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Correlation of functional and radiological results with three-dimensional gait analysis in patients with unilateral slipped capital femoral epiphysis

Femur başı epifiz kayması tanılı hastalarda klinik ve radyolojik sonuçların yürüme analizi ile korelasyonu

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ABSTRACT

Aim: The aim of this study was to evaluate the correlation between gait analysis and clinical and radiographic results in patients operated for slipped capital femoral epiphysis (SCFE).
Materials and Methods: This study included 31 patients with unilateral SCFE. The mean follow-up time was 3.3 ± 1.4 years. Harris hip score (HHS) and the Pediatric Outcomes Data Collection Instruments (PODCI) scores were collected. Slip-angle, alpha-angle, lateral femoral head ratio (LFHR), articulotrochanteric distance (ATD), anteroposterior plane femoral head ratio (AP-FHR), anterior head-neck offset ratio (HNOR), and neck-shaft angle (NSA) were measured. An age-matched control group consisting of 20 healthy individuals was used for comparison.
Results: Transfer and basic mobility subscale of PODCI was correlated with pelvis tilt ROM (r = −0.7, p < 0.001), foot progression angle (FPA) ROM (r =−0.4, p=0.02), and mean spine tilt (r=−0.6, p<0.001). FPA was also correlated with the HHS (r=−0.5, p<0.001) and pain/comfort subscale of PODCI (r=−0.5, p=0.015). Significant correlations were detected between LFHR and mean hip flexion (r=−0.5, p<0.001), pelvic tilt (r=−0.4, p=0.04), and mean spine tilt (r=0.6, p<0.001). Correlations between ATD and mean internal rotation of the hip (r=0.5, p=0.03) and mean dorsal ankle extension (r=−0.4, p=0.03) were also significant. No significant correlation was found between the alpha angle, AP-FHR, and HNOR with the kinematic values.
Conclusion: Clinical scores of patients treated for SCFE were mostly correlated with pelvic tilt ROM, FPA, and spine tilt. LFHR and ATD were observed as the most critical radiological measurements related to a patient's gait function.

Key Words: Gait analysis, slipped capital femoral epiphysis, radiologic correlation, clinical correlation, impingement

ÖZ

Amaç: Bu çalışmanın amacı femur başı epifiz kayması (FBEK) nedeniyle opere edilen hastalarda yürüme analizi ile klinik ve radyolojik sonuçların korelasyonunu değerlendirmekti.
Hastalar ve Yöntem: Bu çalışmaya ortalama takibi 3.3 ± 1.4 yıl olan tek taraflı FBEK tanısıyla opere edilen 31 hasta dahil edildi. Klinik değerlendirme Harris kalça skoru (HKS) ve Pediatrik Veri Toplama Aracı (PVTA) skoru ile yapıldı. Radyolojik değerlendirme için kayma açısı, alpha alçısı, lateral femur başı oranı, artikulotrokanterik mesafe (ATM), ön-arka planda femur başı oranı, anterior baş-boyun offset oranı ve boyun şaft açısı ölçümü yapıldı. Yaş eşleşmeli 20 sağlıklı bireyden kontrol grubu oluşturuldu.
Bulgular: PVTA transfer ve temel mobilite alt ölçeği; pelvis tilt eklem hareket açıklığı (EHA) (r = −0.7, p <0.001), ayak ilerleme açısı EHA (r =−0.4, p=0.02) ve ortalama omurga tilti (r=−0.6, p<0.001) ile anlamlı korelasyon gösterdi. Ayrıca ayak ilerleme açısı ile HKS (r=−0.5, p<0.001) ve PVTA ağrı/konfor alt ölçeği anlamlı korelasyon gösterdi (r=−0.5, p=0.015). Lateral femur başı oranı ile ortalama kalça fleksiyonu (r=−0.5, p<0.001), pelvik tilti (r=−0.4, p=0.04) ve ortalama omurga tilti (r=0.6, p<0.001) koreleydi. ATM ile ortalama kalça iç rotasyonu (r=0.5, p=0.03) ve ortalama ayak bileği ekstansiyonu (r=−0.4, p=0.03) koreleydi. Alfa açısı, Ön-arka femur başı oranı ve anterior baş boyun ofsetinin kinematik değerlerle korelasyonu gösterilemedi.
Sonuç: FBEK nedeniyle opere edilen hastalarda klinik skorlar çoğunlukla pelvik tilt EHA, ayak ilerleme açısı ve omurga tilti ile korelasyon gösterirken, radyolojik sonuçlardan lateral femur başı oranı ve ATM'nin yürüme fonksiyonu ile ilişkili olduğu anlaşılmıştır.

Anahtar kelimeler: yürüme analizi, femur başı epifiz kayması, eklem kinematiği, radyolojik korelasyon, klinik korelasyon, sıkışma

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INTRODUCTION

Slipped capital femoral epiphysis (SCFE) is one of the most common hip joint pathologies during the adolescence period [1]. After in situ pinning, three planar residual deformities occur according to the degree of slip [2]. Residual deformities can be summarized as femoroacetabular impingement, shortening of the femoral neck, femoral anteversion loss, and metaphyseal changes in the anterior and superior part of the neck [3]. These deformities affect the functional capacity of patients and pose a risk for hip osteoarthritis [3]. Major operations, such as osteotomy or debridement, are performed to treat newly occurred deformities after slippage, with the guidance of clinical examination and radiological evaluation. However, imaging is a static measure and range of motion tests are not performed under loaded activities of daily living. Afterwards, for surgeries (including in situ pinning and thereafter osteotomy or debridement), patient scores are useful in addressing short-term benefits, but require subjective patient feedback for their assessment and might not be useful indicators of longer-term outcomes [4-6]. All these issues cause the functional outcome of treatment to be ignored [7]. After the closure of the epiphysis, current assessment methods are inadequate to evaluate first, the effect of functional outcomes, and then the impact of residual deformity in the proximal femur on movement [8,9].

Gait is the most common repetitive voluntary movement of the lower limbs and essential activity of daily living. Correlation of the clinical and radiological results of deformity after slippage with gait analysis (GA), which provides a better understanding of the functional results, may lead to a better evaluation of indications of future joint preservation surgeries. There are a limited number of studies on the evaluation of patients with SCFE by objective methods such as GA [8, 10-12].

The aim of this study was to evaluate the correlation between GA and clinical and radiographic results in patients operated for SCFE.

MATERIALS and METHODS

Between 2005 and 2013, the records of patients who underwent in situ pinning surgery with a diagnosis of SCFE were analyzed retrospectively on a computerized patient record system. Thirty-one patients with chronic unilateral SCFE (Figure 1.) were included in the study, and 45 patients were excluded. Criteria for exclusion were as follows: clinically or radiologically bilateral slip at the time of first admission or follow-up (n = 14), open reduction or osteotomy (n = 11), history of revision surgery, less than 2 years of follow-up (n = 6), presence of musculoskeletal system disease developing primary or secondary gait disturbance such as fracture or scoliosis (n = 3), development of avascular necrosis (AVN) (n = 3), and chondrolysis (n = 1) complications. We also excluded two patients who did not take the GA test and five patients who did not visit the outpatient clinic regularly. In addition, the study was approved by the Institutional Review Board (IRB) (2014).

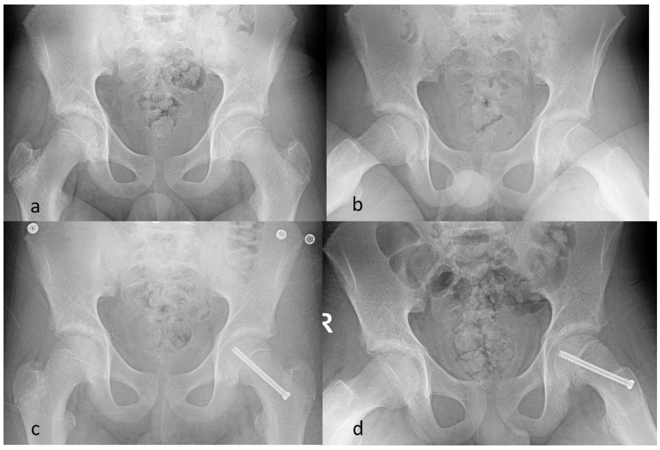

Figure 1 - One of our patients treated with in situ pining. a-b: preoperative anteroposterior and lateral view of healthy and slipped hips. c-d: postoperative anteroposterior and lateral view of healthy and slipped hips.

A full body GA was performed using a the Vicon Bonita System (Oxford Metrics Ltd., Oxford, England) in all patients. Three records that were compatible with each other and the highest patient compliance were included in the study. Averages of these three selected records were used in statistical calculations. The minimum and maximum values were calculated from the peak values in the direction of movement in the stance phase.

The mean age of patients when gait analyses were performed was 16.5 ± 2.5 years, and mean body mass index (BMI) was 27.78±5.6 kg/m2. A control group was formed of volunteers whose mean age was 17.84 ± 1.47 years (range, 16-20), with a mean BMI of 27.72±2.61 kg/m2. The SCFE and control groups were similar in age (p = 0.51) and BMI (p = 0.21). The control group (7 females, 13 males) consisted of healthy individuals without any gait-influencing disorder. The neurological examination, including spasticity and motor strength, as well as the limb length discrepancy were also evaluated before the gait exam in both groups. A scoliosis screening test, examination for tibia rotational deformity, hip, knee and ankle joint contractures were routinely performed in both groups. We also evaluated hip, knee, ankle, and foot joints angular measurements with goniometer. Hip flexion, hip joint flexion contracture, hip internal rotation (IR) and hip external rotations (ER), and hip abduction and adduction exams were performed in the supine position, whereas hip extension and femoral anteversion were assessed in the prone position. The two groups were clinically examined on the same day as the GA, by an experienced physiotherapist and senior orthopedic surgeons.

The Harris Hip Score (HHS) and the Pediatric Outcomes Data Collection Instruments (PODCI) score were used to measure the quality of life and physical function of patients.

The deformity analysis of the proximal femur was performed by the following x-ray views:

1.Slip-angle: anteroposterior (AP) and Lateral (LAT) view of hip [13]

2. Femoral head ratio (FHR): AP view of pelvis AP (Figure 2.) [3]

3. Lateral femoral head ratio (LFHR): LAT view of hip (Figure 2.) [14]

4. Alpha angle: AP and LAT view of hip (Figure 3.) [15, 16]

5. Anterior femoral head-neck offset ratio (HNOR): LAT view of hip (Figure 3.) [17]

6. Articulotrochanteric distance (ATD): AP view of pelvis; and

7. Femoral neck-shaft angle (NSA): AP view of hip [18]

Southwick slip-angles were measured both preoperatively and 6 months postoperatively, whereas other radiological measurements were performed while x-rays were being taken on the same day of GA.

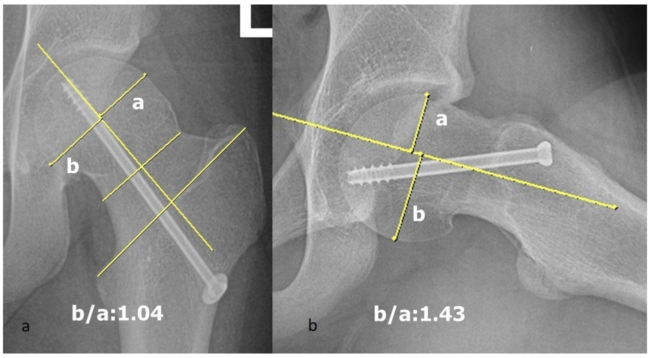

Figure 1 - One of our patients treated with in situ pining. a-b: preoperative anteroposterior and lateral view of healthy and slipped hips. c-d: postoperative anteroposterior and lateral view of healthy and slipped hips.

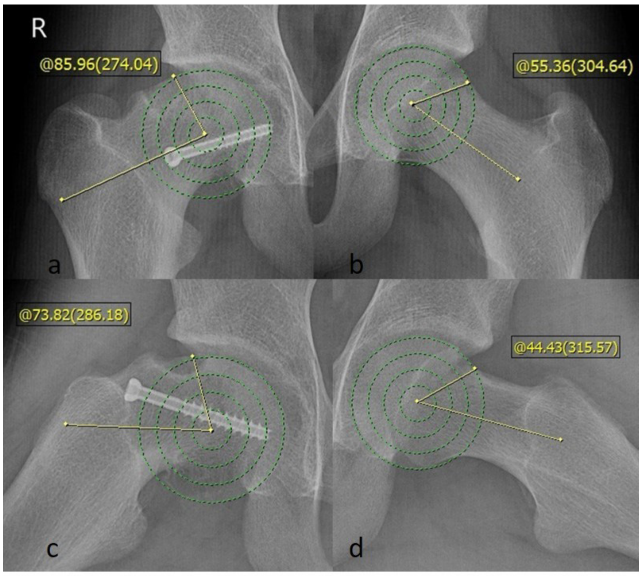

Figure 3 - a-b: Alpha angle measurement method on anteroposterior plane of slipped hip and healthy hip. c-d; Alpha angle measurement method on lateral plane of slipped hip and healthy hip.

Replicate measurements correlated significantly between observers. Values of correlation coefficients between two different measurements that ranged between 0.88 and 0.99 were acceptable.

Statistical analysis

The resulting data was analyzed using the IBM Statistics 19.5 (SPSS Inc., IBM, IL, USA). Kurtosis and skewness values were used to analyze the distribution of data. Kinetic and kinematic data of the SCFE and control groups were compared with an independent t-test. All GA data was correlated

Table 1. Statistically significant gait deviations between SCFE patients after epiphysis closure and control group

Kinematic variables	Group	Mean (SD)	Mean Difference	95% CI of the Difference	Sig. (2-tailed)
Pelvis tilt ROM	SCFE	3.5 (1.5)	1.2	0.5 / 1.8	<0.01
	Control	2.3 (0.5)			
Hip flexion ROM	SCFE	35.1 (3.7)	-4.6	-6.8 /-2.3	<0.01
	Control	39.8 (4.6)			
Min. pelvic obliquity	SCFE	-3.1(1.9)	2.7	1.7 / 3.8	<0.01
	Control	-5.7 (1.8)			
Max. pelvic obliquity	SCFE	2.4 (1.8)	-1.2	-2.3 / -0.1	0,02
	Control	3.6 (1.9)			
Pelvis obliquity ROM	SCFE	5.5 (2.3)	-3.9	-5.4 / -2.5	<0.01
	Control	9.5 (2.8)			
Min. Hip abduction	SCFE	-4.01 (3.1)	3.6	1.8 / 5.4	<0.01
	Control	-7.6 (3.5)			
Hip abduction ROM	SCFE	10.8 (2.9)	-2.1	-3.8 / -3.3	0,02
	Control	12.9 (3.4)			
Max. knee abduction	SCFE	10.8 (5.8)	1.8	-1.9 / 5.5	0,03
	Control	6.5 (7.9)			
Knee Abduction ROM	SCFE	15.2 (6.1)	4.4	0.9 / 7.9	0,01
	Control	10.7 (6.9)			
Mean FPA	SCFE	-11.1 (7.7)	-5.9	-9.9 / -1.9	0,01
	Control	-5.2 (6.5)			
Min. FPA	SCFE	-14.2 (8.1)	-5.9	-10.2 / -1.6	<0.01
	Control	-8.3 (7.5)			
Max. FPA	SCFE	-6.3 (8.1)	-5.5	-9.4 /-1.6	0,02
	Control	-0.9 (6.1)			
Ankle rotation ROM	SCFE	31.2 (1.7)	8.2	3.4 / 13.1	0,01
	Control	22.9 (6.7)			
Mean thorax tilt	SCFE	5.6 (5.4)	4.2	1.5 / 6.9	<0.01
	Control	1.4 (4.4)			
Min. thorax tilt (towards swinging limb)	SCFE	3.7 (5.9)	4.9	2.2 / 7.7	<0.01
	Control	-1.2 (4.4)			
Max. thorax tilt (towards supporting limb)	SCFE	7.4 (5.7)	4	1.2 / 6.9	<0.01
	Control	3.4 (4.3)			
Spine tilt ROM	SCFE	5.1 (3.3)	-2.8	-4.5 / -0.9	0,02
	Control	7.8 (3.4)			

The joint kinematic values of the SCFE patients and control group were compared between the axial, frontal, and sagittal planes, but statistically significant differences were noted only in the table. SD= standard deviation; CI = Confidence interval; ROM = range of motion; FPA = foot

with radiological and clinical findings using Pearson's correlation test. A value of $p < 0.05$ was considered statistically significant.

RESULTS

The mean age of patients (1 female, 30 males) at the time of surgery who were included in the study was 13.5 ± 2.2 years and mean follow-up was 3.3 ± 1.4 years.

At the last follow-up, the slip side hip range of motion (ROM) was measured as follows: mean hip flexion 118.2^{0}(100–140), mean hip extension 280(20–35), mean hip abduction 50.1^{0}(45–60), mean hip adduction 45.4^{0}(35–50), mean hip internal rotation (IR) 28^{0}(0–50), mean hip external rotation (ER) 51^{0}(45-60).

According to the control group, statistically significant gait deviations are presented in Table 1. We did not observe any statistically significant difference in kinetic measurements, cadence, step

Table 2. Significant correlations of patient scores with gait analyses Statistically significant correlations were noted only in the table.

Patient scores	Mean score (SD)	Pearson Correlation	Pelvis tilt ROM	Min. hip flexion	FPA ROM	Ankle rotation ROM	Mean spine tilt	Min. spine tilt towards supporting limb	Max. spine tilt towards swinging limb	Step width
Transfer & Basic Mobilitya	97 (4)	Coef.	-0.7**		-0.4*		-0.6**	-0.5**	-0.5**	
		Sig. (2-tailed)	<0.01		0.02		<0.01	<0.01	<0.01	
Sports and Physical Functioninga	85 (12)	Coef.	-0.6**		-0.5**	-0.4*	-0.6**	-0.6**	-0.5**	
		Sig. (2-tailed)	<0.01		<0.01	0.04	0	<0.01	<0.03	
Pain/Comforta	75 (17)	Coef.			-0.5*					
		Sig. (2-tailed)			0.015					
Happinessa	82 (17)	Coef.			-0.5*					
		Sig. (2-tailed)			0.01					
Global functioninga	9 (8)	Coef.	-0.6**		-0.5**		-0.5**	-0.5**	-0.4*	
		Sig. (2-tailed)	<0.01		<0.01		<0.01	0.01	0.02	
Harris hip score	96 (6)	Coef.		0.4*	-0.5**					-0.4*
		Sig. (2-tailed)		0.04	0.01					0,05

aAdolescent (parent and self report) Pediatrics Outcomes Data Collection Instrument-Lower extremity outcome scales of standardized means; SD= standard deviation; ROM = range of motion; FPA = foot progression angle; min.= minimum; max = maximum. * = Correlation is significant at the 0.05 level (2-tailed). **= Correlation is significant at the 0.01 level (2-tailed).

Table 3. Radiologic correlations with kinematic parameters

Kinematic parameters	Lateral femoral head ratio		Articulo-trochanteric Distance		Femoral neck – shaft angle	
	Pearson Correlation	Sig. (2-tailed)	Pearson Correlation	Sig. (2-tailed)	Pearson Correlation	Sig. (2-tailed)
Min. Pelvic tilt	-0.4*	0.04				
Mean hip flex	-0.5**	<0.01				
Min. hip flex	-0.4*	0.02				
Max. hip flex	-0.5**	<0.01				
Mean knee flex	-0.4*	0.01				
Min. knee flex	-0.4*	0.02				
Mean dorsal ankle extension			-0.4*	0.03		
Max. dorsal ankle extension	-0.4*	0.03				
Max. knee abd. angle			0.4*	0.02		
Knee abd. ROM			0.4*	0.03		
Mean internal rotation of hip			0.5*	0.03	0.4*	0.04
Min. internal rotation of hip			0.4*	0.04		
Max. internal rotation of hip			0.4*	0.04	0.4*	0.04
Mean spine tilt	0.6**	<0.01				
Min. Spine tilt towards supporting limb	0.6**	<0.01				
Max. spine tilt towards swinging limb	0.6**	<0.01				

ROM = range of motion; FPA = foot progression angle; min.= minimum; max = maximum; abd =abduction; flex = flexion; CC; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

width, and gait velocity.

The PODCI score standardized means with HHS obtained at the patient's last controls and the correlations of these scores with the GA, are shown in Table 2. Our results demonstrated that pelvis tilt ROM, FPA ROM, mean spine tilt, min. and max. spine tilt, were significantly correlated with at least three subscales of PODCI scores. In addition, min. hip flexion, FPA ROM, and step width were significantly correlated with HHS.

In the radiological deformity analysis, measurement of variables represented as mean ± standard deviation were as follows: pre-operative AP Southwick slip-angle was 19.7±14.2, pre-operative lateral Southwick slip-angle was 32.7±16, post-operative AP Southwick slip-angle was 14.5±9, post-operative lateral Southwick slip-angle was 23.4±15.29, AP Femoral Head Ratio was 1.3 ±0.2, lateral Femoral Head Ratio was 1.9±0.7, articulotrochanteric distance was 11.8±6.79, AP plane alpha angle was 73.4±15.9, lateral plane alfa angle was 64.8±16.1, anterior Head-Neck Offset Ratio was 0.04±0.07, femoral neck-shaft angle was 127.8±6.1. A significant correlation was found between the AP plane Southwick slip-angle and mean knee flexion ($r = -0,357$ $p < 0.05$), thorax tilt ROM ($r = 0.385$, $p < 0.05$), and walking speed ($r = 0.379$, $p < 0.05$). A significant correlation was found only with walking speed ($r = 0.514$, $p < 0.01$) for the lateral plane Southwick slip-angle. No significant correlation was found between the AP and Lat. plane of the alpha angle, AP-FHR, and HNOR with kinematic values. Correlations of ATD, NSA, and LFHR with the transverse plane, sagittal plane, and spinal kinematics were notable (Table 3).

DISCUSSION

According to our current knowledge, in patients with chronic SCFE, complex deformity occurs after in situ pinning [2]. The femoral neck becomes shorter due to premature epiphysiodesis, and the greater trochanter continues to grow. Another controversial subject is the femoral neck/shaft angle measurement, and alpha angle measurement in these patients whose femoral head's center of rotation has changed. These measurements should be different from the traditional description because in the latter, the femoral head is centralized on the femoral neck, whereas in SCFE patients, the femoral head is not centralized on the femoral neck [19]. This situation has not been questioned and discussed previously in the literature in patients with SCFE. The determination of gait disorders by GA and identification of which gait abnormalities correlate with the radiological deformity will enable the radiological deformity to both target and guide treatment.

In our patient group, whereas the pelvis tilt ROM increased, the hip flexion-extension ROM, max. knee flexion, knee flexion-extension ROM significantly decreased. Although differences in mean, minimum, and maximum hip flexion were observed, they were not statistically significant. These differences, however, resulted in a statistically significant difference in hip flexion/extension ROM. While the coronal plane of pelvis ROM and hip ROM decreased significantly, a significant increase in coronal plane knee abduction-adduction ROM was detected. In addition, our findings seem to be consistent with studies with a similar group of patients that was operated on for SCFE. Westhoff et al. reported a significant increase in pelvis sagittal ROM, and significant decreases in both hip sagittal and knee flexion ROM [8]. While Sangeux et al. found slight gait deviations from the normal in the sagittal plane during the entire gait cycle, they reported an increase in pelvic obliquity during the swing phase [12]. Song et al. observed that as long as the degree of slip increased, pelvic obliquity also increased [10]. The most notable gait deviation in the transverse plane was detected in the rotation of the foot in our study. The increase in foot rotation ROM was not significant, but a significant increase in the foot mean-max-min. ER was detected. The increase in the FPA may have been caused by retroversion of the proximal femur and the orientation of the hip toward ER posture to protect itself from metaphyseal impaction of the proximal femur [20]. There was a significant increase in the mean and min.-max. tilt in thorax kinematics, but a significant decrease was found in thorax tilt ROM. The significant decrease in spine tilt ROM in our study was similar to the study by Westhoff et al. who reported a significant decrease in spine ROM compared with the pelvis [8].

The inverse correlation of PODCI and HHS scores with kinematic data especially with pelvic tilt ROM, FPA ROM, and spine tilt is remarkable. In Westhoff et al.'s study, clinical dissatisfaction was found to be positively correlated with the decrease in sagittal plane hip ROM and the decrease in pelvic obliquity [7]. However, in this study, the variety of treatments, especially osteotomy, may have caused differences in the expected proximal femoral deformity in patients. Song et al. observed that patients with mild and severe slip who had in situ pinning, showed correlation with both pain and function in the patients grouped according to the degree of slippage, but this was not statistically significant [10]. The impact of remodeling or metaphyseal changes in both hip joint kinematics and acquired patient scores may explain this besides the slip-angle [21].

In our study, the slip-angle in the AP plane showed a positive correlation with the mean knee flexion, thorax tilt ROM, and gait velocity, but it showed a positive correlation with only gait velocity in the lateral plane. The highest correlation between GA and radiological measurements was found between the LFHR and the ATD in our study. In a similar study, Song et al. reported that as the slip-angle increased, both pelvic obliquity and trunk obliquity increased, and during the gait cycle, the hip was mostly in the extension, adduction, and ER posture [10]. They also found a decrease in knee flexion and an increase in ER of foot progression with increased slip-angle. Westhoff et al. noted that the strength of the correlation between step size, sagittal pelvis ROM, and FPA increased with the poor radiological index [8]. In a similar study in which patients with a slip-angle less than 30° were excluded, Sangeux et al. reported that kinematic values were not correlated with radiometric measurements (i.e., alpha angle, slip-angle) [12]. This might be, as they expressed, because of the exclusion of patients with a mild slip from the study, which may have led to the accumulation of high levels of radiological deformity measurements. In previous studies, in patients with cam morphology, NSA has been shown to cause increased stress on the hip and has been reported to have smaller values in patients with symptomatic impingement syndrome. Our findings demonstrated that NSA had a positive correlation with only min. hip IR and mean hip IR of the kinematic values. The reason for this may be that the post-slip deformity does not consist only of the impingement deformity, it is because the femoral head and femoral neck are not on the same plane due to sliding and consequently, the hip's center of rotation has changed [22].

In our study, no correlation was found between kinematic and kinetic values and the alpha angle, which is one of the most important radiologic impingement criteria widely used in clinical practice. It seemed that the alpha angle did not correlate with gait functions. There are two possible reasons for this. One of them is the measurement method, and the other one is about the compensation mechanism. In the description by Nötzli, which is widely cited in studies, the center of the femoral neck and the center of the femoral head are on the same axis [16]. However, the femoral neck axis does not pass through the center of the femoral head after an epiphyseal slip. In this case, the line parallel to the femoral neck axis can be used. However, this measurement yields different results than the angular values measured by the line connecting the midpoint between the narrowest level of the femoral neck and the center of the femoral head [16,23]. Therefore, we must be careful when planning surgical treatment of head-neck deformity with open or arthroscopic osteoplasty.

Clinical examination and radiological findings, as it is in patients with SCFE, may not affect the patient's score and quality of life on the short term. In this dynamic deformity seen in the growth phase, hip motions and patient scores are not related only to the slip-angle. For example, in patients with SCFE with moderate and severe slip, the decrease in hip joint ROM was found to be the same, which was linked to metaphyseal changes in the femoral neck during remodeling [24]. In addition to this information, it has been demonstrated that both short-term improvement in patient's score and radiologic deformity can be achieved with corrective osteotomies [23]. It has also been shown that a corrective osteotomy may be useful to prevent possible hip arthrosis in long-term follow-ups [24]. However, these treatments may continue to be ineffective. Diab et al. could not detect differences in follow-up scores of in situ pinning from osteotomy groups after 7 years of follow-up [25]. Proximal femoral osteotomy surgery that provides alignment without correcting the contour of the head and neck junction may be the reason. Open or arthroscopic removal of the metaphyseal hump in the head and neck junction after a slight slip that does not cause serious alignment deformity may provide adequate joint motion and most importantly impingement treatment. However, both the provision of head and neck contour and alignment surgery may be considered in the surgical planning of patients with severe slip. Since patients show both radiological and clinical normalization due to remodeling in follow-ups, it makes treatment choices more complicated. Therefore, a clear understanding of the effect of this dynamic deformity on hip function through reliable radiologic and functional measurements, is of critical importance before any surgical intervention.

The main limitation of this study was that most patients in our study group did not have severe slipped epiphysis. The mean slip-angle of our study population was relatively moderate. However, we applied the same treatment to these patients and evaluated a relatively homogeneous patient population compared with a matched control group. In addition, we evaluated all aspects of hip deformity in patients with SCFE such as slip-angle, alpha angle, tilt indexes (lateral and anteroposterior femoral head ratio), articulotrochanteric distance, and femoral neck/shaft angle. This study is the first in the literature evaluating all aspects of hip deformity and its correlation with three-dimensional GA compared with healthy individuals. Our study may guide further studies when evaluating the association between gait function and patients' clinical and radiological outcomes.

Conclusion: According to our results, the clinical scores of patients treated for SCFE were mostly correlated with pelvic tilt ROM, FPA, and spine tilt. Compensatory mechanism in pelvic tilt and spine tilt, as well as external rotation of the foot, is significantly associated with clinical scores. LFHR and ATD were observed as the most essential radiological measurements related to the patient's gait function.

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