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ORIGINAL CLINICAL ARTICLE

Radiological outcome and gait function of SCFE patients after growth arrest

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Abstract

Purpose Slipped capital femoral epiphysis (SCFE) represents the most common disorder of the hip in adolescents and a preliminary stage of degenerative joint disease. Up to now, functional outcome evaluation measured by objective instruments has been commonly neglected. The present study investigates whether the pathoanatomy of the hip joint after SCFE—analyzed on a standard X-ray—match functional results gained by three-dimensional gait analysis. A variation of functional outcome depending on the radiological findings after growth arrest is hypothesized.

Methods Thirty-seven SCFE patients after growth arrest [mean age 18.5 years, standard deviation (SD) 4.61] with unilateral affection were included. The pathoanatomy of the hip joint was classified according to the radiological index of Heyman and Herndon and to asphericity. Three-dimensional gait analysis parameters were evaluated and subgroup analysis was performed according to the radiological results.

Results The radiological findings revealed very good results in general (average comprehensive index of Heyman and Herndon 94 ± 9 %, asphericity grade <2). Significant deviations of gait parameters in relation to the radiological result were an increase in step width, sagittal range of motion (ROM) of the pelvis and foot progression for the worse subgroup.

Conclusions Taken as a whole, the pathoanatomy of the hip joint after SCFE matched the functional results gained by gait analysis. Functional outcome varied slightly depending on the radiological findings after growth arrest. Differences were most pronounced for foot progression. Only with the help of gait analysis was it possible to describe deviations more precisely and objectively. Further studies are required in order to show which alterations are relevant for the development of secondary osteoarthritis.

Keywords Slipped capital femoral epiphysis · Instrumented gait analysis · Radiological outcome · Growth arrest

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Introduction

Slipped capital femoral epiphysis (SCFE) represents the most common disorder of the hip in adolescents [1, 2]. As residual changes can cause the development of secondary osteoarthritis, SCFE is regarded as a deformity presenting a preliminary stage of degenerative joint disease [3]. Up to now, outcome evaluation has been solely based on clinical and radiological results [4–6]. These did not take into account functional aspects. Only two publications evaluated the gait pattern by three-dimensional gait analysis [7, 8]: one analyzed solely the parameters foot progression angle and difference in stride length [9]. Compared to the controls, Westhoff et al. [8] found statistically significant impairments of the gait in SCFE patients after growth arrest: patients' gait velocity was slower, cadence decreased, and step width increased; timing became asymmetrical with reduced stance phase mainly due to reduced single support phase on the slip side compared to the sound side; deviations of the kinematics in the sagittal plane consisted in an increased range of motion (ROM) of the pelvis in combination with a reduced ROM of the involved hip and knee; in the frontal plane, ROM of the pelvis was reduced; in the transverse plane. the maximum foot progression angle was significantly externally rotated; analysis of the kinetics revealed that, overall, less positive mechanical work was provided.

Based on these findings, the present study investigates whether the pathoanatomy of the hip joint after SCFE—analyzed on a standard X-ray—match functional results gained by gait analysis. A variation of functional outcome depending on the radiological findings after growth arrest is hypothesized. Assessment of the relevance of gait analysis data is accomplished.

Patients and methods

Between 1986 and 2005, 89 SCFE patients were identified who have had surgery at our department. Inclusion criteria were a diagnosis of unilateral SCFE, completed growth arrest, and the availability of an X-ray of the pelvis in standing position and in Imhaeuser view after growth arrest. Only unilaterally affected patients were included so that deviations on the non-affected side could be interpreted as the compensation mechanism and are, with certainty, not due to the affects of the other hip. Exclusion criteria were any other disorder leading to gait alterations or a status after total hip replacement.

Fifty-two (58 %) patients agreed to take part in the study. Thirty-seven of these met the inclusion criteria. The average age at the time of surgery was 13.2 years [range 10.0–15.9 years, standard deviation (SD) 1.50] and 18.5 years (range 13.4–32.0, SD 4.61) at follow-up examination. The average body mass index (BMI) at the time of surgery was 24.6 kg/m^2 (range 17.3–32.5 kg/m^2, SD 4.0) and at follow-up, it was 26.9 kg/m^2 (range 18.4–34.2 kg/m^2, SD 4.5). The study population included five cases of acute, ten of acute on chronic, and 22 of chronic SCFE. Twenty-three patients were treated using Kirschner wires, seven using nails, one using screw fixation, three patients underwent subcapital osteotomy, and three Imhaeuser osteotomy. The average slipping angle was 31.4° (range 8°–60°, SD 14.1°). One patient sustained avascular necrosis of the femoral head after pinning with Kirschner wires, requiring Imhaeuser osteotomy over the course of the disease. There were no reports of chondrolysis or pin penetration. Four patients of the K-wire group required re-pinning because of growth.

The X-rays were analyzed according to the index of Heyman and Herndon [10] and to Mose [11]. The index of Heyman and Herndon is a comprehensive quotient calculated by averaging the results of the following four quotients: epiphyseal quotient, head–neck quotient, acetabular quotient, and acetabulum neck quotient. Each quotient is derived by dividing the corresponding index of the patient's slip side by the index of the patient's sound side. The calculation of the particular indices is shown in Fig. 1. A comprehensive quotient of ≥90 % is considered as being excellent. A quotient of 80–89 % is rated as a good, 70–79 % a fair, 60–69 % a poor, and less than 60 % a bad result.

With the help of a positioning device made of concentric circles, the asphericity of the femoral head could be assessed. According to Mose [11], spherity is given if the femoral head's surface deviates less than 2 mm from a given circle of the positioning device in the frontal and sagittal planes. Deviations >2 to ≤3 mm are classified as aspheric grade 1, >3 to ≤4 mm as aspheric grade 2, and >4 mm as aspheric grade 3.

Instrumented three-dimensional gait analysis was performed on all subjects. According to the Helen Hayes model extended by Richard Baker [12], 22 body markers were placed on each subject. With the help of a Vicon 512 system with eight 50-Hz cameras and two AMTI force plates, spatiotemporal, kinematic, and kinetic data were recorded. The subjects walked along a 10-m walkway barefooted at a self-selected speed. The subjects did not know about the presence of the force plates that had to be hit at

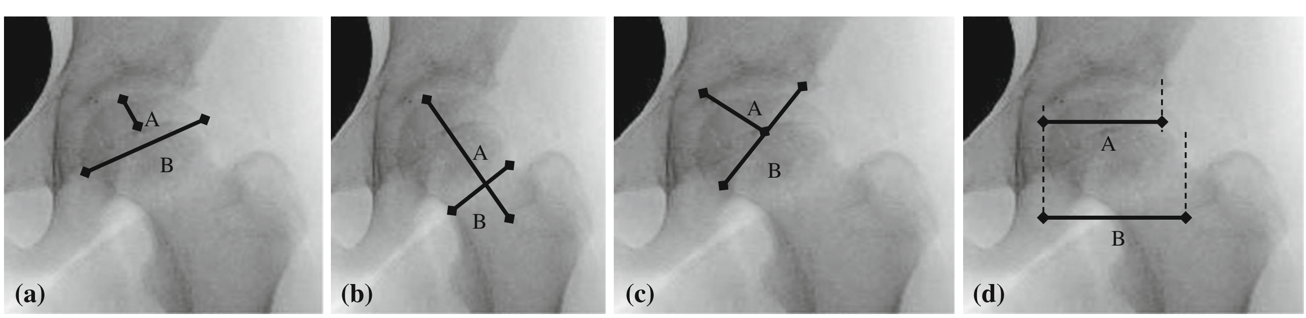

Fig. 1 Radiological index according to Heyman and Herndon [10]. **a** Epiphyseal index: epiphyseal height *A* divided by epiphyseal width *B*. **b** Head–neck index: length of femoral neck *A* divided by width of femoral neck *B*. **c** Acetabular index: acetabular depth *A* divided by acetabular width *B*. **d** Acetabulum neck index: covered part of femoral head *A* divided by epiphyseal width *B*

least five times with each foot. Data of each gait cycle were normalized to 100 %. The resulting graphs consisted of 51 points, with each point representing 2 % of the gait cycle. Data were checked for consistency and averaged.

Processing of the gait analysis data was done separately for the patients' left and right limbs. The arithmetic mean and standard deviation (SD) were calculated. The kinematic data evaluation included mainly the analysis of the maximum and minimum value, as well the ROM measurement of the trunk, the pelvis, the hip, the knee, and the ankle in the sagittal, frontal, and transverse planes. Positive and negative mechanical work were analyzed by identifying the areas under the power curve using the trapezoidal rule; positive values indicate work performed by concentrically acting muscles, while negative values indicate work performed by eccentrically contracting muscles.

A subgroup analysis was performed in order to detect the influence of the radiological outcome on gait. Patients with a radiological index of Heyman and Herndon ≥90 % represented the subgroup "excellent" ($n = 26$), while patients with an index <90 % formed the subgroup "good or fair" ($n = 11$).

Statistical analysis was performed using SPSS software and utilizing the Wilcoxon signed-rank test for comparing patients' slip and sound sides, and the Mann–Whitney *U*-test for comparing patients' sides and the control group. A *p*-value below 0.05 was considered as being statistically significant.

The study has been approved by the local ethics committee for medical studies. Patients or their parents gave their written informed consent.

Results

The radiological findings according to the index of Heyman and Herndon revealed very good results in general

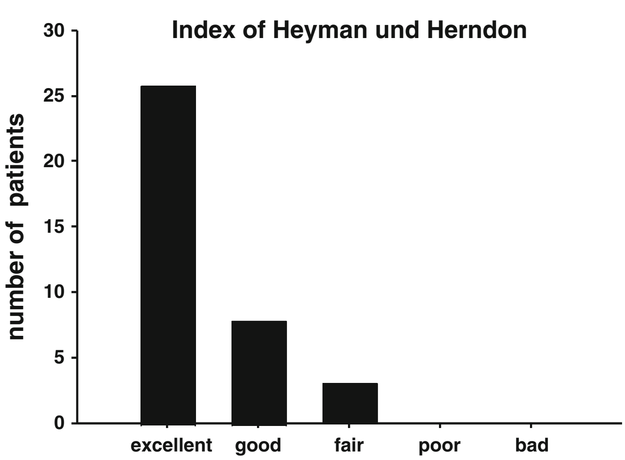

Fig. 2 Radiological results according to the index of Heyman and Herndon ($n = 37$)

(Fig. 2). The average comprehensive quotient of all 37 patients examined was 94 ± 9 %. None of the patients displayed a poor or bad result. Analysis of the four particular quotients that compose the comprehensive quotient showed good results for the epiphyseal quotient (mean 97 ± 21 %), acetabular quotient (mean 93 ± 14 %), and acetabulum head quotient (mean 100 ± 9 %). Only the head–neck quotient was considerably decreased (mean 84 ± 13 %), indicating a shortening and thickening of the patients' femoral neck on the slip side.

Asphericity measurements according to Mose in the anterior–posterior view revealed an average asphericity of grade 1.6 ± 1.2 on the slip side and 1.3 ± 1.1 on the sound side (Fig. 3). The difference was not statistically significant. Imhaeuser radiographs displayed an average asphericity of grade 1.2 ± 1.0 on the slip side and 0.7 ± 1.0 on the sound side. In this plane, the difference was statistically significant ($p = 0.04$).

The analysis of spatiotemporal parameters according to the radiological results revealed that a worse radiological index correlated with a further increase of step width (Table 1). There was no significant difference for gait velocity, cadence, and duration of the different phases of the gait cycle (stance, single stance, double stance, swing phase) between the radiological subgroups "excellent" and "good or fair".

For kinematic parameters in the sagittal plane, subgroup analysis showed an increase in ROM of the pelvis for the worse subgroup ($p < 0.001$). Maximum dorsal extension of the ankle increased in the worse subgroup on the sound side ($p = 0.050$). In the frontal plane, no statistically significant differences between the radiological subgroups could be found. Analysis of the transverse plane revealed a significant increase of external rotation of the longitudinal axis of the foot in relation to the walking direction ("foot progression") in the worse subgroup. On both of the patients' sides, the minimum foot progression displayed more externally oriented values on both sides during stance the phase (slip $p < 0.001$, sound $p = 0.028$), as well as during the whole gait cycle (slip $p = 0.002$, sound $p = 0.050$). Besides, an increase in the maximum foot progression during stance on the slip side ($p < 0.001$) was found. There were no significant differences in the motion pattern of the hip or knee joint in any plane between the two groups.

Comparing the two subgroups, a correlation was found between the radiological index of Heyman and Herndon and the patient's BMI. The worse radiological subgroup revealed a significantly higher BMI at the time of surgery compared to the superior subgroup (27.4 ± 3.6 vs. 23.4 ± 3.4 kg/m^2, $p = 0.01$). At follow-up after growth arrest, the difference was nearly equalized. By then, the BMI of both subgroups could be classified as obese (26.1 ± 4.2 vs. 27.7 ± 4.0 kg/m^2).

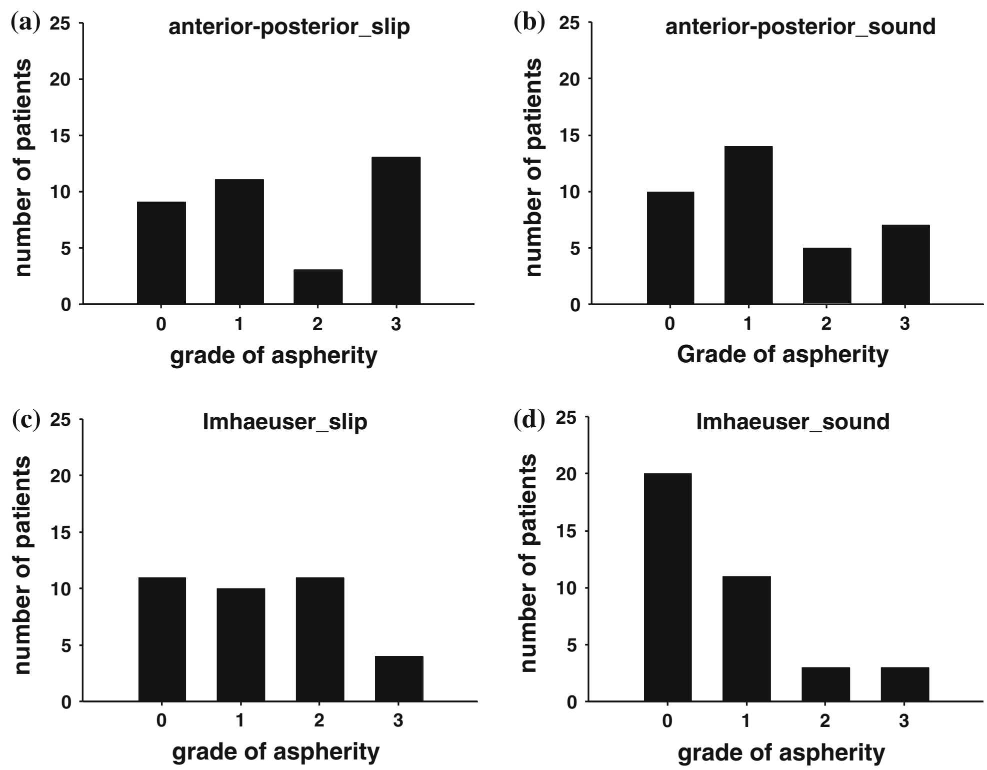

Fig. 3 Asphery measurements according to Mose: anterior–posterior view **a** slip side and **b** sound side; Imhaeuser radiographs **c** slip side and **d** sound side ($n = 36$)

Table 1 Significant results of subgroup analysis according to the radiological index of Heyman and Herndon; arithmetical mean (μ) and standard deviation (SD), subgroup "excellent" $n = 26$, subgroup "good or fair" $n = 11$, p-value for comparison between the two subgroups

Parameter	Excellent subgroup, μ (SD)	Good or fair subgroup, μ (SD)	p-Value
Step width (m)	0.14 (0.03)	0.19 (0.04)	0.005
ROM pelvis sagittal (°)	2.3 (0.55)	3.20 (0.80)	<0.001
Maximum dorsal extension ankle: sound side (°)	14.5 (3.19)	16.8 (2.28)	0.050
Minimum foot progression gait cycle: slip side (°)	−1.4 (6.45)	−9.0 (5.75)	0.002
Minimum foot progression gait cycle: sound side (°)	−2.9 (6.29)	−7.5 (6.81)	0.050
Minimum foot progression stance phase: slip side (°)	−1.5 (6.42)	−11.3 (5.97)	<0.001
Minimum foot progression stance phase: sound side (°)	−3.2 (6.38)	−8.6 (6.20)	0.028
Maximum foot progression stance phase: slip side (°)	−7.5 (6.00)	−17.2 (6.77)	<0.001

Discussion

SCFE is the most common disorder of the hip in adolescents and its sequelae are considered as predisposing factors for secondary osteoarthritis [3]. For improving treatment strategies, reliable tools for outcome evaluation are mandatory. Up to now, functional aspects and especially the influence on gait assessed by objective measuring instruments have been commonly neglected in outcome studies. Usually, only subjective, clinical, and radiological parameters have been evaluated [4–6]. Gait impairments in SCFE patients after growth arrest have been demonstrated by Westhoff et al. [8]. Not only the movement pattern of the hip joint but also of the pelvis, knee, and ankle were affected. The impairments could be partly explained as a consequence of the disease itself and partly as an effect of the patient's obese constitution. The criterion "after growth arrest" is of importance, as it assumes that remodeling processes at the hip were mainly completed.

Our study now investigates whether the pathoanatomy after SCFE analyzed by a standard X-ray has an influence on the patient's gait after growth arrest. The pathoanatomy was classified according to the index of Heyman and Herndon, which is a good indicator to describe the anatomical changes of the proximal femur itself and in relation to the acetabulum in comparison to the sound side. Being a comprehensive quotient of four different parameters, the index of Heyman and Herndon is particularly suitable to evaluate the various anatomical aspects of the hip that are essential for hip function. The index, or parts of it, have been used for radiological outcome evaluation of hip diseases in different studies [13–15]. Besides, the shape of the femoral head was evaluated according to Mose [11] because asperity of the femoral head can cause decreased function and, in the long term, osteoarthritis of the hip. It has been previously used for evaluation in SCFE, Perthes' disease, and hip dysplasia [6, 13, 15].

In order to investigate the influence of radiological outcome on SCFE patients' gait, subgroup analysis was performed. For spatiotemporal parameters, it revealed an increase of step width in the worse subgroup. An increased step width leads to more stability and might reduce hip loading; it is, therefore, usually associated with pain reduction on the one hand [16] and obesity on the other hand [17]. Both factors should be considered in the case of our study. First, a worse radiological result could cause a stronger need to alter gait patterns in order to prevent pain. Second, the worse subgroup has a slightly higher BMI (27.7 ± 4.0 vs. 26.1 ± 4.2 kg/m^2), so the influence of obesity on gait could be increased, on average.

For kinematic parameters in the sagittal plane, the worse radiological subgroup showed a slight—but statistically significant—increase in the ROM of the pelvis. This fits findings of the analysis of the whole study population [8]. Patients had a significant higher ROM of the pelvis in the sagittal plane compared to the controls. Besides. patients' ROM of the hip on the slip side was decreased, so the increased movement of the pelvis could be regarded as a way of compensating for the reduced hip movement. This mechanism has been described in the literature in connection with diseases of the hip [16, 18, 19]. It is regarded as a way to achieve extension of the leg, despite reduced hip movement [20].

The most pronounced differences between the subgroups were found in the transverse plane: the worse radiological subgroup's minimal foot progression displayed more externally oriented values on both sides during the full gait cycle, as well as during the stance phase. Besides, the maximal external foot progression in the stance phase was significantly increased on the slip side for the worse subgroup (17.2° vs. 7.5°). This is consonant with the findings of the analysis of the whole study population [8], which revealed that patients had a significantly increased external rotation of the foot compared to the control group. Increased external foot progression in SCFE patients has already been described in the literature [7, 9]. As it is observed on both the slip and the sound sides, it can be regarded as a sign of coxa retrotorta, which is considered to be a biomechanical risk factor for the occurrence of SCFE [21]. Another reason for the increase in external foot progression could be patient obesity, as stated in the literature [17]. Regarding patients' BMI, this connection could partly explain the difference between the worse and better radiological subgroup. Nevertheless, the enormous increase in external foot progression in the worse radiological subgroup compared to the better radiological subgroup shows that even small radiological alterations lead to functional changes in the transverse plane. Therefore, it can be concluded that the transverse plane seems to be the most sensitive plane to indicate functional impairments. Further studies are needed in order to investigate this relationship.

Overall, it is surprising that no further deviations of the kinematics—especially at the pelvis in the frontal plane and at the hip—or of the kinetics of the hip could be found according to the radiological outcome. This could be due to the fact that the subgroup "good or fair" was relatively small and there were no patients with a poor outcome. So, the radiological differences between the groups were not very pronounced.

It could be argued whether a standard X-ray is the appropriate method for evaluating the configuration of the hip joint. A computed tomography (CT) scan with three-dimensional reconstruction views would definitely be more informative. However, we feel that this is not justifiable ethically, due to radiation exposure.

In the context of data analysis, it occurred that the BMI of the radiologically worse subgroup was increased significantly at the time of surgery compared to the better subgroup. This is an interesting finding and further studies are needed in order to investigate whether a causal connection exists.

In conclusion, it can be stated that, in general, radiological examination revealed pleasing results that altered only slightly from the control group. At large, the radiological findings matched the functional results gained by gait analysis and the hypothesized variation of functional outcome depending on the radiological findings after growth arrest could be found. But the difference in the functional impairments during gait between the patients with an excellent and good/fair radiological result measured by three-dimensional instrumented gait analysis in early adulthood was minor and most pronounced in the transverse plane (foot progression angle).

Only with the help of gait analysis was it possible to describe deviations more precisely and to detect functional modifications, as an unphysiological gait pattern can lead to unphysiological stresses on joints and can, consequently, cause early onset of degenerative damage. Further studies are required in order to show which deviations are relevant in respect to the development of osteoarthritis. Improved knowledge in this context should help to assess whether special treatment regimens including physiotherapy or surgery may influence the long-term outcome of SCFE.

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Conflict of interest Each author certifies that he or she has no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article. The authors declare that they have no conflict of interest.

Ethical statement The study has been approved by the local ethics committee for medical studies. Patients or their parents gave their written informed consent.

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