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Original Article

Gait abnormalities following slipped capital femoral epiphysis

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Abstract

Aim: The aim of this study was to compare the gait function following slipped capital femoral epiphysis (SCFE) with the healthy controls.

Material and Methods: We included 31 of 76 SCFE patients who were treated with in situ pinning between 2005 and 2013. We excluded patients with radiographic or clinical evidence of a contralateral slip, less than 2-years follow-up, incomplete epiphyseal closure, musculoskeletal abnormalities that can affect gait, avascular necrosis or chondrolysis and needed revision surgery. To measure the patients' quality of life and physical function Harris hip score and the Pediatric Outcomes Data Collection Instruments (PODCI) scores were used. All patients and control group were underwent whole-body motion analysis.

Results: 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 from volunteers whose mean age was 17.84 ± 1.47 years that ranged between 16 and 20 years, with a mean BMI of 27.72 ± 2.61 kg/m2. Significant gait deviations were detected in SCFE patients such as (SCFE versus control group); Pelvis tilt range of motion (ROM) (3.5±1.5 - 2.3±0.5, p=<0.01), Hip flexion ROM (35.1±3.7 - 39.8±4.6, p<0.01), Pelvis obliquity ROM (5.5±2.3 - 9.5±2.8, p<0.01), Hip abduction ROM (10.8±2.9 - 12.9±3.4, p=0.02), Knee Abduction ROM (15.2±6.1 - 10.7±6.9, p=0.01), Mean FPA (-11.1±7.7 - -5.2±6.5, p=0.01), Ankle rotation ROM (31.2±1.7 - 22.9±6.7, p=0.01), Mean thorax tilt (5.6±5.4 - 1.4±4.4, p<0.01), Spine tilt ROM (5.1±3.3 - 7.8±3.4, p=0.02).

Conclusion: Significant gait deviations were identified in patients with unilateral-SCFE in comparison with age and BMI matched healthy controls. Three-dimensional gait analysis can be used as an objective method for evaluation of functional outcomes of SCFE.

Keywords: Gait analysis; in situ fixation; slipped capital femoral epiphysis.

INTRODUCTION

Slipped capital femoral epiphysis (SCFE) can be defined as the displacement of femoral head epiphysis over the growth plate in varying amounts which disrupt the normal femoral neck and head relationship (1). In situ pinning is general accepted treatment choice. The general purpose of various treatment options is to stop slipping and degeneration of the hip joint. Because epiphyseal slippage in proximal femur is an important part of adolescent hip problems and early cause of osteoarthrosis in the hip joint (2-4).

The evaluation of treatment outcomes of epiphyseal slippage is made by taking only clinical and radiological criteria. This leads to a disregard of the functional outcomes of the treatment. There are a limited number of studies on the evaluation of the femoral head slippage by gait analysis (5-8). In these studies, all patients treated with in situ pinning, Kirschner wire, nailing, subcapital and trochanteric osteotomy were included. This variety of treatment, especially osteotomy, made a difference in the expected proximal femoral deformity of patients undergoing gait analysis. In addition, patients with short follow-up period were included in the studies, for example, even patients with 1-year follow-up. The inclusion of patients with short-term follow-up might have caused to inclusion of patients without epiphyseal closure. Remodelization of the proximal femur continues in patients without epiphyseal closure, so final result of gait function of patients with SCFE cannot be determined accurately. Gait analysis in unilateral SCFE patients, after closure of the epiphysis, treated with in situ pinning that

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is generally accepted method other than using different implants or proximal femur may provide a safe guide for the treatment of patients with residual deformity after slippage.

The aim of this study was to evaluate the gait abnormalities following slipped capital femoral epiphysis according to the healthy controls.

MATERIAL and METHODS

Retrospectively, between 2005 and 2013, records of patients who underwent in situ pinning surgery with diagnosis of SCFE were searched on a computerized patient record system. The records of 76 patients were satisfactory. Clinically or radiologically bilateral slip at the time of first admission or follow-up, open reduction or osteotomy except for in-situ pinning, revision surgery history, less than 2-year follow-up, presence of musculoskeletal system disease with primary or secondary developing gait disturbance, development of avascular necrosis (AVN) and chondrolysis complications have been considered as criteria for excluding from study. A total of 45 patients; 2 patients who did not admit the GA test, 5 patients who did not visit the outpatient clinic regularly, 6 patients who had inadequate follow-up time, 3 patients who had lateral malleolar fracture, tibia shaft fracture and femur shaft fracture, 11 patients who underwent different surgery other than closed in situ pinning, 14 patients with bilateral slipping, 1 patient with chondrolysis and 3 patients with AVN, were excluded from the study, and 31 patients were included in the study. Written and verbal approvals were obtained from all the patients included in the study. Also, the study was approved by institutional review board (IRB) (2014).

A full body GA was performed using a Vicon Bonita System (Oxford Metrics Ltd., Oxford, England) in all patients. Eight different 100 Hz infrared cameras and two Bertec force platforms (Bertec Corp. Columbus, OH, USA) were used for the analysis. Thirty-four retroreflective markers were placed on specific anatomical points of patients according to Vicon Plug in the gait model. After a static record of the stance phase, patients walked barefooted on a 9 m walk path in a daily walking pattern and speed. At least seven walking records were taken, in which both legs successively pressed with full force on the force platform. Walking records were analyzed with the Vicon Nexus 1.8.2 program. Later, kinematic and kinetic graphics were obtained with the help of Polygon 4.0.1 software. From these records, 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 difference between the maximum and minimum values is expressed as the range of motion (ROM). 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 from volunteers whose mean age was 17.84±1.47 years that ranged between 16 and 20 years, with a mean BMI of 27.72±2.61 kg/m^2. The SCFE and control groups were both age- and BMI-matched. Therefore, they were similar in age ($p = 0.51$) and BMI ($p = 0.21$). There was one female in the SCFE group and seven in the control group, so gender was not matched. The control group (n = 20) consisted of healthy individuals without any history of orthopedic, neurological, or other gait-influencing disorders. All patients and the control group were clinically examined on the same day as the walking analysis by an experienced physiotherapist and senior orthopedic and traumatology surgeons.

A scoliosis screening test, tibia rotational deformity examination, hip joint, knee joint, and ankle joint contractures examination were routinely performed to detect musculoskeletal pathologies that may affect the GA. We also evaluated hip, knee, ankle, and foot joint ROM. Hip flexion, hip joint flexion contracture, hip internal and external rotations, and hip abduction and adduction exams were performed in the supine position, whereas hip extension and femoral anteversion were in the prone position. Angular measurements were performed with a standard goniometer.

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.

On the same day as the GA, pelvis anteroposterior (AP) and frog-leg lateral (Lat.) radiographs were taken.

Statistical analysis

The resulting data were analyzed using 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. 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 motions measured as follows: mean hip flexion 118.2 (100–140), mean hip extension 28 (20–35), mean hip abduction 50.1 (45–60), mean hip adduction (add.) 45.4 (35–50), mean hip IR 28 (0–50), mean hip ER 51 (45-60).

According to the control group, statistically significant gait deviations are presented in Table 1. We observed statistically significant differences between patients with SCFE and the control group in terms of pelvis tilt ROM, hip flexion. ROM, minimum (min.) and maximum (max.) pelvic obliquity, pelvic obliquity ROM, min. hip abduction, hip abduction ROM, max. knee abduction, knee abduction

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

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

The joint kinematic values of patients with SCFE and the 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 progression angle; min.= minimum; max = maximum.
Correlation is significant at the 0.05 level (2-tailed).

Table 2. Radiographic deformity analysis of proximal femur in patients with SCFE

Variables	N	Mean (SD)	Range
Pre-operative AP Southwick slip-angle	31	19.7 (14.2)	3 - 65
Pre-operative Lateral Southwick slip-angle	31	32.7 (16.8)	9 - 85
Post-operative anteroposterior Southwick slip-angle	31	14.5 (9.7)	0 - 42
Post-operative Lateral Southwick slip-angle	31	23.4 (15.29	1 - 56
Anteroposterior Femoral Head Ratio	31	1.3 (0.2)	1 - 1.9
Lateral Femoral Head Ratio	31	1.9 (0.7)	1 - 4
Articulo-trochanteric distance	31	11.8 (6.79	-1 - 25
Anteroposterior plane alfa angle	31	73.4 (15.9)	37 – 97
Lateral plane alfa angle	31	64.8 (16.1)	33 - 104
Anterior head-neck offset ratio	31	0.04 (0.07)	-0.2 – 0.2
Femoral neck – shaft angle	31	127.8 (6.1)	116 - 141

ROM, max. knee abduction, knee abduction ROM, mean FPA, min. and max. FPA, ankle rotation ROM, mean thorax tilt, min. and max. thorax tilt, and spine tilt ROM. Mean/min./max. hip flexion degrees were 6.96 ± 6.76 / -7.1 ± 8.8 / 28.1 ± 6.9 in the SCFE group and 5.9 ± 5.6 / 9.6 ± 6.9 / 30.1 ± 5.2 in the control group without statistically differences ($p > 0.5$). We did not observe any statistically significant differences in kinetic measurements, mean/min./max. hip flexion/extension moment, mean/min./max. knee flex/ext moment, mean/min./max. ankle flexion/extension moment, mean/min./max. hip abduction/adduction moment, and mean/min./max. knee varus/valgus moment. In addition, there were no statistical differences in cadence, step width, and gait velocity.

The means of subscales of PODCI score detected as Transfer & Basic Mobility 97 ± 4, Sports and Physical Functioning 85±12, Pain/Comfort 75 ± 17, Happiness 82 ± 17, Global functioning 9 ± 8. The mean of HHS was 96 ± 6.

Radiological deformity measurements are shown in Table 2.

DISCUSSION

The use of reliable assessment methods, which ensure that we obtain quantitative and objective data on the measurement of post-treatment functions of orthopedic patients, can guide us in the choice of treatment and provide improved benefits to treatment modalities (9). Gait analysis one of these methods, has become a widespread test for demonstrating the effect of the impingement syndrome on gait function and the functional development of this syndrome after treatment (10-12). Although impingement syndrome is one of the main post-SCFE deformities, the number of studies evaluating functional improvement with GA in the SCFE patient group is inadequate and these studies investigate the effect of radiological and clinical outcomes on the patient's function on heterogeneous patients' group (5-8). In this study, it was aimed to determine the gait deviations of SCFE patients in comparison to healthy age and BMI matched controls with GA.

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 (6). 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 (8). Song et al. observed that as long as the degree of slip increased, pelvic obliquity also increased (5). 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 (13). 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 (6). Talking about the demographic characteristics of the patient groups in these reference articles may make the findings of the gait analysis more understandable. In Song et al. study, clinical results according to the Harris hip score displayed very good results with an average slipping angle was 31.6° (range, 8–60°; SD 13.7°) and with a BMI 26.5 kg/m2 (5). In Westhoff et al. study the radiological findings revealed very good results. The average BMI at the time of surgery was 24.6 kg/m2 (range 17.3–32.5 kg/m2, SD 4.0) and at follow-up, it was 26.9 kg/m2 (range 18.4–34.2 kg/m2, SD 4.5) (6).

We found no evidence of impaired hip joint kinetics during gait, which is consistent with most prior studies (10, 12). It is thus likely that most studies (including our own) did not observe altered hip kinetics during gait because gait does not require movement to the end of available ROM (14).

We assessed our patient's overall health, pain, and ability to participate in normal daily activities, as well as more vigorous activities typically associated with young people with PODCI scores and HHS which are commonly accepted and used scores for patients with hip disorders.(15, 16) The scores in PODCI and HHS were excellent. However, we detected many significant kinematic deviations in any definable gait parameter as compared with age- and weight-matched healthy controls.

One of limitation of this study was that we excluded many patients because of the inclusions criteria such as the patients who treated other than in situ pinning and patients with bilateral epiphyseal slip. Therefore, the results of our study do not include results that can be adapted to all SCFE patients. However, we included patients with most common type slippage; chronic unilateral slippage, and we applied the same treatment to these patients in one center and evaluated a relatively homogeneous patient population compared with a matched control group. We also included mild, moderate and severe slip degrees. If we include only mild or severe slips, the result may be misleading. For example, in patients with severe slip angle, kinematic gait deviations the results could be clearer and more exaggerated (5).

In conclusion, we detected significant gait deviations in unilateral SCFE patients who have relatively good clinical and radiological outcomes. These findings may point out early findings of hip instability that could be result in painful hip, or even coxarthrosis in SCFE patients. Our study may guide further studies when evaluating the association between gait function and patients' clinical and radiological outcomes.

Conflict of interest and source of funding: The authors declare that they have no conflict interests. 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. The study was approved by the Baltalimani Bone and Joint Disease Institutional Review Board (IRB) and ethical committee (Ref Number: 2014-03/07).

CONCLUSION

In conclusion, we detected significant gait deviations in unilateral SCFE patients who have relatively good clinical and radiological outcomes. These findings may point out early findings of hip instability that could be result in painful hip, or even coxarthrosis in SCFE patients. Our study may guide further studies when evaluating the association between gait function and patients' clinical and radiological outcomes.

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