Original Article

The lateral view head-neck index (LVHNI): A diagnostic tool for the sequelae of slipped capital femoral epiphysis

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Accepted: 6 March 2013

Keywords
Slipped capital femoral epiphysis; Lateral view head-neck index; Hip osteoarthritis; Hip X-ray; Hip deformity

Summary
Introduction: It is a well-known fact that slipped capital femoral epiphysis (SCFE) is one of the causes of premature hip osteoarthritis and anterior femoroacetabular impingement. But there are no reliable, published diagnostic methods to measure the residual deformity of slipped capital femoral epiphysis. We propose using the lateral view head-neck index (LVHNI) measurement on a specific lateral X-ray view of the hip for this purpose.

Hypothesis: The LVHNI can detect and quantify the posterior translation of the femoral head and this index can be measured reliably.

Materials and methods: A prospective radiography study was performed by three observers. The hip X-rays of patients who were being treated by arthroplasty for hip osteoarthritis (total hip replacement or hip resurfacing) between January 2010 and December 2011 were analyzed. The LVHNI, which quantifies the posterior translation of the femoral head, was measured on a lateral view of the hip in 45° flexion/45° abduction/30° external rotation. The presence of a pistol grip deformity on A/P X-rays was also assessed.

Results: The analysis was performed on 131 hips in 120 patients having an average age of 61 years (range 37–91). The chosen LVHNI threshold of 9% resulted in a sensitivity of 89.1% (95% CI: 78.8%–95.5%) and a specificity of 82.4% (95% CI: 71.2%–89.7%) for detecting the presence of a pistol grip deformity. Twenty percent of the hips with no visible deformity on A/P X-rays had a pathological index value. The inter-observer reproducibility was good for the LHNI [intraclass correlation coefficient (ICC): 0.61; 95% CI: 0.51–0.71] and for detecting a pistol grip deformity (ICC: 0.74; 95% CI: 0.62–0.85). The intra-observer reproducibility was excellent for the LHNI (ICC: 0.78; 95% CI: 0.57–0.88) and the pistol grip deformity (ICC: 0.85; 95% CI: 0.74–0.92).

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Introduction

Slipped capital femoral epiphysis (SCFE) is usually diagnosed in adolescents based on intense or persistent pain in the hip joint [1]. Many have suggested that minor forms of subclinical SCFE exist that go undetected during childhood. These may be responsible for certain primary hip osteoarthritis cases because of the resulting cam-effect [2,3]. Studies that have sought to confirm this hypothesis by performing measurements on A/P X-rays have had debatable reproducibility [4]. Although the femoral head slips downwards relative to the neck axis, it mainly moves backwards. It seems logical to analyze this pathology using a lateral hip view, as described in children (Lauenstein view) [5].

The purpose of this study was to determine the reproducibility and threshold value for the lateral view head-neck index (LVHNI). This index quantifies the posterior translation of the femoral head center relative to the femoral neck axis on a specific lateral hip view (hip in 45° flexion/45° abduction/30° external rotation) [6]. This index was measured on X-rays of patients having advanced hip osteoarthritis that required hip arthroplasty. Our working hypothesis was that the LVHNI could be measured reliably and can detect and quantify posterior translation of the femoral head.

Material and methods

Patients

This was a prospective, continuous, single-center study where the X-rays of patients receiving hip arthroplasty (total hip replacement or hip resurfacing) for osteoarthritis between January 2010 and December 2011 were analyzed. This study consisted of performing hip measurements on A/P and lateral views of each patient’s hip. Three variables were defined on the X-rays: presence of a pistol grip deformity [7] on the A/P view, osteoarthritis stage according to the Tonnis classification [8] and LVHNI measurement on the lateral view. In all, 157 hips were analyzed during this period. All patients received a standard X-ray assessment at the same radiology center on the eve of the surgical procedure. This consisted of a weight-bearing A/P view of the pelvis and a special lateral frog-leg view with the patient supine and the hip in 45° flexion, 45° abduction and 30° external rotation. This experimentally [6] and clinically [9] validated frog-leg view, shows the anterior and posterior margins of the femoral neck and allows the true neck axis to be accurately determined, along with its position relative to the femoral head center (Fig. 1). The X-ray tube was placed 120 cm from the patient, and the A/P direction of the beam was centered over the pubic symphysis.

Patients were excluded if they had documented previous surgery or hip-femur pathology, very advanced osteoarthritis that does not allow the lateral X-ray to be performed because of significant hip stiffness, or a femoral head deformity that would interfere with precise analysis of the head center. The quality of the X-ray was ensured by evaluating the following criteria: obvious symmetry of the obturator holes and ilium wings [10], and also objective criteria to ensure that pelvic rotation (end of coccyx and symphysis pubis aligned within 1 cm) and pelvic version (end of coccyx and symphysis pubis within 1–3 cm of each other) were neutral [11]. The desired 15° of femur internal rotation was achieved when the base of the lesser trochanter was not visible and was obscured by the medial cortex of the femoral diaphysis [12]. These criteria were assessed carefully because even a slight rotational change could result in significant measurement differences [13]. When these criteria were applied to the 157 hips operated for hip osteoarthritis over the study period, only 131 were retained for the analysis (26 excluded or 16.6%).

Methods

The LVHNI was analyzed on a lateral view of the hip (Fig. 2). It was defined as the ratio between the smallest distance (d) separating the true femoral neck axis from the femoral head center (corresponding to the perpendicular line from the true neck axis passing through the head center) divided by the diameter of the femoral head (D’) in centimeters. This ratio was expressed as a percentage to prevent inevitable centimeter-level measurement errors that occur because of inter-individual magnification differences related to a patient’s size.

\[
\text{LVHNI} = \frac{d}{D'} \times 100
\]

Figure 1  Frog-leg 45°/45°/30° view that provides good visualization of the anterior and posterior margins of the femoral neck.
The true femoral neck axis was determined by placing two points on the anterior margin of the neck and two points on its posterior margin, with the points being as far apart as possible proximally and distally. The distal points had to be near the base of the femoral neck and the proximal points near the head-neck junction without including any anterior osteophytes. The axis corresponded to the line joining the middle of the two segments (proximal and distal) described above. The extension of the lesser trochanter must not be included when these points are positioned because this would [artificially] increase the index. The femoral head center was defined as the middle of three points (P1, P2, P3) placed on its periphery, which corresponds to a digitized version of the "Mose template" [14]. To avoid measurement bias, the points were placed in areas where the femoral head was free of osteophytes and not visibly deformed. These seven points were used to define the lateral view head-neck index (Fig. 2). When a pistol grip deformity is seen on A/P pelvis X-rays, it is thought to be the visible sequelae of slipped femoral epiphysis [7]. This appears as the superior margin of the head-neck junction being convex and the inferior head-neck junction being more concave (Fig. 3). We believe that the presence of this deformity on A/P views is a sign of significant displacement on a lateral view (by analogy with SCFE in adolescents where the displacement is less pronounced on A/P views than lateral views). As a consequence, a certain number of SCFE will only be visible on a lateral view.

Each patient’s hip X-rays were imported into the Pictin™ imaging module of the OrthoWave™ software (Aria Sarl, Houdain, France). Automated digital measurements of the hip were performed based on the placement of various pre-defined points. The points needed to measure the LVHNI were integrated into this software by the developers. The measurements were performed by three independent observers (J.M., A.E., X.B-I.) using the same image acquisition software. The views were not initially paired (lateral, A/P) so as not to affect the measurements. Preoperative personal data [age, gender, body mass index (BMI), history] were stored in each patient’s file.

Statistical methods

Statistical tests were performed with two software programs (Excel 2007, Microsoft, Redmond, USA; MedCalc™ version 11.6.1.0, MedCalc Software, Mariakerke, Belgium). The average, minimum and maximum values and 95% confidence intervals (95% CI) were calculated for each variable.

The Student’s t-test was used to compare the averages of quantitative variables (age, LVHNI) between independent groups when the sample size was large enough (n > 30) and the assumptions of normality (D’Agostino-Pearson test) and

the middle of these two segments represents the true femoral neck axis; b: P1, P2 and P3 are placed around the femoral head perimeter to determine the head center (c); c: d is defined as the distance in centimeters between the femoral head center and a line perpendicular to the true neck axis that passes through the head center. D is the diameter in centimeters of the femoral head. (LVHNI = d/D x 100).

Figure 2 Placement of the points used to calculate the lateral view head-neck index. a: four points are placed on either side of the femoral neck axis forming two segments. The line joining
equal variances (F-test) were met. The Mann-Whitney U test was used with osteoarthritis stage ordinal data because it was not normally distributed. The inter- and intra-observer reproducibility were determined with the intraclass correlation coefficient and interpreted using the Fleiss rules [15]. The correlation was considered excellent if the coefficient was between 80% and 100%, good if between 60% and 80%, and moderate to poor when lower. A P-value of 0.05 or less was considered as statistically significant.

Results

The analysis included 131 hips (120 patients); the average age was 61 years (range 37–91); the average osteoarthritis stage was 2.5 according to the Tönnis classification. The average LVHNI was 10%. The inter-observer reproducibility was good for the LVHNI [intraclass correlation coefficient (ICC) = 0.61; 95% CI = 0.51–0.71] and for detecting a pistol grip deformity (ICC = 0.74; 95% CI = 0.62–0.85). The intra-observer reproducibility was excellent for the LVHNI (ICC = 0.78; 95% CI = 0.57–0.88) and the pistol grip deformity (ICC = 0.85; 95% CI = 0.74–0.92). The area under the ROC curve was 0.91 (95% CI: 0.86–0.96) (Fig. 4). By correlating the presence of a pistol grip deformity on the A/P view with the lateral view head-neck index, we determined that a LVHNI value of 10% resulted in achieving a maximum sensitivity of 89.1% (95% CI: 78.8%–95.5%) and specificity of 89.7% (95% CI: 79.9%–95.8%) to detect a pistol grip deformity, along with a Youden index of 78.7% (Table 1). A lower value (9%) led to the detection of slipped femoral epiphysis that was visible only on the lateral view. This 9% threshold reduced the specificity to 82.4% (95% CI: 71.2%–89.7%) but had the same sensitivity for detecting a pistol grip deformity. Clinically, this translates to a greater number of patients without abnormal findings on the A/P X-rays having a pathological index value (greater number of false negatives). Most of the patients (56/69 hips) having a LVHNI above 9% also had a pistol grip deformity on A/P X-rays, unlike those having an index below 9% (7/68 hips). With a 9% threshold value, 13 of the 68 hips (20%) without a pistol grip deformity on A/P X-rays had a pathological index; 10% of hips with a pistol grip deformity had a non-pathological index value (Table 2).

There were 69 patients in the pathological LVHNI group > 9% and 62 in the LVHNI group < 9%. These two groups

<table>
<thead>
<tr>
<th>Threshold (%)</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Correct classification (%)</th>
<th>Youden index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>90.6</td>
<td>66.2</td>
<td>78.0</td>
<td>56.8</td>
</tr>
<tr>
<td>9</td>
<td>89.1</td>
<td>82.4</td>
<td>85.6</td>
<td>71.4</td>
</tr>
<tr>
<td>10</td>
<td>89.1</td>
<td>89.7</td>
<td>89.4</td>
<td>78.7</td>
</tr>
</tbody>
</table>

Figure 3 A/P X-rays of the pelvis showing a bilateral pistol grip deformity of the proximal femur.

<table>
<thead>
<tr>
<th>PG +</th>
<th>PG −</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG +</td>
<td>PG −</td>
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<tr>
<td>PG +</td>
<td>PG −</td>
</tr>
<tr>
<td>PG +</td>
<td>PG −</td>
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</tbody>
</table>

Table 2 Number of patients in each group as a function of the index value and the presence of a pistol grip deformity (on A/P X-rays). This table shows that 20% of patients without a deformity on A/P X-rays actually have greater than 9% posterior translation and that 90% of patient with a pistol grip deformity have a pathological index.

Figure 4 ROC curve. The inflection point of the curve defines a 10% threshold value. A reduction in this threshold leads to higher sensitivity and lower specificity; the inverse is also true.
sized were comparable in terms of the osteoarthritis stage, but not in terms of gender. The male to female sex ratio was 7.3:1 in the LVHNI > 9% group and 1.13:1 in the other group. Also, the average age of patients in the pathological LVHNI group was about eight years less than in the non-pathological group (Table 3). There was also a trend towards femoral head retroversion in comparison to the neck of all the analyzed hips. Only three hips had an index value of 0 and none had a negative index value (Fig. 5).

Discussion

Our initial hypothesis was confirmed. The LVHNI can be used to determine and quantify the posterior translation of the femoral head center relative to the femoral neck axis, with good intra- and inter-observer reproducibility. The index value was considered pathological if the posterior translation of the femoral head was greater than 9%. Patients with a pathological index value were mostly male and younger than patients having a LVHNI within normal limits (below 9%). This is a reliable diagnostic method to measure the deformity sequelae of slipped femoral epiphysis in adults with osteoarthritis (Figs. 6 and 7). The LVHNI could also be measure on other standard lateral views of the femoral neck (Dunn, cross-table, etc.) or on CT scan slices or MRI in the anteroposterior plane of the neck axis, which would be performed upon request or reconstructed with imaging software [16].

Our study has numerous limitations, the first being that a pistol grip deformity was used as evidence for SCFE sequelae. Although recognized as being the visible sequelae of SCFE [17,18], its etiology is currently debated, since some reports have suggest that it could be the result of femorocacetabular impingement [19] or osteoarthritis-related degeneration [20–22]. Stulberg et al. believed that this deformity was the sequelae of pathology acquired during childhood, either Legg-Perthes-Calve disease or SCFE [7]. Although the analysis of this deformity is subjective and observer-dependent, its reproducibility is good [23] and there is a proven relationship between a pistol grip deformity and hip osteoarthritis [23,24]. This was the most pertinent criterion and its use, by analogy in pediatrics, was based on the idea that SCFE viewed on A/P X-rays is also displaced on the lateral view, while a displacement visible on the lateral view might not be associated with a pistol grip deformity on A/P view (20% of cases in this study). Thus, we used this reference to set a high threshold value and to assume that an index value above 9% was a sign of SCFE sequelae, so as to minimize the bias relative to this reference. A second limitation involves the precision of the measurement methods used in this study to define the true femoral neck axis and femoral head center. Since the shape of the femoral neck resembles an ovoid cylinder, the true neck axis should be analyzed in a three-dimensional radiographic study. But the fact that we precisely and strictly standardized the lateral view position (45° /45°/30°) allows us to think in two dimensions and assume that the neck has a rectangular shape, which greatly reduces the measurement bias. In addition, our current clinical practice does not include a preoperative CT scan or MRI for standard hip replacement surgery. The location of the femoral head center was determined with a standard three-point method. For patients with advanced osteoarthritis and femoral head deformity, the points were placed on the spherical part of the femoral head. If the deformity was too extensive, the analysis was not performed. The EOS™ system (EOS, Paris, France) could be an alternative to the 3D analysis of this index. Third, a significant number of patients (16.6%, 26 of 157) were excluded. Although this number of exclusions is acceptable, we excluded X-rays that did not fit within our predefined, strict quality criteria because we were concerned with optimizing the measurement and results. Since these X-rays were excluded a priori from the hip measurements, the validity of this study should not be affected.

Table 3  Number of patients in each group as a function of LVHNI value. The group with a lateral view head-neck index above 9% mostly consisted of men and developed osteoarthritis at a younger age than the group with a LVHNI below 9%.

<table>
<thead>
<tr>
<th></th>
<th>LVHNI &gt; 9% group 69 cases</th>
<th>LVHNI &lt; 9% group 62 cases</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>57.5 years (37–78)</td>
<td>65.2 years (44–91)</td>
<td>0.0040</td>
</tr>
<tr>
<td>OA stage</td>
<td>2.4</td>
<td>2.6</td>
<td>0.0850</td>
</tr>
<tr>
<td>Average LVHNI</td>
<td>14.7% (9%–24%)</td>
<td>5.5% (0%–8%)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Sex-ratio (M:F)</td>
<td>7.3:1</td>
<td>1.13:1</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Oa: osteoarthritis; LVHNI: lateral view head-neck index; M: male; F: female.
Various series have found that idiopathic hip osteoarthritis makes up 30 to 80% of cases [25–27]. This is in part related to the lack of validated diagnostic methods to look for SCFE sequelae on lateral views of the hip, while its mechanical impact (cam-effect) on the progression of arthritis has been clearly demonstrated in femoroacetabular impingement studies [3,9,25,28]. The standard diagnostic criteria for SCFE in children cannot be used in adults. Klein’s line is disrupted by the presence of anterior osteophytes secondary to the arthritis and Southwick angle [29] cannot be measured since the growth plates are closed. Various authors have sought to prove with X-rays that SCFE is a significant cause of early hip osteoarthritis, but only A/P views were used: measurement of femoral head ratio [30], pistol grip deformity [7], distance between the femoral head center and neck axis [12,31]. There has been growing interest in the anatomy of the head-neck junction over the past 10 years, with the development of measurements that can be used in the diagnosis of hip impingement [20,32]. The measurement of the anterior femoral head-neck offset on lateral radiographs (cross-table) [33], the alpha angle [34] and the triangular index [24] have advanced hip impingement research by demonstrating the presence of an anterior bump at the head-neck junction, but have not shed light on the causes of this impingement. These measurements cannot be used to look for SCFE sequelae because they included all the known etiologies for hip impingement.

Our study was also based on previous anatomy work [17,18] on X-rays of mature cadaver specimens where the posterior and inferior tilting of the femoral head could be easily visualized on lateral views. Goodman et al. [18] demonstrated that the incidence of this deformity was the same in the various age brackets studied, which meant that this was not a degenerative deformity secondary to arthritis-related remodeling, but a deformity acquired in young subjects that progressed to osteoarthritis. This was in direct conflict with the conclusions of Resnick [35]. He proposed using a measurement similar to the Southwick angle in adults, but it could not be performed on standard X-rays [34]. The LVHNI was inspired by conclusions drawn

Figure 6  a: lateral view (45°/45°/30°) of normal hip (index <9%); b: the femoral neck axis bisects the femoral head center. The lateral view head-neck index was 0%.
from these various published studies and guided by the goal of moving towards determining the etiology of hip osteoarthritis using simple, standard X-rays. An X-ray analysis could be performed to compare the value of this index between a young, healthy population and a population with hip impingement to help refine the threshold value and to have a prognostic value for hip osteoarthritis progression in these patients. This work could be supplemented by an epidemiological study where the LVHNI is used to determine the proportion of SCFE sequelae in hip osteoarthritis.

Conclusion

The lateral view head-neck index is a simple, reproducible radiography tool that reveals the sequelae of SCFE in adults with hip osteoarthritis using a specific lateral X-ray view. Its implementation could be beneficial in the search for etiological factors in hip osteoarthritis and also anterior femoracetabular impingement.

Disclosure of interest

P. Chiron is a consultant for Zimmer, Smith and Nephew and Sanofi, and has received royalties from Zimmer and Integra. The other authors have no conflict of interest to disclose relative to this article.

Acknowledgements

We are grateful to Jean-Alain Epinette, inventor of the OrthoWave™ software for collaborating with us on this project.

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