Significance of clinical and radiographic findings in young adults after slipped capital femoral epiphysis

Christoph Zilkens · Bernd Bittersohl · Marcus Jäger ·
Falk Miese · Johannes Schultz · Jörn Kircher ·
Bettina Westhoff · Rüdiger Krauspe

Received: 20 March 2010 / Revised: 13 July 2010 / Accepted: 19 July 2010 / Published online: 8 August 2010
© Springer-Verlag 2010

Abstract The purpose of this study was to assess the clinical and radiographic presentation of young adults in the mid-term follow-up after pinning in situ for mild to moderate slipped capital femoral epiphysis (SCFE). We postulated that there was a correlation between the degree of head-neck-offset decrease and clinical and radiographic signs of hip joint degeneration. Thirty-eight young adults (average age 23.4 ± 3.6 years old) with various grades of femoral head-neck-offset pathologies were assessed clinically via Harris hip score (HHS), Tegner-Lysholm score (TLS) and Short Form 36 (SF-36), and radiographic signs of OA were measured on plain X-ray films after a follow-up of 11.1 ± 3.8 years. We conclude that clinical and radiographic signs of joint degeneration appear early in the follow-up after SCFE, but there is no linear correlation between offset-pathology and joint degeneration.

Introduction

Most premature osteoarthritis (OA) of the hip joint is a sequel of acquired or developmental hip disorders such as developmental hip dysplasia (DDH), Legg-Calvé-Perthes disease (LCPD) or slipped capital femoral epiphysis (SCFE). In SCFE, a direct correlation has been presumed between slip

severity and patient long-term outcome with less favourable results for patients with more severe deformity [1–3]. OA due to SCFE is reported to develop in up to 41% of the cases [4].

Specific disease- and treatment-related complications of SCFE include chronic loss of range of motion, secondary degenerative OA due to femoroacetabular impingement (FAI) and other biomechanical parameters, avascular necrosis of the femoral head, chondrolysis and surgery-related complications such as metal failure or migration, infections and fractures.

The reduced head-neck-offset as residual deformity of SCFE may lead to a transmission of abnormal force patterns through the femoral head/neck junction and the acetabular rim which is prototypical for the cam type of femoroacetabular impingement (FAI) [5]. Subsequently, functional limitations, articular cartilage damage and premature OA may occur [6–9].

In our study we reviewed the clinical and radiological outcome of young patients in the intermediate follow-up after pinning in situ for mild or moderate SCFE. For comparative analysis, the study cohort of 38 patients was subdivided according to the degree of femoral head-neck-offset pathology. We postulated that there was a correlation between the degree of reduced offset and clinical disability (hip range of motion, Harris hip score, Tegner-Lysholm activity score, Short Form health survey SF-36) and radiographic signs of OA (Tönnis grade, minimal joint space width at the weight bearing zone).

Materials and methods

This study was approved by the local ethics committee for medical studies and informed consent was obtained from all patients.

C. Zilkens (✉) · B. Bittersohl · M. Jäger · J. Schultz · J. Kircher ·
B. Westhoff · R. Krauspe
Department of Orthopaedic Surgery,
University Hospital of Duesseldorf,
Duesseldorf, Germany
e-mail: christoph.zilkens@med.uni-duesseldorf.de

F. Miese
Department of Radiology, University Hospital of Duesseldorf,
Duesseldorf, Germany

Study population

In a retrospective study, the databases of two adjacent orthopaedic hospitals were screened for patients who had been treated for mild (slip angle $<30^\circ$) or moderate (slip angle $30\text{--}50^\circ$) SCFE by pinning in situ and prophylactic pinning of the contralateral hip. Prophylactic pinning of the unaffected contralateral hip joint was performed on a routine basis as standard clinical guideline in the two institutions. Exclusion criteria were age less than the legal age of 18 years, a follow-up period postoperatively of 20 years or more, further hip surgery other than pinning in situ and hip diseases other than SCFE. Regardless of the presence of symptoms, a total of 38 adult patients (25 males, 13 females; mean age at follow-up 23.4 ± 3.6 years, range 18.1–30.5 years) who were treated surgically between 1990 and 2005 could be included in the study. The mean follow-up after pinning in situ was 11.1 ± 3.8 years (range 3.6–19.5 years) and mean age at surgery was 12.2 ± 2.1 years (range 6.8–17.4 years). Bilateral hip joint involvement was present in nine patients, leaving 29 contralateral hip joints as a clinically and radiologically healthy control group for range of motion assessment.

Asymptomatic and radiographically normal appearing hip joints of SCFE patients (control group 1) were used for ROM comparison because (1) hereby, a truly matched statistical comparison between normal and SCFE hip joints from one individual (radiographically verified) was possible (hip joint ROM varies due to constitutional parameters such as size, body weight, gender and other parameters such as training condition, laxity of ligaments) and (2) an abnormal hip joint morphology that may be asymptomatic cannot be ruled out without radiographic evaluation. For ethical reasons, however, X-rays were not obtained from control group 2. Ten bilaterally asymptomatic volunteers (control group 2) were included since functional HHS- and Tegner-Lysholm items such as walking ability, ability to use public transportation, level of sports activity and others cannot clearly differentiate between unilateral asymptomatic and unilateral symptomatic hip joints versus completely asymptomatic joints.

Clinical assessment

Hip function and clinical symptoms were evaluated with the Harris hip score (HHS) [10]. In addition, the activity level with regard to occupation and sports activity of each individual was graded according to the Tegner-Lysholm activity score ranging from 0 points (sick leave or disability pension) to 10 points (competitive sports: national or international elite) [11]. The Short Form health survey SF-36 was applied to measure the health-related quality of life and to elucidate the interdependence between morbidity,

satisfaction, risk factors, health related behaviours, social status, age and gender on the one side and the subjective assessment of health-related quality of life on the other [12].

Detailed range of motion (ROM) assessment of both hip joints was performed by one well-trained medical technical assistant who was blinded to other clinical and radiological parameters. Twenty-nine contralateral radiographically and clinically normal appearing hips served as a control group for ROM and radiographic assessment. Ten asymptomatic volunteers served as a control group for the HHS and Tegner-Lysholm score assessment.

Plain radiographic evaluation

An anterior-posterior radiograph of the pelvis in the standard technique with neutral rotation of the pelvis and with the beam centred on the symphysis pubis and a lateral view (Lauenstein) of the hip were obtained. Plain radiographic evaluation included Tönnis grading [13] and measurement of the minimal joint space width (JSW) at the weight-bearing zone [14]. Alpha-angle measurement [15] was performed on the Lauenstein view for femoral head-neck offset analysis. Alpha-angle values were used to classify three sub-groups: group 1, subjects with normal femoral head-neck offset (alpha angle $<50^\circ$); group 2, subjects where a mild offset decrease was noted (alpha angle $50\text{--}60^\circ$); and group 3, subjects exhibiting severe offset insufficiency (alpha angle $>60^\circ$) (Fig. 1).

Statistical analyses

SPSS® software (version 16.0, SPSS Institute, Chicago, IL, USA) was used for all statistical analyses. Continuous data was expressed as mean and standard deviations (SD). In order to reveal statistically significant differences between the various study groups and the control group, the Mann-Whitney U-test (independent samples) or the Student's *t*-test (parametric variables, independent samples) was applied. *P*-values below 0.05 were considered to prove statistically significant differences.

Results

Out of 38 hips, eight hips (21.1%) were classified as group 1 (no offset decrease), nine hips (23.7%) as group 2 (moderate offset decrease), and 21 hips (55.3%) as group 3 (severe offset decrease). Nine out of 38 contralateral hips showed moderate or severe offset decrease; these joints were excluded from the control group leaving 29 clinically and radiologically normal appearing hip joints as controls. With regard to radiological evidence of OA, Tönnis grade 0

Fig. 1 Three groups of offset decrease of the femoral head/neck junction in the follow-up after slipped capital femoral epiphysis (SCFE) according to the alpha-angles (Nötzli [15]) assessed in the lateral (Lauenstein) view of the hip. **a** Group 1, no offset decrease, alpha-angle $<50^\circ$. **b** Group 2, moderate offset decrease, alpha-angle between 50° and 60° . **c** Group 3, severe offset decrease, alpha-angle $>60^\circ$

was documented in nine hips in the group of non-affected hips (9/29), in no hip in study group 1 (0/8), in two hips in study group 2 (2/9) and in one hip in study group 3 (1/21). Tönnis grade 1 was documented in 20 hips in the group of non-affected hips (20/21), in eight hips in study group 1 (8/8), in seven hips in study group 2 (7/9) and in 20 hips in study group 3 (20/21). The minimal joint space width in the weight bearing zone was 3.2 ± 0.6 mm in the group of non-affected hips, 3.6 ± 0.5 mm in study group 1, 3.3 ± 0.7 mm in study group 2 and 3.4 ± 0.5 mm in study group 3. There was no statistically significant difference between the four

groups concerning Tönnis grade of OA or minimal joint space width measurement ($p > 0.05$).

Detailed information on range of motion measurement is given in Table 1. Note that there is no statistically significant difference between the different groups of offset decrease and the control group of 29 non-affected contralateral hips. Internal rotation in 90° of hip flexion is reduced to 22° in study group 3, but statistical significance was not reached.

Mean values and range for the HHS items for pain, function, the overall HHS (HHS sum) and for the Tegner-Lysholm score are shown in Table 2. Statistically significant differences were noted (p -values ranging from <0.001 to 0.035) for the HHS item pain, HHS sum and Tegner-Lysholm in all three study groups compared to ten healthy volunteers. Results of the Short Form health survey (SF-36) questionnaire for the whole study group and for groups 1–3 in comparison to normative data for the German population (male, ages 20–29 years) are provided in Table 3. We found considerable differences between the study groups and the normative data for *physical functioning* (PF) and *role physical* (RP). However, no significant differences were noted for the remaining parameters.

Discussion

The reduced head-neck-offset as residual deformity of SCFE is prototypical for cam-type femoroacetabular impingement (FAI) [6, 8, 9] that may cause pain, disability and early hip joint OA. The risk of developing OA has been reported to correlate with the grade of residual hip deformity [1, 16–18]. However, the exact mechanisms of hip joint damage and degeneration are still far from being understood, and patients with severe offset decrease due to SCFE may do well even for decades whereas patients with minor hip deformities may develop early OA.

In this study we compared clinical and radiographic findings of 38 young adults with various grades of head-neck offset pathologies in the mid-term follow-up after pinning in situ for mild or moderate SCFE. We classified the offset decrease as a consequence of SCFE into three different groups and questioned whether or not there were significant differences between the groups with respect to clinical or radiographic parameters.

In this series signs of mild radiographic OA were found in 92.1% (35 hips) of the affected hip joints. However, no statistically significant difference was noted between the different grades of offset decrease. Interestingly, in 68.9% (20 hips) of the non-affected, prophylactically stabilized hip joints there were also signs of mild OA. We observed no difference in terms of minimal joint space width in the weight bearing zone comparing the different study groups.

Table 1 Hip range of motion (ROM) of the different study groups (group 1, no offset decrease; group 2, moderate offset decrease; group 3, severe offset decrease) in comparison to the non-affected hips of the opposite side

ROM	Study group 1 (no offset decrease) (n=8)	Non-affected hips (n=29)	p-value
EXT	15.0°±7.5	15.3°±7.1	0.999
FLEX	105.6°±8.6	106.9°±7.7	0.992
ABD	31.8°±13.1	28.9°±6.2	0.636
ADD	17.5°±7.5	16.5°±3.8	0.943
IRO	31.8°±7.4	28.9°±9.4	0.829
ERO	40.6°±5.6	40.2°±7.7	0.998
ROM	Study group 2 (moderate offset decrease) (n=9)	Non-affected hips (n=29)	p-value
EXT	12.2°±3.6	15.3°±7.1	0.545
FLEX	100.0°±30.7	106.9°±7.7	0.423
ABD	26.1°±5.4	28.9°±6.2	0.617
ADD	13.9°±6.5	16.5°±3.8	0.385
IRO	31.1°±9.6	28.9°±9.4	0.911
ERO	39.4°±10.4	40.2°±7.7	0.991
ROM	Study group 3 (severe offset decrease) (n=21)	Non-affected hips (n=29)	p-value
EXT	14.5°±7.5	15.3°±7.1	0.964
FLEX	104.1°±8.1	106.9°±7.7	0.824
ABD	28.3°±5.3	28.9°±6.2	0.983
ADD	14.3°±4.2	16.5°±3.8	0.282
IRO	22.4°±11.0	28.9°±9.4	0.064
ERO	40.0°±6.1	40.2°±7.7	1.000

EXT extension, FLEX flexion, ABD abduction, ADD adduction, IRO internal rotation in 90° of flexion, ERO3 external rotation in 90° of flexion
Values are given as mean ± standard deviation (SD)

There was no statistically significant difference in ROM between the groups and in comparison to the healthy opposite hips

Furthermore, in contrast to our expectations, we found that the group of affected hips had a slightly higher mean joint space width (3.4 ± 0.6 mm, range 3–5 mm) compared to the contralateral, normal appearing controls (3.2 ± 0.6 mm, range 2–5 mm). This finding may be a result of a systemic co-factor of the disease or just show the limits of these measurements, but there might be a geometric change due to the slip of the epiphysis leading to an apparently larger joint space. Additionally, radiographic assessment may not reflect the precise damage to the articular cartilage [19]. There was no statistically significant reduction of any motion amplitude within the study groups when compared to the healthy, normal appearing controls (Table 1). Even in hips with severe offset decrease, there was only a trend towards impairment of range of motion that did not reach statistical significance. At least for the group with severe offset decrease we expected a painful restriction of internal rotation in 90° of hip flexion which is pathognomonic for patients with symptomatic FAI [20]. The Harris hip score revealed excellent results for the study group of 38 affected hips (HHS sum 91.9 ± 10.2 points, range 60–100 points). Statistically significant differences were noted (*p*-values ranging from <0.001 to 0.035) for HHS items for pain and

the overall score values (HHS sum) in all three study groups compared to ten healthy volunteers (Table 2). With regard to occupational and sports activity using the Tegner-Lysholm activity score, there were statistically significant differences in all groups of deformity in comparison to the healthy control group. The fact that even the group with no offset decrease and low pain level reached significantly lower scores in the Tegner-Lysholm activity score raises the question of what precluded the patients from pursuing sports more intensely. However, interpretation of the Tegner-Lysholm score, which was developed for the short-term follow-up after ligamentous knee injuries, might be problematic in the longer-term follow-up after SCFE. Also, higher activity levels may even contribute to earlier OA due to overloading of the SCFE hip.

There were remarkable differences between the study group patients and the corresponding normative data regarding the items *physical functioning* (PF) and of *role physical* (RP) of the SF-36 questionnaire. The other items did not show significant differences between the study population and normative data. This should be the subject of further and larger studies on how, when and to what extent young adults with a history of SCFE are impaired with

Table 2 Clinical evaluation by means of the Harris hip score (HHS) items for pain, function, range of motion (ROM) and the overall HHS (sum) and by means of the Tegner-Lysholm activity score for the different study groups (group I, no offset decrease; group II, moderate offset decrease; group III, severe offset decrease) in comparison to ten healthy volunteers

Evaluation	Study group 1 (no offset decrease) (n=8)	Volunteers (n=10)	p-value
HHS pain (points)	35.3±9.0	44.0±0.0	0.005*
HHS function (points)	44.5±2.9	47.0±0.0	0.015*
HHS sum (points)	88.5±11.9	100.0±0.0	0.005*
Tegner-Lysholm (points)	3.58	4.60	0.024*
Evaluation	Study group 2 (moderate offset decrease) (n=9)	Volunteers (n=10)	p-value
HHS pain (points)	38.4±8.2	44.0±0.0	0.008*
HHS function (points)	44.3±4.9	47.0±0.0	0.054
HHS sum (points)	91.6±13.0	100.0±0.0	0.003*
Tegner-Lysholm (points)	3.44	4.60	0.035*
Evaluation	Study group 3 (severe offset decrease) (n=21)	Volunteers (n=10)	p-value
HHS pain (points)	40.3±0.0	44.0±0.0	0.003*
HHS function (points)	44.7±4.0	47.0±0.0	0.028*
HHS sum (points)	93.4±8.2	100.0±0.0	<0.001**
Tegner-Lysholm (points)	3.87	4.60	0.001*

Values are given as mean ± standard deviation (SD)

Statistically significant differences in values ($p<0.05$) were found for all groups in HHS items for pain, the overall HHS (sum) and for the Tegner-Lysholm activity score compared to healthy, asymptomatic individuals. Interestingly, there was no statistically significant difference observed among the three different groups of offset pathology

* $p<0.05$

** $p<0.001$

regard to psychological, social, physical and everyday life components of well-being and function as perceived by the SF-36 questionnaire.

Our data are to some extent comparable to findings of other studies. At a mean follow-up of 41 years, Carney and Weinstein [21] noted evidence of joint degeneration in 63% where mild epiphyseal slip was evident at surgery and degeneration was apparent in all hips with moderate and severe epiphyseal slip. Häggglund et al. [22] noted OA in 24–53% at follow-up of 28 years after pinning in situ in 157 hips. Jerre et al. [23] assessed the range of motion

32.7 years after various forms of treatment in 128 hip joints after SCFE and noted no significant loss of motion except for some loss of internal rotation compared to normal hips; this was not statistically significant. Ross et al. [17] reported that many patients did well in the first two decades after SCFE but that symptoms increased and function decreased thereafter.

Contrary to studies that aimed at investigating the outcome of different modalities of treatment for SCFE, in our study we compared the intermediate clinical and radiological presentation of young patients all treated by

Table 3 SF-36 Short Form health survey

SF-36 measure	PF	RP	BP	GH	VT	SF	RE	MH
Study group (median) n=38	90	100	88	71	60	100	100	78
Study group (mean±SD) (n=38)	86.7±13.0	78.9±33.7	81.5±20.7	65.0±20.9	62.2±14.7	95.0±9.4	92.9±19.2	77.3±15.2
Normative data (mean±SD) (male, age 20–29 years)	95.6±9.2	92.0±20.7	77.1±23.0	73.2±15.8	63.2±15.4	90.7±14.9	94.2±18.2	75.7±13.9
Study group 1 (no offset decrease) (n=8)	86.2±12.4	68.7±39.5	75.5±20.2	61.0±25.1	63.7±17.2	93.7±13.3	79.1±35.3	82.5±11.9
Study group 2 (mild offset decrease) (n=9)	82.7±14.3	58.3±41.4	70.2±29.3	57.6±24.3	66.1±19.3	90.2±10.4	100.0±0.0	76.4±10.4
Study group 3 (severe offset decrease) (n=21)	88.5±12.9	91.6±21.4	88.5±13.5	69.7±17.2	60.0±11.5	97.6±6.3	95.2±11.9	75.8±17.8

PF physical functioning, RP role physical, BP bodily pain, GH general health, VT vitality, SF social functioning, RE role emotional, MH mental health, SD standard deviation

Substantially different values in the groups PF and RP

pinning in situ, regardless of the presence of symptoms. We expected the presence of symptomatic femoroacetabular impingement, pain, loss of function and early osteoarthritis at least to some extent in patients with significant offset pathologies (group 3).

In this cohort of 18–30-year-old adults, we found excellent results as measured by the Harris hip score (average, 91.9 ± 10.2 points). There was no limitation in the range of motion but in contrast we found radiographic signs of mild OA in 92.1% of the affected and 68.9% of the contralateral hip joints. We speculate that the radiographic findings are early signs which do not lead to clinical symptoms at this time. The same cohort will be followed for another decade. At that later period the correlation of clinical and radiographic measurements might be different with more symptoms from more progressive degeneration.

The results of a large cadaver study performed by Goodman et al. [24] showed that the contribution of subclinical SCFE to the development of primary OA of the hip joint was only 8% and that in only 37% of these cases, grade 2 OA developed. These results imply that even in the presence of predisposing factors such as a reduced head-neck offset, other thus far unknown factors might be more important as main aetiological factors in the pathogenesis of OA.

It remains contentious whether or not and how anatomical deviations due to SCFE predispose to the development of early OA and whether or not “prearthrotic deformity”, “tilt deformity” or “pistol grip deformity” are a sequel of SCFE or rather degenerative changes in later adulthood. Today and with respect to the femoroacetabular impingement, the question of how to surgically treat SCFE and/or residual hip deformities after SCFE is still vigorously debated. In a classic report, Leunig et al. [6] suggest that degenerative hip disease in children with SCFE can be triggered by early mechanical damage of the acetabular cartilage, and that FAI and long-term deterioration increase with the extent of deformity. In our study we found that in young people, the outcome after mild and moderate SCFE might be favourable even in the presence of severe offset pathologies and that in contrast radiographic signs of early OA may develop in hips without any anatomical deformity.

Other biochemical or biomechanical factors such as shear stress to the affected and to the opposite hip that contribute to the development of OA may be at work and need further investigation [25, 26].

Our study and other data raise the question about the pathomechanisms of labral and cartilage damage after SCFE. Additionally, a major factor for successful hip joint preservation is the extent of irreversible cartilage damage prior to surgery [5]. As a consequence of our findings and controversies in the literature [3], there is a need for the

implementation of new and more sophisticated magnetic resonance imaging techniques that are sensitive to biochemical changes within the joint cartilage such as delayed gadolinium enhanced MRI of cartilage (dGEMRIC), which might have the potential to further enlighten the interrelation of hip deformity, cartilage degeneration and the development of OA.

Using plain radiographs instead of radial MRI images to stratify the study cohort into three different groups of offset pathology might have biased the comparison analysis due to the decreased accuracy of alpha-angle measurement [27].

Another limitation of this study was the relatively small study cohort and the wide range of the follow-up period which might be a confounding factor in clinical presentation. On the other hand, the individuals were assessed regardless of the presence of symptoms, which excludes the risk of only analysing a subgroup of patients who are followed because of a symptomatic course after SCFE. However, our findings correlate well with previously reported studies on the mid-term outcome after SCFE.

The findings of this study in the intermediate-term follow-up after SCFE might be summarised as follows: (1) There is no linear correlation between offset-pathology and joint degeneration; (2) Radiographic signs of mild OA develop early in all groups of offset pathology in the affected hip as well as in the contralateral hip; (3) Range of motion remains within normal range for a long time; and (4) Signs of hip joint degeneration manifest early using clinical scores such as the Harris hip score, Tegner-Lysholm activity score or SF-36.

Acknowledgments This study was supported by a research grant of the “German Osteoarthritis Aid” (“Deutsche Arthrose-Hilfe e.V.”). We thank Mrs. Kamps for technical support.

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

References

1. Carney BT, Weinstein SL, Noble J (1991) Long-term follow-up of slipped capital femoral epiphysis. *J Bone Joint Surg Am* 73:667–674
2. Oram V (1953) Epiphysiolysis of the head of the femur; a follow-up examination with special reference to end results and the social prognosis. *Acta Orthop Scand* 23:100–120
3. Sella K, Wild A, Westhoff B et al (2006) Clinical outcome after transfixation of the epiphysis with Kirschner wires in unstable slipped capital femoral epiphysis. *Int Orthop* 30:342–347
4. Velasco R, Schai PA, Exner GU (1998) Slipped capital femoral epiphysis: a long-term follow-up study after open reduction of the femoral head combined with subcapital wedge resection. *J Pediatr Orthop B* 7:43–52

5. Beck M, Leunig M, Parvizi J et al (2004) Anterior femoroacetabular impingement: part II. Midterm results of surgical treatment. *Clin Orthop Relat Res* 67–73
6. Leunig M, Casillas MM, Hamlet M et al (2000) Slipped capital femoral epiphysis: early mechanical damage to the acetabular cartilage by a prominent femoral metaphysis. *Acta Orthop Scand* 71:370–375
7. Harris WH (1986) Etiology of osteoarthritis of the hip. *Clin Orthop Relat Res* 213:20–33
8. Stulberg SD, Cordell LD, Harris WH et al (1975) Unrecognized childhood hip disease: a major cause of idiopathic osteoarthritis of the hip. In: St. Louis RL Jr, Mosby CV (eds) *Proceedings of the third open scientific meeting of the hip society*, pp 212–228
9. Ganz R, Leunig M, Leunig-Ganz K et al (2008) The etiology of osteoarthritis of the hip: an integrated mechanical concept. *Clin Orthop Relat Res* 466:264–272
10. Harris WH (1969) Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am* 51:737–755
11. Tegner Y, Lysholm J (1985) Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res* 43–49
12. Ware JE Jr, Sherbourne CD (1992) The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. *Med Care* 30:473–483
13. Tönnis D (1976) Normal values of the hip joint for the evaluation of X-rays in children and adults. *Clin Orthop Relat Res* 119:39–47
14. Croft P, Cooper C, Wickham C et al (1990) Defining osteoarthritis of the hip for epidemiologic studies. *Am J Epidemiol* 132:514–522
15. Notzli HP, Wyss TF, Stoecklin CH et al (2002) The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. *J Bone Joint Surg Br* 84:556–560
16. Jerre T (1950) A study in slipped capital femoral epiphysis. *Acta Orthop Scand* 6
17. Ross PM, Lyne ED, Morawa LG (1979) Slipped capital femoral epiphysis long-term results after 10–38 years. *Clin Orthop Relat Res* 176–180
18. Schai PA, Exner GU, Hansch O (1996) Prevention of secondary coxarthrosis in slipped capital femoral epiphysis: a long-term follow-up study after corrective intertrochanteric osteotomy. *J Pediatr Orthop B* 5:135–143
19. Zilkens C, Holstein A, Bittersohl B et al (2010) Delayed gadolinium-enhanced magnetic resonance imaging of cartilage in the long-term follow-up after Perthes disease. *J Pediatr Orthop* 30:147–153
20. Clohisy JC, Knaus ER, Hunt DM et al (2009) Clinical presentation of patients with symptomatic anterior hip impingement. *Clin Orthop Relat Res* 467:638–644
21. Carney BT, Weinstein SL (1996) Natural history of untreated chronic slipped capital femoral epiphysis. *Clin Orthop Relat Res* 43–47
22. Hägglund G, Hansson LI, Sandstrom S (1987) Slipped capital femoral epiphysis in southern Sweden. Long-term results after nailing/pinning. *Clin Orthop Relat Res* 217:190–200
23. Jerre R, Billing L, Karlsson J (1996) Loss of hip motion in slipped capital femoral epiphysis: a calculation from the slipping angle and the slope. *J Pediatr Orthop B* 5:144–150
24. Goodman DA, Feighan JE, Smith AD et al (1997) Subclinical slipped capital femoral epiphysis. Relationship to osteoarthritis of the hip. *J Bone Joint Surg Am* 79:1489–1497
25. Zupanc O, Krizancic M, Daniel M et al (2008) Shear stress in epiphyseal growth plate is a risk factor for slipped capital femoral epiphysis. *J Pediatr Orthop* 28:444–451
26. Fishkin Z, Armstrong DG, Shah H et al (2006) Proximal femoral physis shear in slipped capital femoral epiphysis—a finite element study. *J Pediatr Orthop* 26:291–294
27. Dudda M, Albers C, Mamisch TC et al (2009) Do normal radiographs exclude asphericity of the femoral head-neck junction? *Clin Orthop Relat Res* 467:651–659