The gait function of slipped capital femoral epiphysis in patients after growth arrest and its correlation with the clinical outcome

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Abstract

Purpose Slipped capital femoral epiphysis (SCFE) represents the preliminary stage of osteoarthritis. Reliable tools for outcome evaluation should be developed to prevent persisting defects. The functional outcome of SCFE-patients after growth arrest is analysed by instrumented 3D-gait analysis (GA). The results are matched to the clinical examination findings.

Methods A total of 39 SCFE patients after growth arrest (18.8 years; BMI 26.5 kg/m²) with unilateral affection were included. The clinical results were classified according to Harris hip and clinical Heyman Herndon scores. 3D-GA-parameters were evaluated and compared to the sound side and a group of 40 healthy adults (28.0 years; 21.9 kg/m²). The subgroup analysis was performed according to clinical results. **Results** The clinical examination revealed very good results. GA could detect even small alterations. Some parameters indicated sustained functional impairments: Compared to the control group patients' walking speed ($p=0.022$), step frequency ($p<0.001$) and single support of the slip side ($p<0.001$) decreased, while step width ($p=0.014$), double support ($p=0.004$) and stance time of sound side increased ($p=0.001$). For kinematics patients, the sagittal range of motion (ROM) of pelvis ($p<0.001$) and the external rotation of the ankle on both sides increased ($p=0.011$) and sagittal ROM of hip ($p=0.002$) and knee flexion of slip side ($p<0.001$) decreased. The sagittal ROM

of the ankle on the slip side decreased compared to the sound side ($p=0.003$). Subgroup analysis revealed a positive correlation between clinically unsatisfying results and GA parameters.

Conclusions Functional impairments in SCFE-patients can be found even after growth arrest. Alterations are explained partly by the disease and partly by patients' constitution. BMI-matched controls and long-term follow-up are needed.

Introduction

Slipped capital femoral epiphysis (SCFE) is the most common disorder of the hip in adolescents [1, 2]. In SCFE a non-traumatic displacement of the epiphysis from the metaphysis into medial, dorsal and caudal directions occurs through the physeal plate. As its aetiology and treatment concepts have not been resolved [3–5], the disease is an often discussed topic to date. The debate about the treatment concepts is still controversial [2, 6]. Residual changes can lead to the development of secondary osteoarthritis. SCFE is therefore regarded as a deformity presenting a preliminary stage of degenerative joint disease [4, 7]. The development of reliable tools for evaluating therapy and outcomes are necessary in order to detect persisting deviations and to understand their influence on long-term outcome.

Up to now outcome has been evaluated solely by clinical and radiological evaluation that did not take into account any functional aspects. The present study aims to analyse the functional outcome of SCFE-patients after growth arrest by implementing an instrumented three-dimensional gait analysis (GA). The existence of permanent gait deviations is determined by comparing results with a group of healthy adults.

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The functional results are matched to the clinical examination findings which are routinely used for evaluation. Then the significance of results gained by GA is assessed.

Materials and methods

Study population

Patients

A total of 89 patients could be identified who have had surgery for SCFE between 1986 and 2005 at our department. The inclusion criteria were a diagnosis of unilateral SCFE and completed growth arrest. The exclusion criteria were any other disorder leading to gait alterations and a previous total hip replacement. Thus, 52 (58%) agreed to take part in the study, of which 39 met the inclusion criteria. The average age was 13.2 years (range, 10.0–15.9 years; SD 1.42) at surgery and 18.8 years (range, 13.3–32.0; SD 4.62) at follow-up examination. The average body-mass-index (BMI) at follow-up was 26.5 kg/m² (range, 18.4–34.2 kg/m²; SD 4.0). There were 5 cases of acute, 11 of acute-on chronic and 23 of chronic SCFE. Twenty-four patients were treated using Kirschner wires, eight using nails, one using screw fixation, three patients underwent subcapital osteotomy and three Imhäuser osteotomy. The average slipping angle was 31.6° (range, 8–60°; SD 13.7°).

Controls

The control group consisted of 40 healthy adults without any history of orthopaedic, neurological or other gait influencing disorders. The average age was 28 years (range, 21–52 years; SD. 6.9), and the average BMI was 21.9 kg/m² (range, 16.1–27.1; SD 1.8) All subjects underwent clinical examination and instrumented three-dimensional GA.

Clinical examinations

The clinical findings were evaluated according to the score of Heyman and Herndon [8] (Fig. 1) and Harris hip score

(HHS) [9]. The criteria of Harris hip score are “pain“, “function“, “absence of deformity” and “range of motion of the hip“. In total 100 points can be achieved in which “pain“ and “function“ with a maximum of 91 points are of most significant value.

Instrumented three-dimensional gait analysis

All subjects underwent instrumented three-dimensional GA. Twenty-two body markers were placed according to the Helen Hayes model extended by Richard Baker [10]. Spatiotemporal, kinematic and kinetic data were recorded with a VICON 512 system with eight 50-Hz cameras and two AMTI force plates. The subjects walked on a 10-m walkway, bare-footed, at a self-selected speed. The force plates had to be hit at least five times with each foot. The subjects did not know about the presence of the force plates. For analysis, data of each gait cycle were normalized to 100%. The resulting graphs consisted of 51 points, each point representing 2% of the gait cycle. Data were checked for consistency and averaged.

Data analysis

Processing of the GA data was done separately for the patients' left and right limbs. For the control group no distinction between limbs was made. Arithmetical mean and standard deviation (SD) were calculated. The mechanical work in the sagittal plane was calculated by integrating the area under the power curves. This method had been used previously by several authors [11, 12]. In addition to the analysis of the whole study population a subgroup analysis was performed in order to detect the influence of the clinical outcome on gait.

Statistical analysis was performed using SPSS software and utilizing Wilcoxon signed-rank test for comparing patients' slip and sound sides and Mann-Whitney U test for comparing patients' sides and the control group. A p-value below 0.05 was considered statistically significant. The study has been approved by the local ethics committee for medical studies. Patients or their parents gave their written informed consent.

Fig. 1 Score of Heyman and Herndon

group	rating	limp	pain	range of motion of the hip			
				internal rotation	abduction	flexion	reconstructive surgery
1	excellent	no	no	normal	normal	normal	no
2	good	no	no	slight limitation	normal	normal	no
3	fair	no	no	slight limitation	slight limitation	normal	no
4	poor	mild	slight after strenuous activity	slight limitation	slight limitation	slight limitation	no
5	failure	yes	with activity	marked limitation	marked limitation	marked limitation	yes

Fig. 2 Clinical results according to the Harris hip score (a) and the Heyman Herndon classification (b)

Results

Clinical examination

Clinical results according to the Harris hip score displayed very good results for most patients (Fig. 2a). Nevertheless, using the clinical Heyman Herndon classification a differentiation

between good and rather poor clinical results could be established (Fig. 2b). There was a correlation between patients' scoring in the HHS and the Heyman Herndon score: Patients assigned to the Heyman Herndon groups 1–3 had an average HHS of 99.5 ± 1.1 points, patients assigned to Heyman Herndon group 4 and 5 had an average HHS of 92.5 ± 5.9 points ($p < 0.001$).

Fig. 3 Sagittal plane kinematics

Instrumented three-dimensional gait analysis

Spatiotemporal parameters

Compared to the controls, patients' gait velocity was slower (1.21 m/s vs. 1.29 m/s, $p=0.022$), cadence decreased (109.8 vs. 117.1 steps/min, $p<0.001$) and step width increased (0.15 m vs. 0.13 m, $p=0.014$).

The stance phase was significantly reduced on the slip side (59.9%) compared to the sound side (60.6%, $p=0.001$); on the

sound side the stance phase was increased compared to the controls (59.7%, $p=0.006$). The single support phase on the slip side (39.4%) was shorter compared to the sound side (40.5%, $p<0.001$) as well as to the controls (40.2%, $p=0.035$).

Kinematics

Sagittal plane In the sagittal plane patients' pelvic range of motion (ROM) was significantly higher than in the control

Table 1 Kinematic parameters in the sagittal, frontal and transverse planes

Parameter	Slip side		Sound side		Control		p1	p2	p3
	μ	σ	μ	σ	μ	σ	Slip-sound	Slip-control	Sound-control
Sagittal plane									
Maximal pelvic tilt	13.9	5.15	14.0	5.9	12.8	4.41	0.848	0.362	0.383
Minimal pelvic tilt	11.3	5.16	11.2	5.17	10.9	4.39	0.115	0.883	0.914
ROM pelvis sagittal	2.7	0.72	2.7	0.72	1.9	0.89		<0.001	<0.001
Maximal hip flexion	34.3	7.06	35.6	6.69	35.8	5.34	0.064	0.290	0.791
Minimal hip flexion	-5.7	7.26	-6.5	6.62	-7.6	4.14	0.364	0.416	0.367
ROM hip sagittal	40.0	4.65	42.2	4.63	43.4	4.56	0.002	0.002	0.176
Maximal knee flexion	53.2	6.38	55.1	6.68	58.6	4.29	0.051	<0.001	0.009
Minimal knee flexion	0.0	4.46	-0.1	5.03	1.8	3.16	0.911	0.104	0.071
ROM knee sagittal	53.2	5.01	55.3	5.32	56.9	3.32	0.004	0.001	0.108
Maximal dorsal extension ankle	13.7	3.83	15.1	3.07	15.9	2.26	0.003	0.015	0.155
Minimal dorsal extension ankle	-13.0	4.69	-13.6	4.66	-12.4	6.16	0.503	0.617	0.327
ROM ankle sagittal	26.8	5.12	28.7	5.16	28.3	5.66	0.003	0.139	0.969
Frontal plane									
Maximal pelvic obliquity	3.0	3.02	2.6	3.22	4.4	1.20	0.442	0.025	0.001
Minimal pelvic obliquity	-2.6	3.21	-3.0	2.98	-4.3	1.17	0.435	0.001	0.027
ROM pelvis	5.7	3.08	5.7	3.08	8.7	2.35		<0.001	<0.001
Maximal hip adduction	5.1	4.87	4.9	4.14	4.8	2.15	0.848	0.666	0.829
Minimal hip adduction	-6.3	4.27	-6.6	4.20	-6.1	2.22	0.845	0.724	0.977
ROM hip	11.5	4.08	11.5	4.24	10.9	2.01	0.774	0.556	0.977
Maximal thorax tilt (towards swinging limb)	1.9	2.10	1.5	2.17	1.4	0.66	0.498	0.193	0.665
Minimal thorax tilt (towards supporting limb)	-1.8	2.60	-2.2	2.08	-1.6	0.69	0.404	0.885	0.161
ROM thorax	3.7	2.00	3.8	1.92	3.0	1.32	0.535	0.298	0.198
Maximal spine tilt (towards swinging limb)	3.4	3.28	3.8	3.62	5.5	1.27	0.648	0.015	0.161
Minimal spine tilt (towards supporting limb)	-4.1	4.06	-4.5	3.30	-5.6	1.25	0.623	0.109	0.148
ROM spine	7.7	3.52	8.4	3.47	11.1	2.51	0.174	<0.001	0.001
Transverse plane									
Maximal internal rotation pelvis	5.0	3.68	3.4	4.09	5.2	2.44	0.078	0.969	0.009
Minimal internal rotation pelvis	-2.8	3.80	-4.9	3.83	-4.8	2.37	0.018	0.001	0.731
ROM pelvis transversal	7.9	3.35	8.3	3.68	10.0	4.78	0.116	0.058	0.114
Minimal external rotation foot total gait cycle	-3.7	6.96	-4.4	6.80	-1.8	4.32	0.501	0.367	0.074
Minimal external rotation foot stance phase	-4.6	7.56	-4.9	6.81	-1.9	4.28	0.631	0.239	0.047
Maximal external rotation foot stance phase	-10.4	7.47	-11.2	6.36	-5.5	4.94	0.425	0.011	<0.001
ROM foot transversal	11.9	4.36	14.0	4.32	12.7	4.09	0.004	0.224	0.255

Arithmetical mean (μ) and standard deviation (σ) in degrees, patient group $n=39$, control group $n=40$, p1: p-value for comparison of slip side and sound side, p2: p-value for comparison of slip side and control group, p3: p-value for comparison of sound side and control group; statistically significant p-values are highlighted, thorax: inclination of trunk in relation to space; spine: inclination of trunk in relation to pelvis

group (2.7 ± 0.72 vs. 1.9 ± 0.89). However patients' ROM of the hip was significantly smaller on the slip side (40.0 ± 4.65) compared to the sound side (42.2 ± 4.63) and the control group (43.4 ± 4.56). A decrease in maximum hip flexion as well as an increase in minimum hip flexion on the slip side could be seen (Fig. 3, Table 1). Also, the patients' ROM of the knee was smaller on the slip side (53.2 ± 5.01) compared to the sound side (55.3 ± 5.32) and control group (56.9 ± 3.32). At the ankle a smaller maximum dorsal extension on the slip side was found resulting in a significantly reduced total ROM compared to the sound side (26.8 ± 5.12 vs. 28.7 ± 5.16).

Frontal plane The ROM of the spine relative to the pelvis (7.7 ± 3.52 vs. 11.1 ± 2.51) was significantly decreased compared to the controls. In addition, pelvic ROM (5.7 ± 3.08 vs. 8.7 ± 2.35) was significantly decreased due to a reduced maximum and minimum pelvic obliquity (Fig. 4). No further significant deviations could be found (Table 1).

Transverse plane The most striking finding was the patients' excess in external rotation of the longitudinal axis of the foot in relation to the direction of forward progression ("foot progression") on both sides compared to the controls (Fig. 5). Also the ROM of the foot was significantly smaller on the slip side (11.9 ± 4.36 vs. 14.0 ± 4.32) compared to the sound side.

Kinetics

The patients showed, in total, less positive mechanical work, especially on the slip side (0.249 J/kg), compared to the control group (0.270 J/kg). This was mainly due to a decrease in positive mechanical work at the hip and ankle (Table 2). Regarding the negative mechanical work, an increase on both patients' sides could be seen. A shift of negative mechanical work from the knee towards the hip could be noticed in the patients compared to the control

Fig. 4 Frontal plane kinematics of the pelvis

Fig. 5 Foot progression

group (Table 2). Total mechanical work of the sound side increased compared to the control group (Table 2).

Correlation clinical results and gait

In order to evaluate the influence of the clinical results on gait a subgroup analysis was performed. Patients with a clinical Heyman Herndon score ≤ 2 were assigned to the subgroup "good or excellent" ($n=17$), patients with a clinical Heyman Herndon score >2 to the subgroup "fair or worse" ($n=22$). Table 3 summarizes statistically significant differences between subgroups.

Discussion

SCFE is the most common disorder of the hip in adolescents and residual deformity is considered to be a predisposing factor for secondary osteoarthritis. Therefore the development of efficient treatment strategies based upon a reliable evaluation tool is mandatory. Up to now outcome studies have evaluated only subjective, clinical and radiological parameters [13–15]. Functional aspects and especially the influence on gait have been commonly neglected. According to our literature research there has been only one study focusing on this aspect [16]. In that study patients were also included when growth was not completed. So our study aims to analyse the gait pattern after SCFE in patients after growth arrest and the influence of clinical treatment on gait. The criterion "after growth arrest" suggested that remodeling processes at the hip were mainly completed.

Instrumented GA revealed interesting gait deviations in SCFE-patients on the slip and sound sides: in regards to spatiotemporal parameters a slower walking speed resulting from a decreased cadence at an even stride time was noticed in SCFE subjects compared to the control group (1.21 vs. 1.29 m/s). This could be explained by a general

Table 2 Positive and negative mechanical work and total mechanical work in the sagittal plane

Mechanical work sagittal plane (in J/kg)									
Measure	Slip side		Sound side		Control group		p1	p2	p3
	$\mu(\sigma)$	%	$\mu(\sigma)$	%	$\mu(\sigma)$	%	Slip-sound	Slip-control	Sound-control
Positive mechanical work									
Hip	0.081 (0.030)	32	0.089 (0.037)	34	0.096 (0.028)	36	0.01	0.06	0.096
Knee	0.037 (0.018)	15	.037 (0.015)	14	0.029 (0.014)	11	0.661	0.041	0.021
Ankle	.131 (0.029)	53	0.136 (0.033)	52	0.145 (0.042)	54	0.203	0.294	0.511
Sum	0.249	100	0.262	100	0.270	100			
Negative mechanical work									
Hip	0.082 (0.057)	33	0.083 (0.051)	31	0.055 (0.019)	24	0.989	0.056	0.008
Knee	0.090 (0.029)	36	0.010 (0.036)	37	0.106 (0.030)	46	0.094	0.039	0.399
Ankle	0.079 (0.022)	31	0.084 (0.019)	32	0.069 (0.026)	30	0.137	0.199	0.010
Sum	0.251	100	0.267	100	0.230	100			
Total mechanical work									
Hip	0.163 (0.060)	42	0.172 (0.057)	42	0.151 (0.033)	43	0.203	0.294	0.097
Knee	0.128 (0.038)	33	0.137 (0.047)	32	0.135 (0.037)	30	0.219	0.433	0.969
Ankle	0.210 (0.044)	25	0.221 (0.044)	26	0.214 (0.041)	27	0.067	0.992	0.583
Sum	0.501	100	0.530	100	0.500	100			

Arithmetical mean μ and standard deviation σ of mechanical work in joules per kilogram given as absolute value and as percentage of total. $p1$ is the p-value for the comparison of slip side and sound side; $p2$ is the p-value for the comparison of slip side and control group; $p3$ is the p-value for the comparison of the sound side and control group. Statistically significant p-values are highlighted

slowing down of movements caused by the patients' higher BMI [17]. But Song et al. [16] reported a slower walking speed of SCFE-patients compared to a body weight-matched

Table 3 Statistically significant results of subgroup analysis of spatiotemporal and kinematic parameters as well as mechanical work (in J/kg) according to clinical Heyman Herndon score

Subgroups according to clinical Heyman Herndon score					
	Good or excellent		Fair or worse		<i>p</i>
	μ	σ	μ	σ	
Spatiotemporal parameters					
Step length/body height_slip	0.39	0.03	0.37	0.03	0.029
Kinematic parameters					
Minimal hip flexion_sound	−8.7	6.31	−4.7	6.46	0.049
ROM hip sagittal_slip	41.7	3.85	38.5	4.87	0.040
Maximal pelvic obliquity_slip	4.1	3.25	2.1	2.53	0.018
Negative mechanical work					
Hip sagittal_slip	10.6	6.34	6.2	4.19	0.015
Hip sagittal_sound	10.3	5.91	6.7	3.50	0.049

Displayed are arithmetical mean (μ) and standard deviation (σ) of parameters with statistically significant differences between the subgroups. Clinical Heyman Herndon score "good or excellent", $n=17$; fair or worse " $n=22$. p-values given are a comparison of the better subgroup vs. worse subgroup

control group, so this could also be a consequence of the disease indicating the beginning of secondary osteoarthritis. The increased step width of the SCFE-patients might be due to being overweight [17]. It facilitates balance and can be a compensation for muscular weakness. In addition, it is described as a way of pain reduction [18].

Asymmetry in patients' gait could be detected: duration of the stance phase and single limb support, marking the most strenuous part of the gait cycle, were significantly longer on the sound compared to the slip side. This proves that even after growth arrest, mechanisms of protecting the affected side are still evident. Duration of double limb support increased. This was in accordance with Song's [16] findings. Further possible reasons for an increased time spent in double support are, lower walking speed [19] as well as obesity [17, 20].

The analysis of kinematic parameters revealed a rise in patients' range of movement of the pelvis in the sagittal plane. The ROM of the hip on the slip side however was significantly smaller than on the sound side and in the control group. These findings are likely to represent a mechanism of compensating limitations in the hip with the help of increased pelvic movement. They are consistent with the results of other authors investigating gait alterations in connection with diseases of the hip [18, 21, 22]. Patients' maximum knee flexion in swing was decreased. This could be explained by the slower walking speed [23]. Also, disease-related reasons could play a role as in accordance with findings of Song et al.

[16]. In the frontal plane, patients' pelvic ROM was decreased significantly symmetrically, due to a reduced maximum and minimum pelvic obliquity. The same applied to movements of the trunk in relation to the pelvis ("ROM spine"). The persistent lowering of the pelvis on the slip side described by Song et al. [16] could not be found in our data. In addition, our findings were not consistent with other authors who found an increase in the range of movement of the pelvis in the frontal plane [21, 22] and in pelvic obliquity [21] in patients with early or severe degenerative joint disease. An explanation might be that on average in our study population there were not any significant signs of degenerative hip disease evident.

The most noticeable finding in the transverse plane was the increase of foot external progression on both patients' sides. These findings are consistent with other studies evaluating the gait of SCFE patients [16] and could be best explained by the existence of a coxa retrotorta—a condition being thought of as a basic biomechanical reason for the development of SCFE next to biological factors [6, 7]. Also a more pronounced outward rotation of the foot in obese subjects has been described [17].

The kinetic findings are in accordance with Song et al. [16] who found in his population of SCFE patients a decline in positive mechanical work at the hip and ankle as well as a decline of negative mechanical work in the knee. Teixeira-Samela et al. [24] described a rise of positive mechanical work at the hip and negative mechanical work at the knee with increasing cadence. Therefore a decrease in cadence is able to explain the findings. Also a decrease of total positive mechanical work in combination with an increase in total negative mechanical work seems to be characteristic for obese individuals as reported by Nantel et al. [25]. The rise in negative mechanical work generated by the patients could be regarded as a sign of reduced gait efficiency.

Furthermore it was interesting that the slip side provided less positive as well as less negative mechanical work compared to the sound side. This can be regarded as a sign of protection of the slip side by means of the sound side even though there was no resulting reduction of step length on the slip side. Further research comparing SCFE patients with a control group of identical BMI should be performed in order to get a better idea of the causes for the changes.

Subgroup analysis revealed a positive correlation between a clinically unsatisfying (fair or worse) result and a reduced step length, a reduced ROM of the hip in the sagittal and a reduced pelvic obliquity in the frontal plane. On the sound side minimal hip flexion (corresponding to maximum extension) was correlated. Furthermore, reduced negative mechanical work of both hips correlated with an unsatisfying clinical result, although this parameter is increased relatively to the controls.

It can be concluded that GA showed significant deviations in gait after SCFE not only at the hip and pelvis but also at the

knee and ankle. The deviations are partly due to the disease itself and partly due to the patients' special constitution (obesity). With the help of GA it was possible to detect even small alterations that otherwise would not have been noticed. Unphysiological gait patterns can lead to unphysiological stresses on joints causing early onset of degenerative damage. Further studies have to show the influence of the radiological outcome on gait. In long-term follow-up they should answer the question as to which of the deviations described are relevant with respect to the development of osteoarthritis and whether special treatment (physiotherapy or surgery) may influence the long-term outcome.

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Conflict of interest The authors declare that they have no conflict of interest.

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