Radiological findings that may indicate a prior silent slipped capital femoral epiphysis in a cohort of 2072 young adults

The reported prevalence of an asymptomatic slip of the contralateral hip in patients operated on for unilateral slipped capital femoral epiphysis (SCFE) is as high as 40%. Based on a population-based cohort of 2072 healthy adolescents (58% women) we report on radiological and clinical findings suggestive of a possible previous SCFE. Common threshold values for Southwick’s lateral head–shaft angle (≥13°) and Murray’s tilt index (≥1.35) were used. New reference intervals for these measurements at skeletal maturity are also presented.

At follow-up the mean age of the patients was 18.6 years (17.2 to 20.1). All answered two questionnaires, had a clinical examination and two hip radiographs.

There was an association between a high head–shaft angle and clinical findings associated with SCFE, such as reduced internal rotation and increased external rotation. Also, 6.6% of the cohort had Southwick’s lateral head–shaft angle ≥13°, suggestive of a possible slip. Murray’s tilt index ≥1.35 was demonstrated in 13.1% of the cohort, predominantly in men, in whom this finding was associated with other radiological findings such as pistol-grip deformity or focal prominence of the femoral neck, but no clinical findings suggestive of SCFE.

This study indicates that 6.6% of young adults have radiological findings consistent with a prior SCFE, which seems to be more common than previously reported.

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Slipped capital femoral epiphysis (SCFE) is one of the most common hip disorders in adolescents, typically diagnosed between 11 and 15 years of age. Known risk factors are male gender, high body mass index (BMI), endocrine disorders such as hypothyroidism, hypogonadism or growth hormone supplement, and a family history of SCFE. The reported incidence varies from four to 80 per 100 000 according to ethnicity and method of ascertainment.

The association between SCFE and the development of degenerative changes has been shown in several previous reports. Murray stated that even a minor silent slip may lead to tilt deformities presenting as an idiopathic osteoarthritis (OA) later in life. However, his view was opposed by Resnick, who claimed that the tilt deformity occasionally seen in some patients with OA is more likely to be secondary to degenerative change. In a recent study on 67 patients with SCFE, we showed that approximately half had radiological findings suggestive of a bilateral slip, of which more than one-third were asymptomatic. The diagnosis was based on radiological findings, including a Southwick’s lateral head–shaft angle ≥13°. Jerre et al. found in a series of 100 patients that up to two-thirds of those with bilateral SCFE had an asymptomatic slip on the contralateral side at later follow-up, based on a slip angle of >13°.

In this study we report on the prevalence of radiological findings suggestive of a previous SCFE, based on the commonly used cut-off values for Southwick’s lateral head–shaft angle and Murray’s tilt index and also present new reference intervals for measurements commonly used for the diagnosis of SCFE.

Patients and Methods

Between 2007 and 2009, 4006 adolescents born in 1989 were approached by letter and invited to participate in a long-term clinical and radiological follow-up of a randomised hip trial. The initial cohort comprised all 5068 newborns delivered at Haukeland University Hospital, Bergen, Norway, during the year 1989. A total of 1062 subjects were excluded from the follow-up owing to death (n = 61), emigration (n = 256), or because they did not live in the catchment area defined for the study (n = 745). A total of 2081 (52%)...
agreed to participate, of whom 1207 (58%) were women. However, seven women were excluded because of uncertainty about their pregnancy status, one woman because of a subluxed hip related to severe cerebral palsy, and one man because of recently taken pelvic radiographs (Fig. 1).

The follow-up at 18 to 20 years of age included two questionnaires, two hip radiographs and a clinical examination. **Questionnaires.** The first questionnaire addressed hip problems in parents and siblings; the second included data on hip pain, walking disabilities, training habits, quality of life according to the EuroQol EQ-5D self-reported assessment,16 and the Western Ontario and McMaster Universities (WOMAC) osteoarthritis index.17 The EQ-5D scored mobility, personal hygiene, usual activities, pain/discomfort, and anxiety/depression on a three-level scale (no problem, some problems and severe problems). The resulting scores were translated into an EQ-5D index, with a maximum score of 100. Death scores 0 and conditions worse than death yield a negative score (EQ-5D index < 0).

The WOMAC index is a three-dimensional patient-centred health status questionnaire designed to capture elements of pain, stiffness and physical disability in patient with OA of the hip. The index is calculated from 24 five-level questions, giving a score between 0 (high Achiever) and 96 (poor achiever).

For physical exercise the subjects were asked to estimate hours a week with activity that made them sweat or breathless (none, half an hour, one hour, two to three hours, four to six hours or > six hours).

**Radiographs.** All examinations were performed at the Radiological Department, Haukeland University Hospital, using a low-dose technique (Digital Diagnost System v1.5; Philips Medical Systems, Eindhoven, The Netherlands). Two views were obtained, an erect anteroposterior (AP) view (feet pointing forward, neutral ab-/adduction position of the hips)18 and a frog-leg view, using a film–focus distance of 1.2 m and centred at 2 cm proximal to the pubis. All examinations were performed by the same, specially trained radiographer according to a standardised protocol. The images were analysed by one observer (LBL) measuring the lateral head–shaft angle (frog-leg view)19 (Fig. 2) and Murray’s tilt index (AP view)9 (Fig. 3), and new reference intervals were established based on the upper 95% reference interval (representing 1.96 standard deviations (SD) from the mean) of our cohort. In order to examine prevalences of radiological findings suggestive of a previous slipped epiphysis, we used cut-off values of 13° for the head–shaft angle13,14 and 1.35 for the tilt index9 according to the literature. In a separate session, the radiographs were
analysed subjectively by one experienced radiologist (KR). The following features suggestive of SCFE were assessed by gross visual inspection: pistol-grip deformity, focal prominence of the femoral neck, and flattening of the lateral aspect of the femoral head. In a third session, all examinations were measured by one of three observers (TGL, IOE or LBL) using a digital program, including three measurements of the joint space width: medially, in the middle and laterally. A joint space width ≤ 2.0 mm was suggestive of degenerative changes.

Clinical examination. The clinical examinations, which were performed by one of five specially trained physicians, included height, weight, leg length differences, hip mobility, Beighton’s hypermobility score, range of movement of the hip and an impingement test in flexion, adduction and internal rotation. All physicians standardised their examination technique prior to the study.

Ethics. The procedures followed were approved by the Regional Committee for Medical and Health Research Ethics and the Norwegian Data Inspectorate. Written informed consent was obtained from all the participants. A total of nine participants were scheduled for immediate follow-up by a senior radiologist (KR) and a senior orthopaedic surgeon (LBE) because of clinical or radiological findings related to the hip, pelvis or lumbosacral spine.

Statistical analysis. Data were summarised using mean and range. Continuous variables were compared using independent samples $t$-tests and chi-squared and Fisher’s exact tests for categorical variables. A significance level of $p < 0.05$ was decided beforehand, and all the reported $p$-values were two-tailed. Associations between different radiological findings were analysed by calculating the odds ratio (OR) with 95% confidence intervals (CI) between each of the features separately, with an OR > 2.0 considered to indicate a clinically relevant association. In order to examine for significant differences in BMI by head–shaft angle, BMI was dichotomised as overweight ($\geq 25$ kg/m$^2$) or not.

In order to adjust for non-responders in the calculation of prevalences we calculated inverse probability weights (IPW) based on a logistic regression model including gender, birth-weight, maternal age, marital status, parity, fetal position, and multiple births as covariates, based on data from the Medical Birth Registry of Norway. Different sets of probability weights were made for each of the prevalence calculations, owing to slight differences in missing values between the measures. The statistical package PASW Statistics 18 (SPSS Inc., Chicago, Illinois) was used for the statistical analyses, and the survey tools in Stata Statistical Software: Release 11 (StataCorp, College Station, Texas) was used to calculate the prevalence estimates.
Table I. Radiological hip measurements in a population-based cohort of 2072 18- to 20-year-olds by gender

<table>
<thead>
<tr>
<th>Hip measurements</th>
<th>Males (n = 873)</th>
<th>Females (n = 1199)</th>
<th>p-value*</th>
<th>Total (n = 2072)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean head–shaft angle (°) (range)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right hip (n = 1798)†</td>
<td>1.4 (-21 to 23)</td>
<td>0.6 (-22 to 20)</td>
<td>0.010</td>
<td>0.9 (-22 to 23)</td>
</tr>
<tr>
<td>Left hip (n = 1712)†</td>
<td>0.5 (-23 to 22)</td>
<td>-1.2 (-27 to 21)</td>
<td>&lt; 0.001</td>
<td>-0.6 (-27 to 22)</td>
</tr>
<tr>
<td>Mean tilt index (°) (range)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right hip (n = 2037)</td>
<td>1.1 (0.7 to 1.9)</td>
<td>1.0 (0.6 to 1.8)</td>
<td>&lt; 0.001</td>
<td>1.1 (0.6 to 1.9)</td>
</tr>
<tr>
<td>Left hip (n = 2042)†</td>
<td>1.1 (0.6 to 2.1)</td>
<td>1.0 (0.5 to 1.7)</td>
<td>&lt; 0.001</td>
<td>1.0 (0.5 to 2.1)</td>
</tr>
</tbody>
</table>

* independent sample t-test
† number of successful measurements

Table II. Prevalence of radiological findings believed to be associated with a prior asymptomatic slipped capital femoral epiphysis in 2072 18- to 20-year-old healthy adolescents by side. Numbers were adjusted for non-responders (CI, confidence interval)

<table>
<thead>
<tr>
<th>Radiological findings</th>
<th>Right hip</th>
<th>Left hip</th>
<th>Left or right hip</th>
<th>Bilateral</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>All participants</td>
<td>3.9 (2.9 to 4.9)</td>
<td>3.1 (2.2 to 3.9)</td>
<td>4.2 (0.33 to 0.52)</td>
<td>1.0 (0.5 to 1.4)</td>
<td>6.6 (5.3 to 7.9)</td>
</tr>
<tr>
<td>Tilt index ≥ 1.35</td>
<td>8.9 (7.5 to 10.2)</td>
<td>6.6 (5.4 to 7.8)</td>
<td>10.5 (9.1 to 11.9)</td>
<td>2.4 (1.7 to 3.1)</td>
<td>13.1 (11.6 to 14.7)</td>
</tr>
<tr>
<td>Male participants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head–shaft angle ≥ 13°</td>
<td>4.4 (2.8 to 6.0)</td>
<td>3.4 (2.0 to 4.7)</td>
<td>4.7 (3.2 to 6.2)</td>
<td>1.1 (0.3 to 1.8)</td>
<td>7.6 (5.4 to 9.8)</td>
</tr>
<tr>
<td>Tilt index ≥ 1.35</td>
<td>13.5 (11.2 to 15.8)</td>
<td>10.5 (8.4 to 12.6)</td>
<td>15.3 (12.8 to 17.7)</td>
<td>4.2 (2.9 to 5.5)</td>
<td>19.9 (17.2 to 22.7)</td>
</tr>
<tr>
<td>Female participants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head–shaft angle ≥ 13°</td>
<td>3.4 (2.3 to 4.5)</td>
<td>2.7 (1.8 to 3.7)</td>
<td>3.8 (2.7 to 5.0)</td>
<td>1.0 (0.4 to 1.5)</td>
<td>5.5 (4.1 to 6.9)</td>
</tr>
<tr>
<td>Tilt index ≥ 1.35</td>
<td>4.0 (2.9 to 5.1)</td>
<td>2.5 (1.6 to 3.4)</td>
<td>5.3 (4.1 to 6.7)</td>
<td>0.5 (0.1 to 0.9)</td>
<td>6.0 (4.6 to 7.3)</td>
</tr>
</tbody>
</table>

Results

A total of 2072 subjects were included in the study, comprising 1199 women and 873 men (Fig. 1). Prevalences were adjusted for non-responders as described in the statistical analysis. The mean age at follow-up was 18.6 years (17.2 to 20.1). It was possible to measure the head–shaft angle in at least one hip in 1925 (93%) of the subjects, and bilaterally in 1588 (77%); the corresponding figures for the tilt index were 2056 (99%) and 2024 (98%), respectively.

The mean head–shaft angle was 0.9° (-22° to 23°) for right hips, -0.6° (-27° to 22°) for left and 0.2° (-27° to 23°) for all hips, with upper 95% reference intervals of 13.9°, 13.3° and 13.8°, respectively. Statistically significant differences were found between men and women (Table I). The mean tilt index was 1.1 (0.6 to 2.1) for right hips, 1.0 (0.5 to 2.1) for left hips and 1.0 (0.5 to 2.1) for both hips (Table I), with upper 95% reference intervals of 1.43, 1.42 and 1.43, respectively.

With prevalences adjusted for non-responders, head–shaft angles ≥ 13° were measured in 7.6% of the men, 5.5% of the women and 6.6% of the entire cohort, whereas a tilt index ≥ 1.35 was found in 19.9% of the men, 6.0% of the women and 13.1% of all (Table II). Only six subjects (four men) tested positive for both markers.

Mean age, BMI and self-reported information on health status, hip problems and exercise at follow-up as well as range of movement of the hip are listed in Tables III and IV. The mean BMI for males and females did not differ (p = 0.05), but was significantly higher (23.8 kg/m²) in those with a head–shaft angle ≥ 13° than in those with lower angles (22.8 kg/m²) (p = 0.019). The difference in BMI remained statistically significant only in men with high angles (p = 0.035, independent sample t-test), and not in women (p = 0.13, independent sample t-test). A BMI ≥ 25 kg/m² was seen in 32 (32%) of those with an angle < 13° than in those with an angle ≥ 13° (p = 0.007, chi-squared test). However, both groups had a mean value below the threshold for overweight, and the clinical importance of this difference in BMI can be questioned. The mean internal hip rotation was decreased by 10° (range of internal rotation 10° to 90°) for persons with a high head–shaft angle compared with those with a low angle (p < 0.001, independent sample t-test), whereas the external rotation was increased by 7° (range of external rotation 0° to 80°) (p < 0.001, independent sample t-test). The differences in internal and external rotation remained statistically significant for both genders, except for left hip in men, where the reduction in internal rotation was not statistically significant (Table IV). No differences between groups were found for the remaining hip movements (Table IV), or for the degree of physical exercise undertaken. When based on our new 95% reference intervals for 18- to 20-year-olds, i.e. using a cut-off value of 14° for head–shaft angle, similar differences were noted for BMI (p = 0.026), increased external rotation (p < 0.001) and reduced internal rotation (p < 0.001, all independent sample t-tests).
reach significance according to our definition of an OR deformity or a focal femoral neck prominence, did not objectively assessed radiological findings, such as pistol-grip deformity, focal prominence of the femoral neck (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck (Table V). No differences were seen between those with a tilt index < or > 1.35 or 1.43 for either gender.

The relationships between the head–shaft angle and subjectively assessed radiological findings, such as pistol-grip deformity or a focal femoral neck prominence, did not reach significance according to our definition of an OR ≥ 2 (Table V). In contrast, tilt index was associated with a pistol-grip deformity, focal prominence of the femoral neck and lateral flattening (Table V).

No differences were seen in mean joint space width (JSW) between high and low head–shaft angle (mean middle JSW 3.7 mm vs 3.7 mm; p = 0.88), or high and low tilt index (mean middle JSW 3.6 mm vs 3.7 mm, p = 0.41)

The mean EQ-5D score was 92 (21 to 100) overall; for men alone the mean was 94 (21 to 100) and for women it was 91 (26 to 100) (p < 0.001) (Table III), with no significant differences according to head–shaft angle (p = 0.21) or tilt index (p = 0.63, all independent sample t-tests). The mean WOMAC score was 1.6 (0 to 68), with women scoring significantly higher (p = 0.002), but no difference was found with respect to the radiological measurements, high vs low head shaft angle (p = 0.17) or high vs low tilt index (p = 0.27, all independent sample t-tests). A total of 99 (4.9%) of the participants reported some problems with walking, but no relationship was found with high or low head–shaft angle (p = 0.81) or tilt index (p = 0.73, both Fisher’s exact test).
A clicking sensation, stiffness, or pain in the hip was reported by 109 participants (5.4%) during the three months prior to review, but this was not associated with any radiological findings.

**Discussion**

In this cohort of healthy 18- to 20-year-old Norwegians we found an association between Southwick’s head–shaft angle ≥ 13° and clinical findings common in patients with SCFE, such as reduced internal rotation, increased external rotation and a high BMI. Based on a cut-off value for head–shaft angle of ≥ 13°, 6.6% of the cohort (7.6% of men and 5.5% of women) had radiological findings indicating a previous slip. A high tilt index (≥ 1.35) demonstrated in 13.1% of the cohort was associated with additional radiological but no clinical findings suggestive of SCFE. With regard to BMI, both groups had a mean value below the limit of overweight, and the clinical relevance should be interpreted with care.

Our new reference intervals (of 1.96 SD from the mean) for the head–shaft angle and the tilt index in 18 to 20-year-olds support the commonly used cut-offs of 13° and 1.35, respectively.13,14 The cut-off of 13° is based on studies addressing radiological findings of SCFE and not on population-based cohorts. For the purposes of comparison, we performed analysis based on commonly used cut-offs, and also searched for associations between known risk factors for, and clinical findings in keeping with, SCFE and the newly established values. The results from the two sets of analyses did not differ substantially.

Several authors have used the difference in head–shaft angle between pathological and healthy hips in the diagnosis of SCFE.25-28 This approach may be flawed, as up to 60% of those suffering SCFE have bilateral involvement.12,29,30 Of the different radiological measurements used to diagnose SCFE,39,15,31 none of the measurements has proved superior with regard to intra- and inter-repeatability measurements.32-34 Carney and Liljenquist34 found the intra-observer variability of the head–shaft angle to be ±6° in a study including 108 hips, while Loder et al.35 in a study of 48 hips, found it to be ±12°. They also tested the variability of several other measurements and concluded that the head–shaft angle classified into discrete categories as mild, moderate and severe slip might increase the accuracy.

The tilt index, including the commonly used cut-off of 1.35, was initially proposed by Murray.9 Based on 100 controls and 200 patients with primary OA, he set the critical value at 1.35, above which a slip was likely. His findings have not been reproduced by others. However, our upper 95% reference interval of 1.43 does not differ substantially.

Typical characteristics of patients with established SCFE are male gender, overweight, and a reduced range of hip movement, especially internal rotation, flexion and abduction.35 Our findings support these associations, as men with high head–shaft angles had a higher mean BMI, lower internal rotation and higher external rotation than the rest of the male cohort. Except for the higher BMI, similar associations were seen for women.

Corresponding associations were not found for the tilt index. In a previous study12 including 67 children and adolescents with an established SCFE, only around 25% had a tilt index > 1.35, particularly those with the more severe slips, suggesting that the tilt index is a poor marker for milder degrees of SCFE. On the other hand, a high tilt index was associated with a pistol-grip deformity, lateral flattening of the femoral head and a focal prominence of the femoral neck. These features have also been associated with femoroacetabular impingement, causing groin pain during movement. Murray9 suggested that the pistol-grip deformity may be caused by a previous slip, but our results lend no support to this theory. Further, Resnick11 proposed that in elderly patients with OA the pistol-grip deformity or tilt index was due to degenerative changes. However, our study indicates that the tilt deformity is present long before any signs of OA have emerged. In our cohort the number of participants with a high tilt index corresponds well with reports addressing impingement.22,36,37 About 20% of young men and 3% to 4% of young women are thought to have a pistol-grip deformity that in time may give rise to cam impingement.

We acknowledge some limitations to our study. For instance there was some difficulty associated with measuring some of the radiographs, particularly with regard to the head–shaft angle. However, these radiographs were randomly distributed among the participants and should not cause any selection bias. Another source for selection bias, when estimating prevalence, was the moderate attendance rate of 52%. One might speculate that teenagers with ongoing hip problems would be more prone to participate. However, no differences in subjectively reported hip problems were found between participants with high tilt indices or head–shaft angles compared to those with lower values. Prevalences were adjusted for non-responders based on observed covariates such as gender, birth-weight, maternal age, marital status, parity, foetal position and multiple births, to reduce the possibility that the calculated prevalences were a result of selection bias. Nevertheless, the results must be generalised with care. Finally, there is the possibility that bony remodelling before skeletal maturity may have masked a previous slip.38,39

The strengths of the study include the population-based design, including analysis of non-responder data from the Medical Birth Registry of Registry, the large number of participants and the standardised clinical examination, imaging and interpretation.

A high number of radiological findings associated with possible previous slips were found in our cohort, far higher than found in clinical studies of patients treated for SCFE.6,30 However, a study by Goodman et al.40 found post-slip morphology in 8% of the male and 6% of female skeletons. Bilateral findings were present in 57%. They also found a correlation between post-slip morphology and the
development of OA. These prevalences correspond well with the numbers found in this study, and our findings may indicate that asymptomatic slips may occur more frequently than previously reported.

In summary, about 6.6% of participants in a large population-based cohort of 18- to 20-year-olds had a head–shaft angle above the previously reported cut-off of 13°. A high head–shaft angle was associated with clinical findings for SCFE, such as reduced internal rotation and higher BMI.

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References