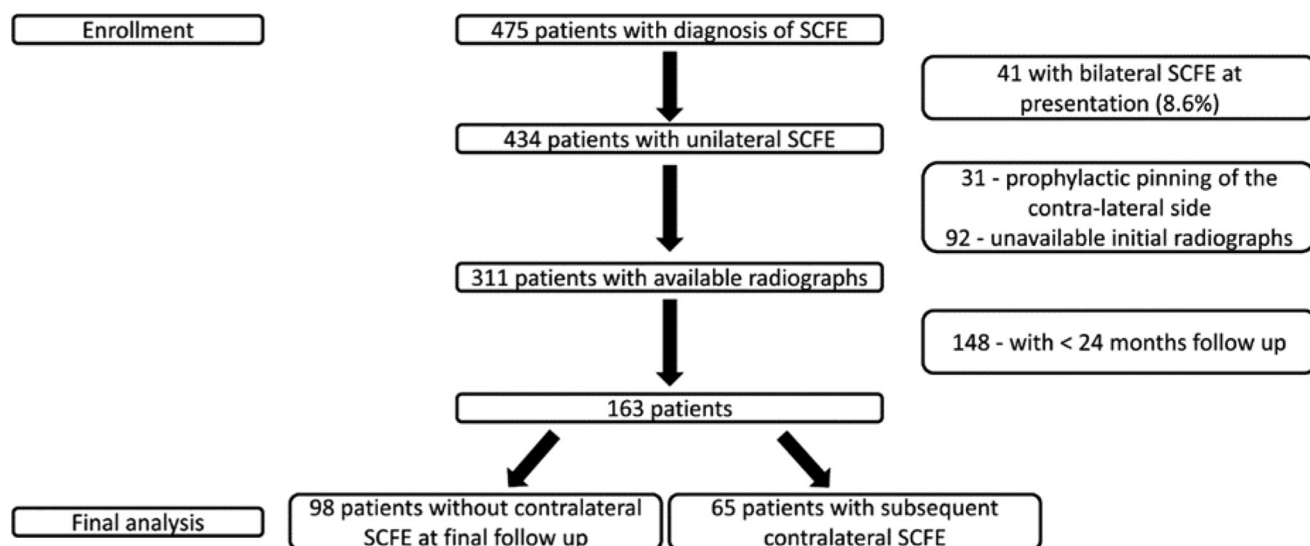


Fig. 1 Study population.

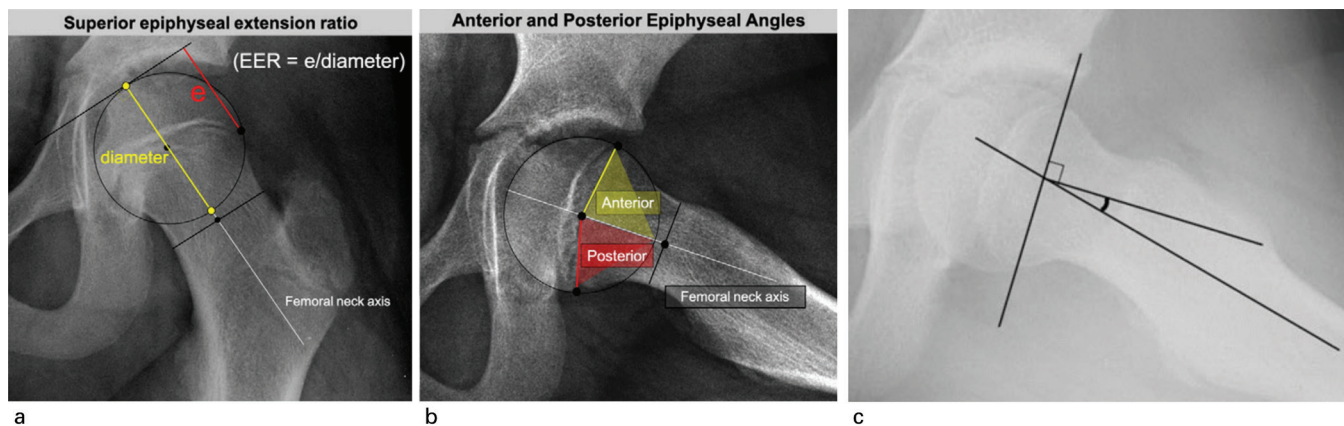


Fig. 2 (a) Superior epiphyseal extension ratio (EER). A line (top black line) is drawn tangential to the femoral head and perpendicular to the femoral neck axis. Another line (red line) connecting the most lateral aspect of the epiphysis to the tangential line is drawn parallel to the femoral neck axis and the distance (e) is measured. The superior epiphyseal extension ratio is calculated by dividing this distance (e) by the diameter of the femoral head (yellow line). Reproduced with permission from Maranhão DA, Ferrer MG, Kim YJ, Miller PE, Novais EN. Predicting risk of contralateral slip in unilateral slipped capital femoral epiphysis: posterior epiphyseal tilt increases and superior epiphyseal extension reduces risk. *J Bone Joint Surg Am* 2019 Feb 6;101(3):209–217, https://journals.lww.com/jbjsjournal/Abstract/2019/02060/Predicting_Risk_of_Contralateral_Slip_in.2.aspx. (b) Anterior and posterior epiphyseal angles. Starting at the centre of the femoral head, one line (yellow line) is drawn to the most anterior aspect of the femoral head and another (red line) is drawn to the most posterior aspect of the femoral head. The anterior epiphyseal angle is formed by the yellow line and the femoral neck axis, and the posterior epiphyseal angle is formed by the red line and the femoral neck axis. Reproduced with permission from Maranhão DA, Ferrer MG, Kim YJ, Miller PE, Novais EN. Predicting risk of contralateral slip in unilateral slipped capital femoral epiphysis: posterior epiphyseal tilt increases and superior epiphyseal extension reduces risk. *J Bone Joint Surg Am* 2019 Feb 6;101(3):209–217, https://journals.lww.com/jbjsjournal/Abstract/2019/02060/Predicting_Risk_of_Contralateral_Slip_in.2.aspx. (c) The PSA is the angle measured by the line along the plane of the physis and a line drawn perpendicular to a line running from a point in the center of the shaft of the femur to a point in the centre of the femoral neck on an axial view. Reproduced with permission from Springer: *Int Orthop*, Kohno Y, Nakashima Y, Kitano T, et al. Subclinical bilateral involvement of the hip in patients with slipped capital femoral epiphysis: a multicentre study. 2014.

Characteristic (ROC) curves for the cut-off value where the area under the curve (AUC) was maximized. Unadjusted logistic regression models were constructed with sequential SCFE as the outcome variable and the variables of interest as single dichotomous predictors. The AUC (c statistic) was derived for each logistic regression model and sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated.

Adjusted multivariate logistic regression was performed to create the final model upon which the Probability Analysis of Sequential SCFE (PASS) Score algorithm is based. Regression coefficients, adjusted odds ratios, 95% confidence intervals and adjusted p-values were determined. An adjusted p-value of less than 0.100 was considered acceptable for the final model. An ROC curve of the final model was constructed to assess the diagnostic performance of the combination of multivariate predictors in predicting sequential contralateral SCFE. The probabilities of sequential SCFE for each combination of predictors in the final model were calculated. Intra-rater reliability was assessed using a two-way random, single measures, absolute agreement (ICC (2,1)) model. A weighted point value was then assigned based on the strength of each predictor. Statistical analysis was performed with SPSS Statistics 26 (IBM Corp., Armonk, New York) and SAS Enterprise Guide 8.1 (SAS Institute, Cary, North Carolina) software packages.

Results

Univariate analysis

In total, 163 patients (88 male, 54%) with unilateral SCFE met the inclusion criteria. Of those, 65 patients (40%) developed contralateral, sequential SCFE at a mean of 9.8 ± 6.4 (range 0.5 to 27.9) months after the initial SCFE. Mean age at initial slip was younger in the sequential group (11.9 ± 1.3 , range 9.3 to 15.1 years) compared to the unilateral group (12.5 ± 1.6 , range 7.7 to 16.7 years) ($p = 0.025$). There appeared to be a significant association between lower BMI and developing sequential SCFE: mean BMI was lower in the sequential SCFE group compared to the unilateral group (26.2 and 28.0 kg/m², respectively, $p = 0.034$). This association may be attributable to the lower age at initial slip of the sequential group: no difference was found between groups when utilizing the CDC BMI-for-age percentiles when comparing means ($p = 0.398$) or the distribution of obese and overweight patients ($p = 0.735$); thus, BMI was excluded from further analysis. Neither initial side of involvement ($p = 0.159$) or classification of clinical stability ($p = 0.377$) were significantly different between the groups.

Analysis of radiographic factors revealed that 72% of the sequential cohort had an open or closing (grade I or II) triradiate status compared to only 34% of the unilateral cohort ($p < 0.001$). Risser staging showed that 19%

of the patients in the unilateral group had a Risser stage of one or higher, compared to only 3% of the patients in the sequential group ($p = 0.002$). The PSA of the affected

hip was not a significant individual predictor of sequential SCFE ($p = 0.200$), however the PSA of the unaffected hip was higher in the sequential group ($p < 0.001$) (Table 1).

Table 1 Univariate analysis

	Unilateral SCFE (N = 98)	Sequential SCFE (N = 65)	P-value
Age (mean \pm SD, years)	12.5 \pm 1.6	11.9 \pm 1.3	0.025 ^{**}
Sex			
Male (%)	47 (48)	41 (63)	0.058 ^{***}
Female (%)	51 (52)	24 (37)	
Initial side			
Right (%)	44 (45)	22 (34)	0.159 ^{***}
Left (%)	54 (55)	43 (66)	
Triradiate status			
Open (grade I and II) (%)	33 (34)	47 (72)	< 0.00 ^{****}
Closed (%)	65 (66)	18 (28)	
Risser stage			
0 (%)	79 (81)	63 (97)	0.002 ^{****}
1–4 (%)	19 (19)	2 (3)	
<i>N valid – unaffected hip</i>	98 (100%)	63 (97%)	
PEA	74.1 \pm 5.7 ^o	64.3 \pm 5.5 ^o	< 0.001 ^{**}
EER	0.72 \pm 0.04	0.65 \pm 0.05	< 0.001 ^{**}
PSA	9.3 \pm 5.7 ^o	15.6 \pm 6.4 ^o	< 0.001 ^{**}
<i>N valid – affected hip</i>	93 (95%)	61 (94%)	
Initial PSA (SCFE side)	43.1 \pm 17.0 ^o	39.7 \pm 16.8 ^o	0.200 ^{****}
<i>N valid</i>	93 (95%)	59 (91%)	
Calculated Southwick	33.8 \pm 15.8 ^o	24.5 \pm 16.1 ^o	<0.001 ^{****}
Southwick classification			
Mild (< 30 ^o) (%)	43 (46)	39 (66)	0.042 ^{****}
Moderate (30–50 ^o) (%)	35 (38)	16 (27)	
Severe (> 50 ^o) (%)	15 (16)	4 (7)	
<i>N valid (%)</i>	85 (87)	58 (89)	
Stability			
Stable (%)	67 (79)	42 (72)	0.377 ^{***}
Unstable (%)	18 (21)	16 (28)	
<i>N valid (%)</i>	73 (75)	48 (74)	
BMI (mean \pm SD, kg/m ²)	28.0 \pm 5.3	26.2 \pm 4.6	0.034 ^{****}
BMI percentiles			
Normal (5th to 85th) (%)	9 (12)	5 (10)	0.735 ^{***}
Overweight (85th to 94th) (%)	14 (19)	12 (25)	
Obese (\geq 95th) (%)	50 (69)	31 (65)	

EER, epiphyseal extension ratio; PEA, posterior epiphyseal angle; PSA, posterior sloping angle

^oIndependent samples T test,

^{**}Significant value

^{***}Chi-square test of proportions

^{****}Mann-Whitney U test

Table 2 Expanded univariate and multivariate analysis (7 variable model AUC = 0.959)

Variable	Selected predictive cut-off value	Unadjusted AUC [*]	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	Adjusted p-value
PEA	< 70 ^o	0.874	92.1	82.7	77.3	94.2	< 0.001 ^{**}
EER	< 0.70	0.778	84.1	71.4	65.4	87.5	< 0.001 ^{**}
PSA	15 ^o +	0.700	55.6	81.6	66.0	74.1	0.039 ^{**}
Calculated Southwick	< 20 ^o	0.627	45.8	79.6	58.7	69.8	0.167
Triradiate status	Open (grade I & II)	0.689	71.4	66.3	57.7	78.3	0.257
Risser stage	0	0.581	96.8	19.4	43.6	90.5	0.265
Age	< 14yr	0.532	92.1	14.3	40.8	73.7	0.971

EER, epiphyseal extension ratio; PEA, posterior epiphyseal angle; PSA, posterior sloping angle

^{*}Unadjusted AUC – area under the curve (c statistic in univariate logistic regression model)

^{**}Significant value

Seven independent variables were identified as significant individual predictors of sequential SCFE: age, triradiate status, Risser stage, calculated Southwick, PEA, EER and PSA. The unadjusted AUC provides the capability of each individual binary classifier to predict sequential SCFE. Sensitivity, specificity, PPV and NPV were also calculated (Table 2).

Multivariate analysis

A seven variable adjusted multivariate logistic regression model was assessed via an ROC curve (AUC = 0.959) indicating excellent diagnostic performance.¹⁸ Adjusted p-values revealed that calculated Southwick angle, triradiate status, Risser stage and age were no longer significant predictors of sequential SCFE (i.e. adjusted p > 0.100). Thus,

they were excluded from the final model. A final model based on three radiographic measurements of the contralateral, uninvolved hip was assessed via regression coefficients, adjusted odds ratios, 95% confidence intervals and adjusted p-values (Table 3). The odds of a sequential SCFE were approximately 73.6 times greater when the PEA was less than 70° than when it was greater than 70°, with the lower and upper confidence limits of that estimation at 16.8 and 333.2, respectively (Table 3). A ROC curve of the final multivariate model revealed that removing the four other variables did not affect diagnostic performance significantly (Δ AUC = -0.005). An AUC of 0.954 suggests that the model will correctly predict the chance of sequential SCFE with over 95% accuracy (Fig. 3).

The predicted probability of sequential SCFE was determined on the basis of eight possible combinations (2 x 2 x 2) of the three radiographic predictors: PEA, PSA and EER. A weighted point value was assigned to each predictor based on diagnostic performance. PEA was the strongest predictor and assigned a point value of three. EER and PSA were weaker and assigned point values of two and one, respectively. A simplified clinical decision-making algorithm for the management of the contralateral hip, called the Probability Analysis of Sequential SCFE (PASS score), is

Table 3 Final adjusted multivariate logistic regression model

Multivariate predictor	Regression coefficient	Adjusted odds ratio	95% Confidence Interval	Adjusted p-value
PEA (< 70°)	4.3	73.6	16.8–333.2	< 0.001
EER (< 0.70)	3.3	28.5	4.2–79.1	< 0.001
PSA (15° +)	1.2	3.2	0.93–11.1	0.065

EER, epiphyseal extension ratio; PEA, posterior epiphyseal angle; PSA, posterior sloping angle

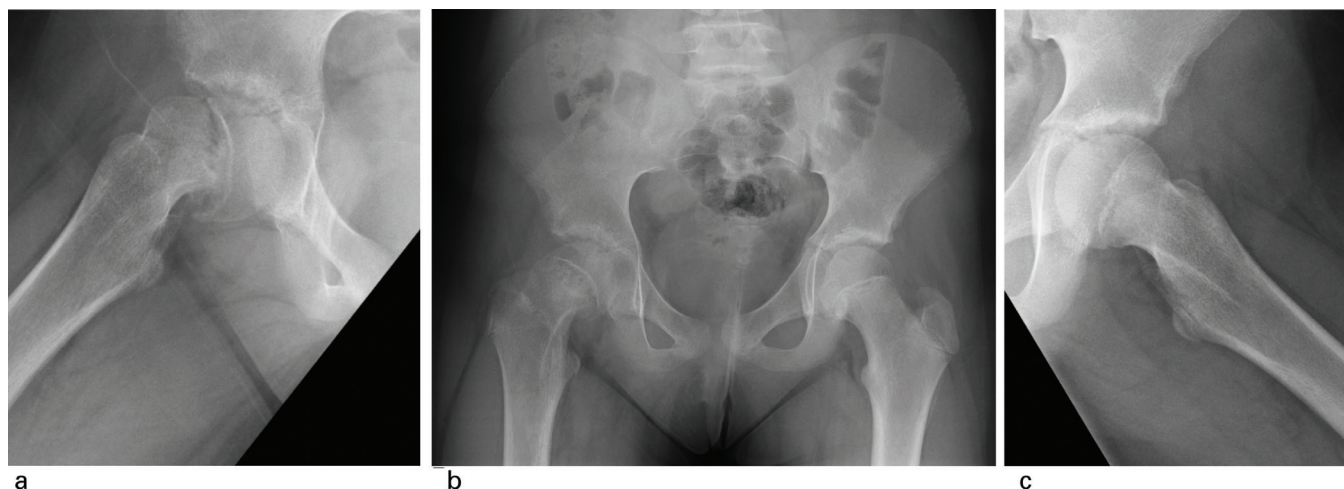


Fig. 3 AP Pelvis (a) and lateral (b,c) views of 12-year, four-month-old female with chronic, severe (61° slip angle), stable right SCFE. Left hip PASS score = six points (PEA = 62°, EER = 0.67, PSA = 19.2°).

Table 4 Probability Analysis of Sequential SCFE (PASS score)

Posterior epiphyseal angle (PEA)	Epiphyseal extension ratio (EER)	Posterior sloping angle (PSA)	Total score (points)	Probability of contralateral slip (%)
< 70° = 3 pts	< 0.70 = 2 pts	15°+ = 1 pt		
3	2	1	6	97.3
3	2	0	5	91.8
3	0	1	4	56.0
0	2	1	3	33.0
3	0	0	3	28.4
0	2	0	2	13.3
0	0	1	1	1.7
0	0	0	0	0.5

Table 5 Summary of current measurements comparing to previous studies

		Unilateral SCFE	Sequential SCFE	p-value	ICC (intra-rater)	95% confidence interval	ICC (inter-rater)
PEA	Current study	74.1 ± 5.7°	64.3 ± 5.5°	< 0.001	0.984	0.979–0.988	-
	Maranho et al ⁹	70.8 ± 7.1°	68.1 ± 8.2°	0.01	0.99	0.99–1.00	0.93
EER	Current study	0.72 ± 0.04	0.65 ± 0.05	< 0.001	0.928	0.903–0.946	-
	Maranho et al ⁹	0.71 ± 0.05	0.69 ± 0.05	0.001	0.96	0.94–0.98	0.83
PSA	Current study	9.3 ± 5.7°	15.6 ± 6.4°	< 0.001	0.992	0.989–0.994	-
	Park et al ⁸	10.6 ± 5.3°	14.5 ± 6.1°	0.001	0.966	0.954–0.975	-
	Kohnno et al ²²	14.3 ± 3.6	18.0 ± 3.6	0.005	0.89	-	0.82

shown in Table 4. Intra-rater reliability was excellent for all three radiographic measures (Table 5).

Discussion

The decision to perform prophylactic screw fixation on the contralateral hip in a patient who presents with a unilateral SCFE is controversial. Long-term studies have shown that even patients with mild deformity are at risk for subsequent labral tears and early arthrosis. However, the ability to predict sequential disease is critical since the surgeon must balance the iatrogenic risk associated with treating an otherwise normal hip against the perceived risk that the family will not reliably return for close radiographic monitoring of the uninvolved hip. Unfortunately, when conservative management is chosen, many families do not seek medical attention at the onset of pain in the contralateral limb despite warnings from the orthopedic providers. In some cases, even when proper precautions have been undertaken, sequential disease can occur without symptoms.

Previous studies have focused on the importance of age (chronologically and biologically) and on several radiographic parameters in an attempt to predict sequential SCFE. Riad et al¹⁹ demonstrated that age at diagnosis is a risk factor for sequential SCFE. Authors recommend prophylactic in situ screw fixation in all girls younger than ten years of age and all boys younger than 12 years of age at presentation. Stasikelis et al²⁰ showed a linear distribution between the modified Oxford bone score and the risk of sequential SCFE. For male gender patients, the age at the time of the initial SCFE was predictive of a sequential slip.

Several studies have demonstrated the significance of the posterior sloping angle (PSA) of the unaffected hip in predicting sequential SCFE.^{8,10,12,21,22} Park et al⁸ stated that PSA is predictive of sequential SCFE in patients presenting with unilateral SCFE. They recommend considering prophylactic screw fixation in females with PSA greater than 13° upon presentation. Bellemore et al,²³ in a bio-mechanical study, presented data that supported the

threshold of 15° PSA as an objective measure for prophylactic fixation of the contralateral hip.

Maranho et al⁹ recently found superior epiphyseal extension ratio (EER) to be an independent factor associated with the likelihood of a sequential SCFE: for each 0.01 increase in the superior epiphyseal extension ratio, the odds of a sequential slip decreased by 6%. Our data showed similar results with predictability of the EER, however slightly less predictive of sequential slip when compared to the PEA.

The average degree of initial SCFE severity was significantly higher in patients with unilateral SCFE compared with patients who subsequently developed a sequential SCFE. These findings correlate with previous data from Loder et al² who reported patients with unilateral SCFE had higher degree deformity at presentation than those with sequential disease (34° versus 21°). Our data produced similar results with an average Southwick angle of 25° versus 34° for sequential and unilateral groups. Comparative data are summarized in Table 5. However, because the PSA of the unaffected hip was higher in the sequential group, the calculated Southwick angle (PSA affected – PSA unaffected) may have been falsely decreased.

Aversano et al⁶ elucidated an association between BMI-for-age and risk for bilateral SCFE both at initial presentation and throughout the remaining growth period. They did not find a significant association between BMI-for-age and sequential slip after initial presentation. Nasreddine et al²⁴ found that patients whose BMI was decreased after initial slip were less likely to progress to bilateral SCFE.

In our study, mean BMI was lower in the sequential SCFE group compared to the unilateral group – 26.16 and 27.98 kg/m², respectively (p = 0.05). Using the BMI-for-age percentile, shown to be more effective in evaluating obesity in the paediatric population, no difference was found in the distribution of patients between the unilateral and sequential groups. We suggest that there is not enough evidence to support BMI as one of the predictors for sequential disease.

A previous study sought to utilize MRI to evaluate contralateral SCFE upon presentation.⁷ This study enrolled 33

patients from 2011 to 2013. In this study, six of 33 patients had positive MRI findings suggestive of a pre-slip. Of the six patients, four proceeded to sequential slip and two did not. Since 2013, subsequent results have shown that several patients in the 'normal MRI' cohort developed sequential SCFE. These patients are thought to represent true sequential disease rather than bilateral disease upon presentation. These outcomes were a driving force in the

development of a more inclusive scoring system to predict patients at risk for sequential SCFE.

In addition, some may argue that higher initial PSA measurements in the asymptomatic 'normal' hip could suggest subclinical, bilateral disease at presentation. However, normal MRI findings at presentation would suggest otherwise. Lack of significant statistical power prevents this study from such conclusion and further study

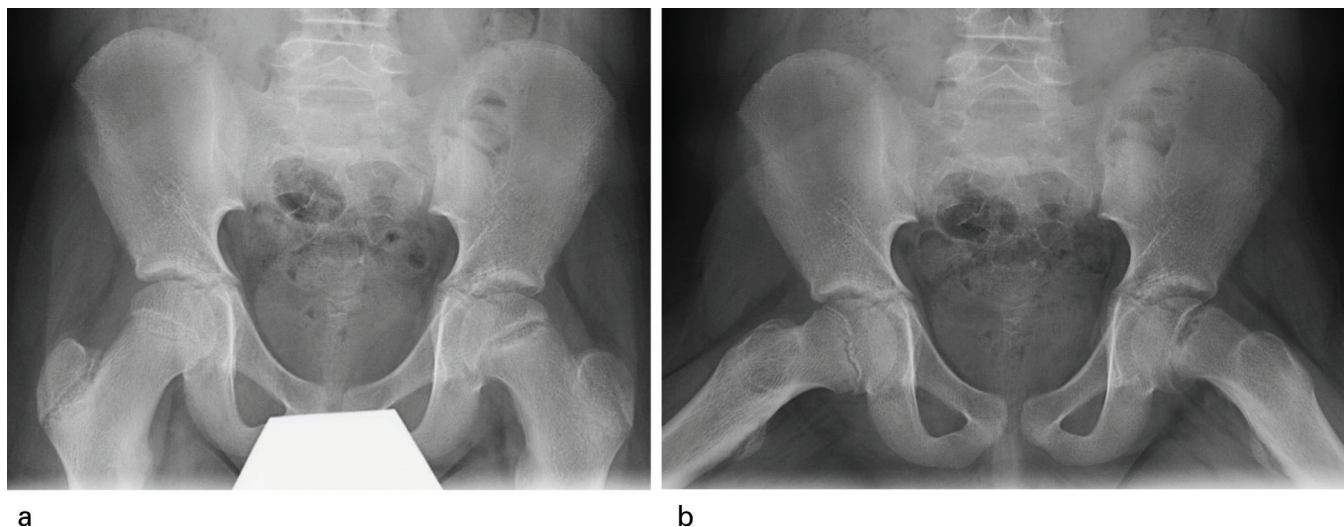


Fig. 4 Anteroposterior (a) and frog pelvis (b) radiographs of an 11-year, three-month-old male with chronic moderate (43° slip angle), stable left SCFE. Grade II open triradiate physis. Right hip measurements: PEA = 67°, EER = 0.60, PSA = 18.6° produce a total PASS score of six, suggestive of a 97% chance for sequential SCFE.

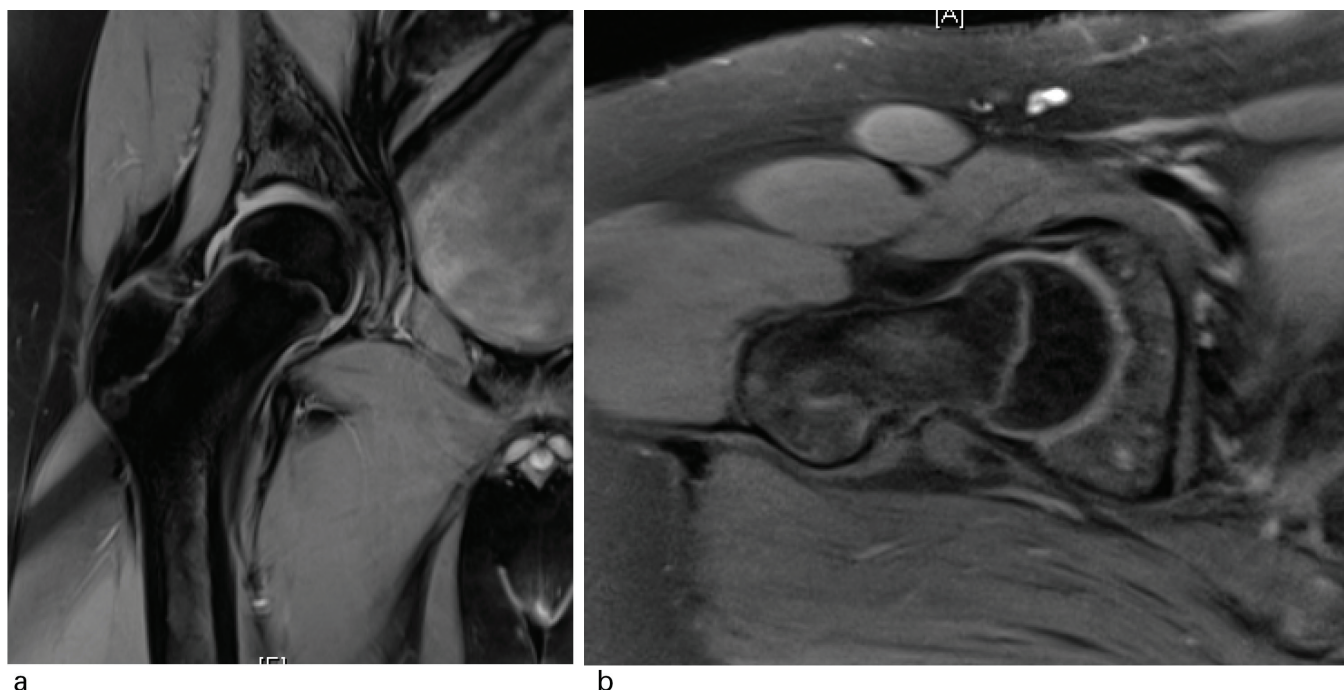


Fig. 5 MRI images of contralateral right hip seen in Figure 4 at time of left hip presentation suggest no evidence of pre-slip on radial and axial oblique fat suppression sequences.

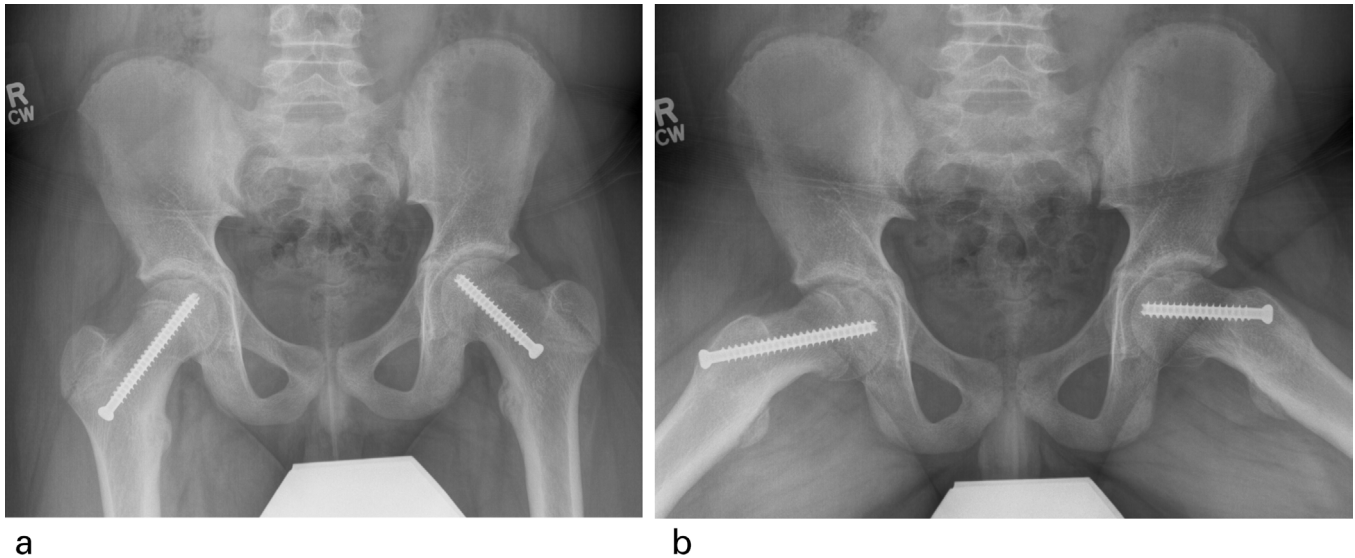


Fig. 6 Anteroposterior (**a**) and frog lateral (**b**) radiographs of patient seen in Figure 4 status post in situ pinning sequential right mild stable SCFE, 19 months following in situ pinning left SCFE.

is needed. Due to these factors, MRI is no longer used routinely in our institution to guide treatment of the contralateral hip and was not utilized in our statistical analysis (Figs. 4–6).

There are several limitations to this study. Due to its retrospective characteristics, the initial number of patients with SCFE decreased considerably – patients were excluded due to absent imaging studies and lack of adequate follow-up. BMI data were available for 75/98 (77%) from the unilateral group and 48/65 (74%) from the sequential group. Clinical stability was documented for 85/98 (87%) from the unilateral group and 58/65 (89%) from the sequential group. In addition, 31 (7.1%) of unilateral SCFE patients were treated with prophylactic pinning at the discretion of the treating surgeon(s) and therefore were removed from analysis. All such factors could potentially reduce the apparent impact of the common indications for prophylactic treatment including age and BMI. Nonetheless, this study comprises one of the largest reported cohorts of patients with sequential SCFE. A single reviewer of radiographic measurements may inherently lead to measurement inaccuracy and bias. However, this study and previous studies have shown strong intra-observer reliability for the measurements of PSA, PEA and EER (Table 5). Such studies have also shown strong inter-observer reliability. Furthermore, difficulty with radiographic reference points in obese patients requires both a significant time commitment and learning curve, and is aided by the radiographic system PACS, which is not universal at this time.

Although patients with open capital femoral physes were followed for a minimum of 24 months after the onset of unilateral SCFE, it is possible that patients in whom a sequential SCFE occurred after this period were

not captured. In our patient cohort, the mean time to the sequential SCFE was 9.7 months, with 95% of cases of subsequent SCFE occurring in the first 24 months after initial SCFE. These data are compatible with the literature in which approximately 90% of cases of sequential SCFE have been reported to occur in the first few months after the diagnosis of initial SCFE.²

Park et al suggested the difference in expected value between prophylactic pinning and observation was small.⁸ Kocher et al performed a systematic review to determine outcome probabilities and to construct an expected-value decision analysis on the utility of prophylactic pinning of the contralateral hip after unilateral SCFE. Their results suggested that in the absence of endocrinopathy, renal disease or unreliable follow-up, a probability of sequential disease exceeding 27% favours prophylactic pinning. The authors advocated a shared decision-making model between physician and patient. Given these data, clinical or radiographic methods of quantitatively assessing the risk of contralateral SCFE would be helpful to the clinician in deciding whether to observe or prophylactically pin the contralateral hip. A PASS score of three or higher suggests a 28% or higher probability of sequential SCFE, above the published threshold for prophylactic pinning.²⁵

Conclusion

There are several independent variables associated with sequential SCFE including triradiate status, Risser staging, initial SCFE severity, PSA, EER and PEA. Utilizing the radiographic measurements of the PSA, EER and PEA creates a clinically significant probability model for risk of the contralateral hip. A PASS score of three or greater predicts a

high probability (28% +) of sequential SCFE and therefore may favour prophylactic screw fixation.

Received 20 April 2020; accepted after revision 14 July 2020

COMPLIANCE WITH ETHICAL STANDARDS

FUNDING STATEMENT

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

OA LICENCE TEXT

This article is distributed under the terms of the Creative Commons Attribution-Non Commercial 4.0 International (CC BY-NC 4.0) licence (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed.

ETHICAL STATEMENT

Ethical approval: This study was approved by our Institutional Review Board. 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.

Informed consent: This retrospective study did not require informed consent.

ICMJE CONFLICT OF INTEREST STATEMENT

CAI reports personal fees from Nuvasie, Orthofix and Smith and Nephew, outside the submitted work.

The other authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

BD: Substantial contributions to the conception and design of the work, Acquisition, analysis and interpretation of the data, Drafting of the work.

SS: Substantial contributions to the conception and design of the work, Acquisition, analysis and interpretation of the data, Drafting of the work, Critical revisions to the manuscript.

JS: Substantial contributions to the conception and design of the work, Acquisition, analysis and interpretation of the data, Drafting of the work.

JY: Substantial contributions to the conception and design of the work, Acquisition, analysis and interpretation of the data, Drafting of the work.

WPS: Substantial contributions to the conception and design of the work, Acquisition, analysis and interpretation of the data, Drafting of the work; critical revisions to the manuscript.

CAI: Substantial contributions to the conception and design of the work, Acquisition, analysis and interpretation of the data, Drafting of the work, Critical revisions to the manuscript.

KEK: Substantial contributions to the conception and design of the work, Acquisition, analysis and interpretation of the data, Drafting of the work, Critical revisions to the manuscript.

REFERENCES

- Hägglund G, Hansson LI, Ordeberg G, Sandström S.** Bilaterality in slipped upper femoral epiphysis. *J Bone Joint Surg [Br]* 1988;70:179-181.
- Loder RT, Aronson DD, Greenfield ML.** The epidemiology of bilateral slipped capital femoral epiphysis. A study of children in Michigan. *J Bone Joint Surg [Am]* 1993;75:1141-1147.

- Hägglund G.** The contralateral hip in slipped capital femoral epiphysis. *J Pediatr Orthop B* 1996;5:158-161.
- Castro FP Jr, Bennett JT, Douzens K.** Epidemiological perspective on prophylactic pinning in patients with unilateral slipped capital femoral epiphysis. *J Pediatr Orthop* 2000;20:745-748.
- Popejoy D, Emara K, Birch J.** Prediction of contralateral slipped capital femoral epiphysis using the modified Oxford bone age score. *J Pediatr Orthop* 2012;32:290-294.
- Aversano MW, Moazzaz P, Scaduto AA, Otsuka NY.** Association between body mass index-for-age and slipped capital femoral epiphysis: the long-term risk for subsequent slip in patients followed until physeal closure. *J Child Orthop* 2016;10:209-213.
- Balch Samora J, Adler B, Druhan S, et al.** MRI in idiopathic, stable, slipped capital femoral epiphysis: evaluation of contralateral pre-slip. *J Child Orthop* 2018;12(5):454-460.
- Park S, Hsu JE, Rendon N, Wolfgruber H, Wells L.** The utility of posterior sloping angle in predicting contralateral slipped capital femoral epiphysis. *J Pediatr Orthop* 2010;30:683-689.
- Maranho DA, Ferrer MG, Kim YJ, Miller PE, Novais EN.** Predicting Risk of Contralateral Slip in Unilateral Slipped Capital Femoral Epiphysis: Posterior Epiphyseal Tilt Increases and Superior Epiphyseal Extension Reduces Risk. *J Bone Joint Surg [Am]* 2019;101:209-217.
- Phillips PM, Phadnis J, Willoughby R, Hunt L.** Posterior sloping angle as a predictor of contralateral slip in slipped capital femoral epiphysis. *J Bone Joint Surg [Am]* 2013;95:146-150.
- Barrios C, Blasco MA, Blasco MC, Gascó J.** Posterior sloping angle of the capital femoral physis: a predictor of bilaterality in slipped capital femoral epiphysis. *J Pediatr Orthop* 2005;25:445-449.
- Zenios M, Ramachandran M, Axt M, Gibbons PJ, Peat J, Little D.** Posterior sloping angle of the capital femoral physis: interobserver and intraobserver reliability testing and predictor of bilaterality. *J Pediatr Orthop* 2007;27:801-804.
- Morris WZ, Napora JK, Conry KT, Liu RW.** Capital femoral epiphyseal extension may confer physeal stability in slipped capital femoral epiphysis. *J Pediatr Orthop* 2019;39:119-124.
- Loder RT, Richards BS, Shapiro PS, Reznick LR, Aronson DD.** Acute slipped capital femoral epiphysis: the importance of physeal stability. *J Bone Joint Surg [Am]* 1993;75:1134-1140.
- Centers for Disease Control and Prevention.** BMI Percentile Calculator for Child and Teen; 2019. <https://www.cdc.gov/healthyweight/bmi/calculator.html> (date last accessed 19 February 2020).
- Centers for Disease Control and Prevention.** Defining Childhood Obesity; 2018. <https://www.cdc.gov/obesity/childhood/defining.html> (date last accessed 19 February 2020).
- Hacquebord JH, Leopold SS.** In brief: The Risser classification: a classic tool for the clinician treating adolescent idiopathic scoliosis. *Clin Orthop Relat Res* 2012;470:2335-2338.
- Carter JV, Pan J, Rai SN, Galandiuk S.** ROC-ing along: evaluation and interpretation of receiver operating characteristic curves. *Surgery* 2016;159:1638-1645.
- Riad J, Bajelidze G, Gabos PG.** Bilateral slipped capital femoral epiphysis: predictive factors for contralateral slip. *J Pediatr Orthop* 2007;27:411-414.

20. **Stasikelis PJ, Sullivan CM, Phillips WA, Polard JA.** Slipped capital femoral epiphysis. Prediction of contralateral involvement. *J Bone Joint Surg [Am]* 1996;78:1149-1155.
21. **Mestriner MB, Verquietini CM, Waisberg G, Akkari M, Fukunaga ET, Santili C.** Radiographic evaluation in epiphysiolysis: possible predictors of bilaterality? *Acta Orthop Bras* 2012;20:203-206.
22. **Kohno Y, Nakashima Y, Kitano T, et al.** Subclinical bilateral involvement of the hip in patients with slipped capital femoral epiphysis: a multicentre study. *Int Orthop* 2014;38:477-482.
23. **Bellemore JM, Carpenter EC, Yu NY, Birke O, Little DG.** Biomechanics of slipped capital femoral epiphysis: evaluation of the posterior sloping angle. *J Pediatr Orthop* 2016;36:651-655.
24. **Nasreddine AY, Heyworth BE, Zurakowski D, Kocher MS.** A reduction in body mass index lowers risk for bilateral slipped capital femoral epiphysis. *Clin Orthop Relat Res* 2013;471:2137-2144.
25. **Kocher MS, Bishop JA, Hresko MT, Millis MB, Kim YJ, Kasser JR.** Prophylactic pinning of the contralateral hip after unilateral slipped capital femoral epiphysis. *J Bone Joint Surg [Am]*. 2004;86:2658-2665.