

The effects of residual hip deformity on coronal alignment of the lower extremity in patients with unilateral slipped capital femoral epiphysis

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Abstract

Purpose The aim of our explorative study was to compare the differences in the coronal alignments of the hip, knee and ankle on the slip side and non-slip sides in patients with slipped capital femoral epiphysis (SCFE).

Methods The study group consisted of 28 patients. On the full-length standing radiographs, measurements of articulo-trochanteric distance (ATD), neck-shaft angle (NSA), femoral offset, hip-knee-ankle axis, femur-tibial angle, mechanical axis deviation ratio (MAD-r), anatomical medial proximal femoral angle (aMPFA), mechanical lateral proximal femoral angle (mLPFA), anatomical lateral distal femoral angle (aLDFA), mechanical lateral distal femoral angle (mLDFA), knee joint line congruency angle, mechanical medial proximal tibial angle (mMPTA), mechanical lateral distal tibial angle (mLDTA), ankle joint line orientation angle (AJOA), and leg length discrepancy (LLD) were performed. The data from the slip side were compared with those from the non-slip side.

Results At skeletal maturity, there were significant differences between the slip side and non-slip side in ATD ($p < 0.001$), NSA ($p < 0.001$), MAD-r ($p < 0.001$), aMPFA ($p < 0.001$), aLDFA ($p = 0.03$), mLDFA ($p = 0.04$), mLDTA ($p = 0.02$), AJOA ($p < 0.001$) and LLD ($p < 0.001$).

Conclusion Residual deformity in the proximal femur after epiphyseal slip and premature epiphysiodesis could cause changes in the coronal alignment of the lower extremity. We

can add lower extremity alignment examination to follow-up protocol to rule out secondary problems in patients with SCFE.

Level of Evidence Level III, retrospective comparative study

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Introduction

Slipped capital femoral epiphysis (SCFE) is a well-defined disorder of the hip in adolescents. It is characterized by pathologic displacement of the proximal femoral epiphysis. In general, the primary purpose of treatment is to fix the femoral head epiphysis to the femur neck in a stable manner and obtain premature epiphysiodesis. In addition, there are also implants that can stabilize the femoral head epiphysis and that allow the femur to grow proximally.¹ After epiphysiodesis, three planar residual deformities may occur; depending on the degree of slip.² Residual deformities may include femoroacetabular impingement, shortening of the femur neck, femur anteversion loss and metaphyseal changes in the anterior and superior part of the neck.³

Pathologies in the axial system are related to lower extremity alignment, while pathologies of the major joints of the lower extremity are self-related.⁴ Furthermore, according to reports in literature, changes resulting from proximal femoral coronal deformities may cause compensatory changes in the orientation angles of the knee and ankle joints.^{5,6} Several studies conducted in paediatric populations show that conditions such as Legg-Calve-Perthes disease, which cause deformities in the proximal femur, may result in coronal malalignment.^{5,7,8} However, there are no studies in the literature describing such effects in SCFE patients.

The aim of our explorative study was to investigate changes in knee and ankle joint orientation angles and coronal axis deviations in the lower extremity following *in situ* pinning in unilateral SCFE patients.

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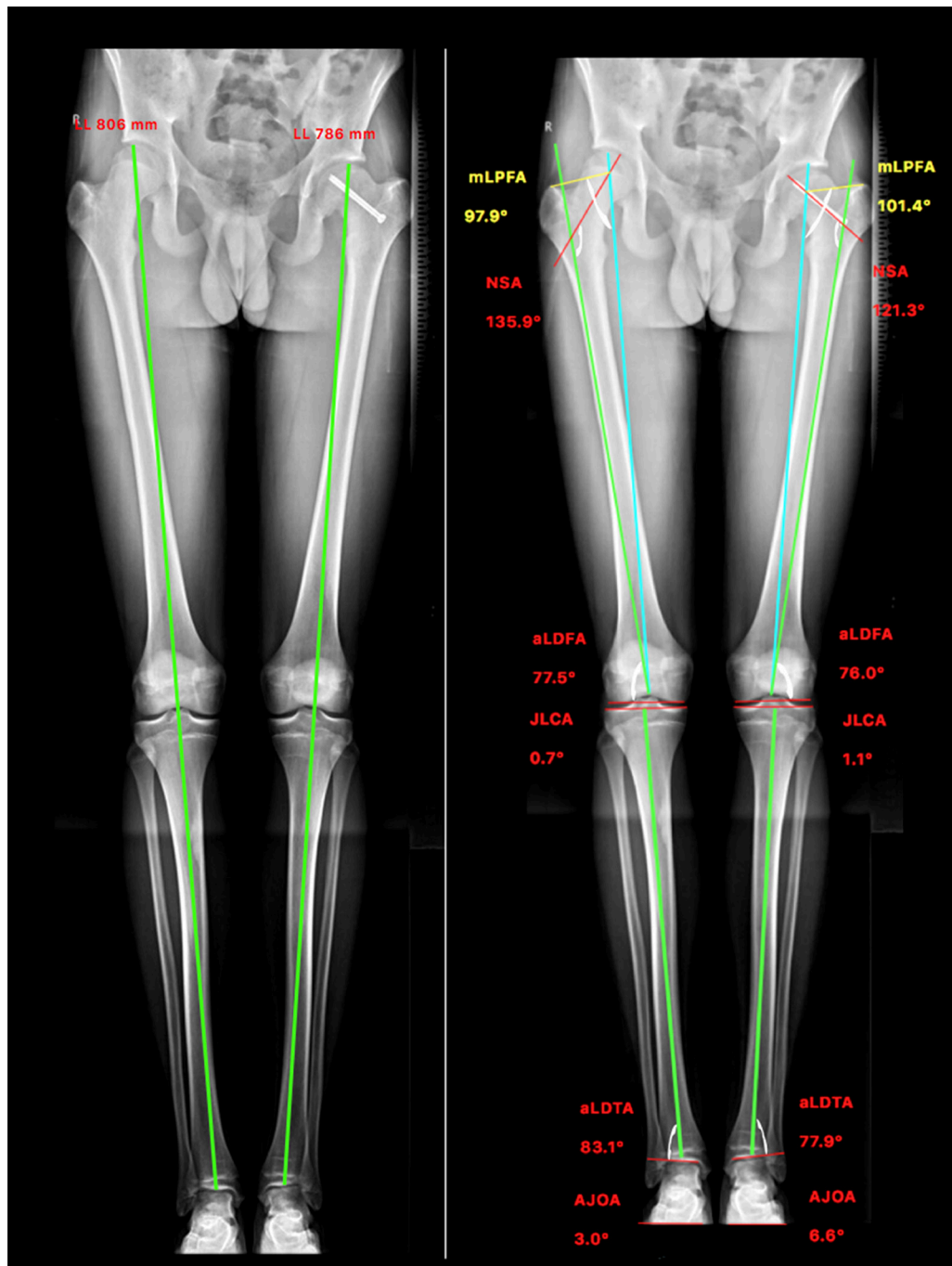


Fig. 1 Two identical full-length lower extremity radiographs of one typical case with showing slip side and non-slip side deformity measurements (LL, limb length; mLPFA, mechanical lateral proximal femoral angle; NSA, neck-shaft angle; aLDFA, anatomical lateral distal femoral angle; JLCA, joint line congruency angle; aLDTA, anatomical lateral distal femoral angle; AJOA, ankle joint line orientation angle).

Patients and methods

This study was conducted following approval by our Institutional Review Board (2014-03/07). Between 2008 and 2013, records of patients who had operations for SCFE were collected from computerized patient record

databases. In total, records for 75 patients were reviewed. Overall, 28 patients who had an unilateral slip, regardless of the grade of the slip, who reached skeletal maturation were included in the study. Written and verbal consent was received from all patients included in the study. Clinical or radiological confirmation of a bilateral slip at the

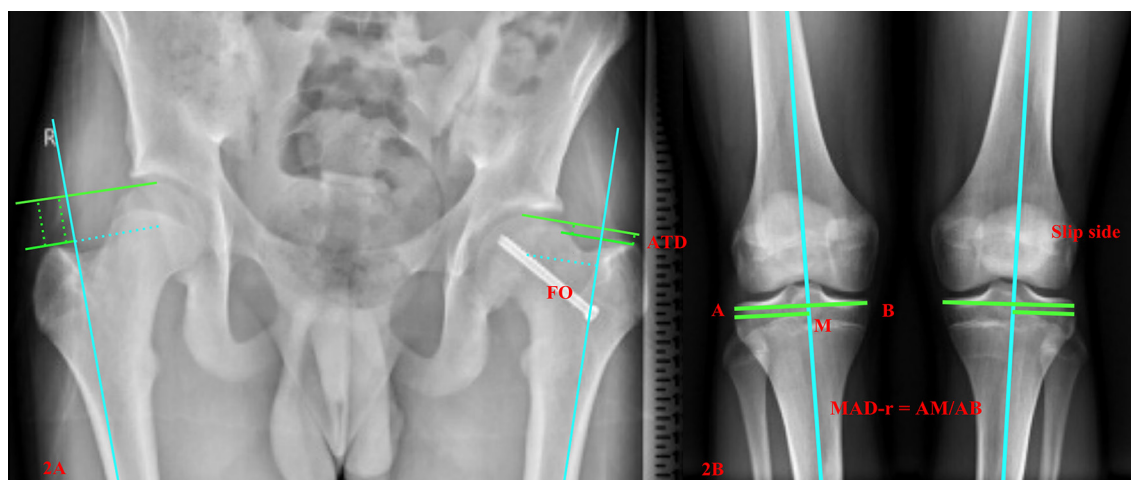


Fig. 2 The pelvis radiograph (right) shows how to femoral offset (FO) (37.2 mm on non-slip side versus 29.3 on slip side), articular distance (ATD) (22.3 mm on non-slip side versus 5.2 mm on slip side) measured. The bilateral knee radiograph (section from full-limb radiograph) shows how mechanical axis deviation ratio (MAD-r) (0.51 on non-slip side but 0.43) on slip side was measured. A, the most lateral point of tibia joint line; M, the point where the mechanical axis crosses the tibia joint line; B, the most medial point of tibia joint line.

time of first admission or during follow-up ($n = 14$), open realignment and fixation or osteotomy except for *in situ* pinning ($n = 12$), history of revision surgery ($n = 3$), prophylactic pinning ($n = 10$) and development of complications such as avascular necrosis or chondrolysis ($n = 4$) were considered as criteria for exclusion from the study. We also excluded three patients who had a history of lower extremity fracture history, and one patient with rigid pes planovalgus. A total of 47 patients were excluded from the study.

Examinations were conducted to rule out limited range of movement in the hip, knee and ankle joints, general ligamentous laxity and other musculoskeletal abnormalities, such as fixed spine, pelvic deformity and joint contracture that could lead to incorrect radiographic measurements. Furthermore, patellar compression tests were performed on both knees and the nature of ankle-related pain in the patients was questioned during the final follow-up. The body mass index of all patients at the first control as well as at the latest follow-up visit were recorded.

Full-length standing radiographs of the limbs, pelvis anteroposterior and frog-leg lateral pelvis radiographic imaging of all patients were performed after radiological epiphysiodesis. When obtaining radiographic images, the patella and the ankle joints were marked on the skin for both legs of the patients to avoid rotational malpositioning. All radiographs were obtained digitally using DDR Inventor V (JSB Medics Co., Bucheon City, South Korea), and measurements were taken using the Infinitt PACS System (Infinitt Healthcare Co., Seoul, South Korea). On each digital radiograph, measurements were performed by two observers (H.U. and S.K.T.) working independently of each other. The Southwick slip angles

were measured preoperatively and six months later post-operatively. The other measurements were performed at the time of the last control. On the full-length standing radiographs, articular distance (ATD), femoral offset, neck-shaft angle (NSA), hip-knee-ankle axis angle (HKA), femur-tibial angle (FTA), mechanical axis deviation ratio (MAD-r), anatomical medial proximal femoral angle (aMPFA), mechanical lateral proximal femoral angle, anatomical lateral distal femoral angle (aLDFA), mechanical lateral distal femoral angle (mLDFA), knee joint line congruency angle (JLCA), mechanical medial proximal tibial angle (mMPTA), mechanical lateral distal tibial angle (mLDTA), ankle joint line orientation angle (AJOA) and leg-length discrepancy (LLD) were measured for the slip and non-slip sides (Figs 1, 2 and 3).⁹ The mean and SD of the measured mechanical and anatomic values were compared. Additionally, patients were categorized according to hip-knee-ankle axis deviation ratio values.

The MAD-r was calculated by dividing the distance from the knee joint centre to the most lateral part of the tibial plateau by the width of the entire tibia plateau (Fig. 2). According to this measurement, a value < 0.5 was indicative of lateral MAD or valgus. However, a value > 0.5 was indicative of medial MAD or varus (Fig. 2). Mechanical axis deviation was expressed as a ratio of the width of the tibial articular surface to avoid errors of magnification.⁵ For joint line orientation angles such as JLCA and AJOA, a positive value was used to define an angle opening towards the lateral aspect of the knee or ankle and a negative value defined an angle opening towards the medial aspect (Fig. 1).

All results were analyzed using SPSS 20.0 (IBM Corporation, New York, New York). Demographic characteristics



Fig. 3 Full-length lower extremity radiograph shows how to measure anatomical medial proximal femoral angle (aMPFA), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA), mechanical lateral distal tibial angle (mLDTA), femur-tibial angle (FTA) and hip-knee-angle-axis (HKA-A). The hip-knee-ankle angle is a measure of lower limb alignment and defined as the angle between the mechanical axes of the femur and the tibia.

of the study patients and radiographic parameters were described as mean and SD with range. Statistical evaluation of the difference between two dependent parameters was made using the Wilcoxon test. The chi-squared (χ^2)

test was used for categorical variables and expressed as observation counts (and percentages). When at least one expected value was < 5 , the Fisher's Exact test was used instead of the chi-squared test. Inter-observer repeatability was estimated for two of the observers with intraclass correlation coefficient. The level of statistical significance was set at $p < 0.05$.

Results

The demographic characteristics of the patient group included in the study, as well as observations following physical examinations on the patients are presented in Table 1. None of our patients, on both the slip side and the non-slip side, had hip flexion contracture, knee flexion contracture and plantar flexion contracture of the ankle. Clinically, anterior knee pain during activity was present in only two patients. In addition, a positive sign on the patellar compression test was observed in both knees of seven patients. A full range of movement in the ankle was observed in all patients. Ankle pain was not reported in any of the patients.

There were 13 patients with grade 1 slip, 11 patients with grade 2 slip and 4 patients with grade 3 slip (Table 1).

A comparison of radiographic measurements of the slip side *versus* the non-slip side is shown in Table 2. The MAD-r was indicative of valgus in 22 of 28 limbs on the slip side, and in 13 of 28 limbs on the non-slip side. According to the MAD-r, there was a significant difference in the frequency of valgus alignment between the slip side and non-slip side groups ($p < 0.001$). Of the 28 patients, measurements of leg-length difference showed shortness in 23 patients (82%) with epiphyseal slip. Leg-length difference was 21 mm in one patient, was between 10 mm to 20 mm in ten patients, and was less than 10 mm in the other 12 patients. Additionally, the frequency of ATD discrepancies was 75% (21 cases in 28 patients).

Replicate measurements correlated significantly between observers. Values for the correlation coefficient between the two different measurements ranged between 0.88 and 0.99 (Table 3).

Discussion

Our main hypothesis in this study was that residual deformity in the proximal femur after epiphyseal slip and premature epiphysodesis could cause changes in the coronal alignment of the lower extremity. Proximal femur morphology showed a decrease in ATD, a decrease in NSA and a decrease in aMPFA in the slip side when compared with the non-slip side. In addition, MAD-r, HKA and FTA measurements were indicative of valgus alignment. However, only the difference in MAD-r was statistically

Table 1. Demographic features of children with unilateral slipped capital femoral epiphysis included in the study

Characteristics			p-value
Female/male (n)	4/24		
Age at operation (yrs) (mean and sd, range)	12.7 sd 1.5, 10 to 15		
Follow-up (yrs) (mean and sd, range)	5.2 sd 1.2, 3 to 7		
Age at final follow-up (yrs) (mean and sd, range)	17.8 sd 1.2, 17 to 21		
Pre-operative BMI and BMI-percentile (mean and sd, range)	26.9 sd 4.6, 22.2 to 37.7	92.6 sd 7.7, 70 to 99	
Final BMI and BMI-percentile (mean and sd, range)	27.2 sd 3.7, 21.1 to 33	91.5 sd 8.3, 65 to 99	
Clinically measured LLD (mm) (mean and sd, range)	5 sd 6.2, 0 to 20		
Radiological measured LLD (mm) (mean and sd, range)	8.4 sd 6.1, 0.4 to 21.9		
Preoperative slip angle AP plane (mean and sd, range)	18.2 sd 4.8, 10 to 28		
Preoperative slip angle lateral plane (mean and sd, range)	39.7 sd 8.4, 26 to 56		
Final hip joint range of movement and Q-angle examination results	Non-slip side (mean and sd)	Slip side (mean and sd)	p-value
Flexion	116.9 sd 14.7	116.7 sd 6.1	0.96
Abduction	49.5 sd 6.7	49.8 sd 7.0	0.84
Adduction	40.1 sd 6.6	37.8 sd 4.3	0.72
Internal rotation	45 sd 6.6	36.6 sd 11.7	< 0.001
External rotation	48.7 sd 9.7	52.1 sd 12.5	0.26
Anteversión	4.8 sd 14.8	4.2 sd 15.3	0.89
Q-angle	14.8 sd 0.9	16.3 sd 7.4	0.37

The p-values indicated in bold indicate statistically significant results. BMI, body mass index; mm, millimeter; Q-angle, quadriceps angle; AP, anteroposterior; LLD, limb-length discrepancy

Table 2. Measurements of lower extremity alignment in 28 limbs that had *in situ* pinned and contralateral normal limbs

Measurement values	Side	Mean (sd)	95% CI of the means		p-value
			Lower	Upper	
FO (mm)	Slip side	40.6 sd 8.6	37.29	43.94	0.4
	Non-slip side	42. sd 8.2	39.07	45.43	
ATD (mm)	Slip side	11.7 sd 6.1	9.37	14.05	< 0.001
	Non-slip side	18.8 sd 6.6	16.26	21.39	
NSA	Slip side	126.4° sd 5.4°	124.32°	128.51°	< 0.001
	Non-slip side	131.2° sd 5.5°	129.05°	133.37°	
mLPFA	Slip side	92.68° sd 6.57°	90.14°	95.23°	0.11
	Non-slip side	90.50° sd 4.24°	88.86°	92.15°	
aMPFA	Slip side	79.8° sd 4.2°	78.20°	81.50°	< 0.001
	Non-slip side	84.2° sd 6.1°	81.91°	86.58°	
aLDFA	Slip side	81.6° sd 3.1°	80.45°	82.88°	0.03
	Non-slip side	83.3° sd 2.1°	82.47°	84.14°	
mLDFA	Slip side	86.6° sd 3.7°	85.46°	87.85°	0.04
	Non-slip side	88.3° sd 2.6°	87.26°	89.26°	
mPMTA	Slip side	88.5° sd 2.7°	87.48°	89.59°	0.70
	Non-slip side	88.8° sd 2.6°	87.79°	89.83°	
mLDTA	Slip side	86.3° sd 3.8°	84.84°	87.80°	0.02
	Non-slip side	88.3° sd 2°	87.56°	89.11°	
Knee-JLCA	Slip side	1.49° sd 0.95°	1.13°	1.87°	0.67
	Non-slip side	1.43° sd 1.1°	1.03°	1.84°	
AJOA	Slip side	1.9° sd 0.8°	1.67°	2.25°	< 0.001
	Non-slip side	1.2° sd 0.7°	0.87°	1.44°	
LL (mm)	Slip side	862.2 sd 48.8	843.34	881.18	< 0.001
	Non-slip side	869.5 sd 48.5	850.77	888.43	
FTA	Slip side	6.45° sd 2.7°	5.38°	7.53°	0.55
	Non-slip side	6.03° sd 2.5°	5.03°	7.03°	
MAD-r	Slip side	0.44 sd 0.07	0.41	0.47	< 0.001
	Non-slip side	0.52 sd 0.08	0.49	0.56	
HKA-A	Slip side	1.9° sd 1.7°	1.30°	2.64°	0.49
	Non-slip side	2.7° sd 1.6°	1.63°	2.95°	

The p-values in bold indicate statistically significant results. CI, confidence interval; FO; femoral offset; ATD; articulo-trochanteric distance; NSA; neck-shaft angle; mLPFA; mechanical lateral proximal femoral angle; aMPFA; anatomical medial proximal femoral angle; aLDFA; anatomical lateral distal femoral angle; mLDFA; mechanical lateral distal femoral angle; mMPFA; mechanical medial proximal tibial angle; mLDTA; mechanical lateral distal tibial angle; knee-JLCA, knee joint line congruency angle; AJOA; ankle joint line orientation angle; PTA; tibial plafond talus angle; LL, limb-length; FTA; femur-tibial angle; MAD-r; mechanical axis deviation ratio; HKA-A; hip knee ankle axis

significant. With regards to knee and ankle orientation angles, there was no statistically significant difference in knee JLCA between the two sides, but the AJOA on the slip side was significantly larger than on the non-slip side. The

other expected deformity, LLD, yielded more favourable results on the non-slip side in parallel with the literature.¹⁰ Similar radiological studies in patients with Legg-Calve-Perthes disease, another common paediatric hip

Table 3. Inter-observer reproducibility was assessed using the intra-class correlation coefficient (ICC)

Radiologic measurements	ICC	CI	p-value
FO	0.915	0.86 to 0.95	< 0.001
ATD	0.931	0.88 to 0.95	< 0.001
NSA	0.902	0.84 to 0.94	< 0.001
mLPFA	0.933	0.89 to 0.98	< 0.001
aMPFA	0.929	0.87 to 0.95	< 0.001
aLDFA	0.916	0.86 to 0.95	< 0.001
mLDFA	0.899	0.82 to 0.94	< 0.001
mPMTA	0.901	0.81 to 0.94	< 0.001
mLDTA	0.934	0.84 to 0.96	< 0.001
Knee-JLCA	0.925	0.87 to 0.95	< 0.001
AJOA	0.967	0.94 to 0.96	< 0.001
LL	0.983	0.86 to 0.99	< 0.001
FTA	0.966	0.94 to 0.98	< 0.001
MAD-r	0.919	0.86 to 0.95	< 0.001
HKA-A	0.884	0.81 to 0.94	< 0.001

CI, confidence interval; FO; femoral offset; ATD; articulo-trochanteric distance; NSA; neck-shaft angle; mLPFA; mechanical lateral proximal femoral angle; aMPFA; anatomical medial proximal femoral angle; aLDFA; anatomical lateral distal femoral angle; mLDFA; mechanical lateral distal femoral angle; mPMTA; mechanical medial proximal tibial angle; mLDTA; mechanical lateral distal tibial angle; knee-JLCA, knee joint line congruency angle; AJOA; ankle joint line orientation angle; PTA; tibial plafond talus angle; LL, limb-length; FTA; femur-tibial angle; MAD-r; mechanical axis deviation ratio; HKA-A; hip knee ankle axis

problem, are available in the literature.⁷⁻¹⁰ The age profile of the patients in these studies was identical to that of the patients in our study group. In these studies, the effects of changes to the morphology of the proximal femur on the alignment of the lower extremity were investigated as well.⁷⁻¹⁰ In these studies, valgus deformity in the knee joint was a common finding. Some authors described it as a compensation for neutralization of the mechanical axis which had been medialized due to varus osteotomy on the proximal femur. As seen in these studies, even with a short follow-up period, individuals who experience a growth spurt may develop compensations in their knees and ankles after hip problems.

No previous studies have reported the effects of *in situ* pinning of the proximal epiphysis on the alignment of the knee and ankle. We predominantly found valgus alignment of both the mechanical and anatomical axes. However, it has been reported that obesity causes valgus alignment in the coronal plane of the extremity. In a prospective study evaluating the findings of lower limb alignment in normal weight and overweight adolescents, the prevalence of abnormal lower extremity alignment was found to be higher in overweight individuals, and the predominant form of deformity was valgus alignment.¹¹ Most individuals in our patient group were overweight, and this may have affected our results. Although we acknowledge this effect, we believe that this effect was minimized because our control group consisted of healthy extremities of the same patients. So, we can assume the valgus alignment of slip side is a consequence of residual deformity of epiphyseal slippage. Furthermore, there were only four patients with severe slip in our study. If these radiological measurements were made in patients with severe

epiphysiolysis, the findings may have been aggravated. Therefore, we believe that our findings should be taken into consideration for future clinical management of these patients.

Remodelling after *in situ* pinning in SCFE patients improves radiological morphology in the proximal femur.¹² Patient score was another confounding factor in the evaluation of the results of this study.^{13,14} However, since we performed our radiological measurements in skeletally mature patients, the chances of clinical and radiological improvement were reduced.

Residual deformity of the proximal femur and possible radiographic changes in the coronal plane of the lower extremity due to possible compensatory mechanisms may potentially be associated with secondary clinical complaints. There are studies in literature that evaluated the functional capacity of SCFE patients by objective methods such as gait analysis. In these studies, it was shown that changes in joint kinematics and clinical scores may be related to radiological deformity of the proximal femur, especially at the head-neck junction.^{15,16} The correlation between the radiologic deformities of knee and ankle and clinical scores may be a subject of future research in SCFE patients over a long-term follow-up duration. None of our patients had ankle pain. Two patients reported knee pain following activity, and there was a positive patellar compression test in seven patients.

Generally, the mechanical axis of the lower extremity passes slightly medially. The normal alignment of the mechanical axis is very important in terms of the proportional distribution of load on the joint surfaces.⁹ Deviation of the mechanical axis may cause premature joint degeneration and the disproportionate load distribution may cause deformation in periarticular metaphyseal bones. The duration of this study may be insufficient to evaluate these effects, especially the clinical reflections. However, the findings of our study may be important to demonstrate the necessity of long-term follow-up studies for potential knee and ankle joint-related clinical symptoms and obtaining radiological assessments in conditions such as arthritis.

The major limitation of the present study was the retrospective evaluation of prospectively followed patient groups. Furthermore, changes in sagittal alignment were not investigated. Also, the follow-up period was relatively short. In addition, due to the small number of SCFE patients with severe slips (grade 3), this study may underestimate the prevalence and severity of lower limb deformities that is potentially present in patients with high grade slips. On the other hand, this is the first study to focus on differences in full-length lower extremity alignment on both the slip side and non-slip sides in patients with unilateral SCFE who underwent *in situ* pinning.

In conclusion, residual deformity in the proximal femur after epiphyseal slip and premature epiphysiodesis could cause changes in the coronal alignment of the lower extremity. We can add lower extremity alignment examination to follow-up protocol to rule out secondary problems in patients with SCFE.

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COMPLIANCE WITH ETHICAL STANDARDS

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

OA LICENCE TEXT

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ETHICAL STATEMENT

Ethical approval: This study has been approved by the ethical review committee and institutional review board of Baltalimani Bone and Joint Diseases Education and Research Hospital. 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: Informed consent was not obtained from the patients included in this study given the retrospective design of the study.

ICMJE CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflict of interest.

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