Original article

Side-to-side variation in normal femoral morphology: 3D CT analysis of 122 femurs

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ABSTRACT

Background: The contralateral femur is often used as reference for reconstruction in unilateral hip joint pathology. The objective of this study was to quantify the side-to-side variation in proximal femur. We hypothesized that significant side-to-side differences exist between left and right femur with implications for preoperative planning and leg length discrepancy following hip arthroplasty.

Materials and methods: CT-based 3D femoral models were reconstructed for 122 paired femurs in 61 young healthy subjects (46.9 ± 6.8 years) with no history of hip pathology. Side-to-side differences of several femoral morphologic parameters, including femoral head diameter, femoral anteversion, horizontal offset and femoral head center location, were compared and correlated with demographic factors using multiple linear regression.

Results: Significant side-to-side differences (P < 0.01) were found in femoral anteversion (4.3 ± 3.8° range; 0.2° to 17.3°), horizontal offset (2.5 ± 2.1 mm; range: 0.1 to 10.3 mm), and femoral head center location (7.1 ± 3.8 mm; range: 0.5 to 19.4 mm). The difference in femoral anteversion was strongly correlated with the difference in neck diameter (R² = 0.79), whereas the difference in horizontal femoral offset was highly correlated with the head diameter difference (R² = 0.72). Femoral head center difference was correlated with the femoral anteversion, horizontal offset and neck-shaft–angle difference (R² = 0.82).

Discussion: Relying on the anatomic landmarks of the contralateral femur during hip arthroplasty may not necessarily result in restoration of native anatomy and leg-length. Knowledge of the baseline side-to-side asymmetry could provide a range of error that would be tolerable following hip reconstruction.

Level of evidence: Level IV.

Type of study: Retrospective observational study.

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1. Introduction

The contralateral, native femur is often used to plan and evaluate accuracy of hip reconstruction, following hemiarthroplasty and total hip arthroplasty [1,2]. Therefore, understanding the normal variations of commonly measured parameters has the potential to improve preoperative planning and postoperative hip evaluation.

Lower limb asymmetry has been observed in kinetic, kinematics and electromyography data for normal gait. Up to date, limited data are available regarding side-to-side proximal femur morphologic differences. Most previous studies focused on bone density, cortical thickness or distal femur geometry [3,4]. Evaluation of proximal femoral geometry has mainly been directed on femoral head and neck diameter using plain x-ray, CT scan of cadavers or two dimensional digital photography of dry bones [5,6]. The plane-based methods may be prone to error due to the 3-dimensional (3D) nature of the femoral geometry [7]. Therefore, a 3D analysis of bilateral proximal femurs, among individuals with no hip pathology, is required to establish the baseline side-to-side asymmetry.

In light of the complex anatomy of proximal femur and the ability of bones to functionally adapt, we hypothesized that significant side-to-side differences exist between left and right femur. Therefore, the purpose of this study was to:

• determine the distribution and quantify the side difference in morphological parameters, such as femoral anteversion, horizontal and vertical offset, neck-shaft angle and femoral head center, between paired femurs, using 3D based CT-models;
• identify whether the femoral asymmetry was correlated with demographic factors such as height, weight, gender, BMI and other proximal femur measurements.

2. Methods

2.1. Subjects

The institution’s internal review board approved the protocol and each patient provided written informed consent prior to participation. Data from 122 paired femurs in 61 volunteers (23 male and 38 female patients) were included. Average age was 46.9 ± 6.8 years, (range: 31 to 58 years). Average BMI was 23.8 ± 2.6 kg/m² (range: 19.1 to 28.8 kg/m²). Inclusion required no previous trauma, asymptomatic hip, no obvious leg length discrepancy, and absence of dysplasia and of degenerative changes on both hips as well as on both knees.

2.2. Three-dimensional (3D) femoral modeling

All subjects were scanned following the same protocol using 64-slice multislice spiral CT computer tomography (CT) scanner (LightSpeed Plus, GE Medical System, Milwaukee, WI) in supine position, from the mid-pelvis to the proximal tibia with settings of 120 kV and 80 mA. The images were acquired along the axial direction with a slice thickness of 1.25 mm, an in plane resolution of 0.74 × 0.74 mm, a matrix size of 512 × 512. Using commercial software (Rhinoceros®, Robert McNeel and Associates, Seattle, WA, USA), the 3D surface models of the femur were reconstructed using gradient threshold and region growing, according to a previously validated and published method [8]. The accuracy of our 3D models was estimated to be 0.4 to 0.6 mm, i.e. 2- to 3-fold higher than in the DeVries et al. [8] work. Thereafter, the right femur was mirrored and best fit aligned to the left distal femur according to the femoral shaft and the distal femur using the method of iterative closest points, to reduce variability, by allowing for side-specific measurements. This technique was previously validated and the 3D deviation analysis showed an average ± standard deviation (SD) error, between mirrored and fixed surface model, of 0.69 ± 0.26 mm (Fig. 1) [9]. Finally, the surface models were imported to a customized MATLAB program (The MathWorks Inc., Natick, MA, USA) for subsequent analyses.

2.3. Definition of anatomical parameters

The anatomical coordinate system of the femur was reconstructed based on the International Society of Biomechanics (ISB) recommendations [10]. A sphere was best fitted to the surface of the femoral head using a Gauss-Newton non linear least square algorithm (MATLAB Optimization Toolbox, The MathWorks, Natick, MA), for determination of the femoral head center (FHC) and diameter. An initial axis was defined from the FHC to the centroid of femoral neck base (Fig. 2A). Outlines perpendicular to the initial axis of the femoral model were obtained from the FHC to the centroid of femoral neck base with 1-mm increments. A best-fit ellipse was applied to each of the femoral neck outlines. The centroid of each ellipse was fit using a least-squares approach to define the neck axis. The process was iterated until the angle between two subsequent axes was less than 0.1° (Fig. 2B). The final axis from the iteration process was defined as true neck axis (TNA). The best fit ellipse long and short axes were defined as neck long (L) and short diameters (S), respectively.

![Fig. 1. Schematic illustration of side-to-side asymmetry (right femur was mirrored and best fit aligned to the distal part of left femur for direct comparison). Absolute differences for femoral head center (FHC) distance, anteversion, horizontal offset (HFO), and neck shaft angle (NSA) are shown. FHC difference is shown with double headed black arrow.](image1)

![Fig. 2. Measurements of three-dimensional morphological parameters. Definitions of true neck axis (TNA), bow angle (BA), femoral mechanical axis (FMA), femoral anatomical axis (FAA), femoral head center (FHC), vertical offset (VFO), horizontal offset (HFO), neck-shaft-angle (NSA) are shown. A. Medial view of right femur. B. Posterior view of right femur. C. Closer view of right proximal femur. The femur was rotated until the HFO and VFO were orthogonal to the view direction.](image2)
Table 1
Summary of side to side asymmetry in paired femurs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total (n=122)</th>
<th>Left (n=61)</th>
<th>Right (n=61)</th>
<th>P-value</th>
<th>(95% CI of the side difference)</th>
<th>Absolute difference Mean (range)</th>
<th>Percent asymmetry</th>
<th>Intra-observer intraclass correlation</th>
<th>Inter-observer intraclass correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEA anteversion (°)</td>
<td>18.4 (8.5)</td>
<td>17 (8.0)</td>
<td>19.7 (8.8)</td>
<td>&lt; 0.01*</td>
<td>(–3.9, –0.9)</td>
<td>4.8 (0.18,3)</td>
<td>31.0</td>
<td>0.89</td>
<td>0.87</td>
</tr>
<tr>
<td>PCA anteversion (°)</td>
<td>12 (8.3)</td>
<td>10.9 (7.7)</td>
<td>13.1 (8.7)</td>
<td>&lt; 0.01*</td>
<td>(–3.4, –0.2)</td>
<td>4.3 (0.2,17.3)</td>
<td>23.4</td>
<td>0.92</td>
<td>0.9</td>
</tr>
<tr>
<td>Neck shaft angle (°)</td>
<td>126.7 (4.7)</td>
<td>126.6 (4.5)</td>
<td>126.7 (4.8)</td>
<td>0.36</td>
<td>(–1.1, 0.64)</td>
<td>2.3 (0.2,14.9)</td>
<td>1.9</td>
<td>0.95</td>
<td>0.92</td>
</tr>
<tr>
<td>Horizontal offset (mm)</td>
<td>37.0 (5.0)</td>
<td>37.6 (5.2)</td>
<td>36.3 (4.6)</td>
<td>&lt; 0.01*</td>
<td>(0.5, 2.0)</td>
<td>2.5 (0.1,10.3)</td>
<td>6.9</td>
<td>0.93</td>
<td>0.90</td>
</tr>
<tr>
<td>Vertical offset (mm)</td>
<td>48.8 (5.1)</td>
<td>48.6 (5.0)</td>
<td>48.9 (5.1)</td>
<td>0.37</td>
<td>(–1.1, 0.3)</td>
<td>2.1 (0.2,7.8)</td>
<td>4.2</td>
<td>0.95</td>
<td>0.94</td>
</tr>
<tr>
<td>Head diameter (mm)</td>
<td>45.5 (3.1)</td>
<td>45.3 (3.1)</td>
<td>45.6 (3.1)</td>
<td>&lt; 0.01*</td>
<td>(–0.5, –0.2)</td>
<td>0.57 (0.1,8.3)</td>
<td>2.7</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>Neck diameter (head–neck junction)</td>
<td>S: 17.0 (1.7)</td>
<td>16.9 (1.4)</td>
<td>17.0 (1.6)</td>
<td>0.27</td>
<td>(0.25, 0.06)</td>
<td>0.45 (0.2,4)</td>
<td>2.6</td>
<td>0.94</td>
<td>0.91</td>
</tr>
<tr>
<td>(head–neck junction) S: 19.1 (1.4)</td>
<td>19.1 (1.4)</td>
<td>19.1 (1.4)</td>
<td>0.7</td>
<td>(–1.3, 1.8)</td>
<td>0.45 (0.1,9)</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(head–neck junction) L: 19.1 (1.4)</td>
<td>19.1 (1.4)</td>
<td>19.1 (1.4)</td>
<td>0.7</td>
<td>(–1.3, 1.8)</td>
<td>0.45 (0.1,9)</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bow angle (°)</td>
<td>21.1 (6.1)</td>
<td>21.1 (6.1)</td>
<td>21.1 (6.7)</td>
<td>0.99</td>
<td>(–2.1, 2.0)</td>
<td>6.3 (0.2,23.0)</td>
<td>31.5</td>
<td>0.87</td>
<td>0.85</td>
</tr>
<tr>
<td>(isthmus) (mm)</td>
<td>L: 16.8 (1.7)</td>
<td>L: 16.6 (1.6)</td>
<td>16.9 (1.8)</td>
<td>0.004*</td>
<td>(–0.47, –0.1)</td>
<td>0.52 (0.3,7)</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Femoral length (mm)</td>
<td>378.6 (23.2)</td>
<td>378.3 (23.2)</td>
<td>378.2 (23.4)</td>
<td>0.01*</td>
<td>(0.25,2.1)</td>
<td>2.9 (0.8,5)</td>
<td>0.77</td>
<td>0.93</td>
<td>0.91</td>
</tr>
<tr>
<td>FAA–TEA angle (°)</td>
<td>96.5</td>
<td>96.4</td>
<td>96.6</td>
<td>0.56</td>
<td>(–1.0, 6)</td>
<td>2.5 (0.8,8)</td>
<td>2.6</td>
<td>0.95</td>
<td>0.94</td>
</tr>
<tr>
<td>FAA–FMA angle (°)</td>
<td>91.0</td>
<td>90.8</td>
<td>91.2</td>
<td>0.25</td>
<td>(–1.2,0.3)</td>
<td>1.7 (0.8,6)</td>
<td>2.4</td>
<td>0.94</td>
<td>0.93</td>
</tr>
<tr>
<td>FAA–FMA angle (°)</td>
<td>6.8</td>
<td>6.8</td>
<td>6.8</td>
<td>0.85</td>
<td>(–0.1,0.2)</td>
<td>0.4 (0.3,1.8)</td>
<td>6.1</td>
<td>0.94</td>
<td>0.93</td>
</tr>
</tbody>
</table>
| L: short diameter; S: long diameter; absolute difference: difference between maximum and minimum left-right; percent asymmetry: 100 × absolute difference/average value of left and right femur. * Statistically significant difference.
Fig. 3. Distribution of proximal femur morphologic parameters in paired femurs.

The posterior condylar axis (PCA) was defined as the line connecting the most posterior aspect of the lateral and medial condyles while the anatomical transepicondylar axis (TEA) by the most prominent points on medial and lateral condyle. Femoral mechanical axis (FMA) was defined as the straight line connecting the center of femoral head and the midpoint of TEA. For definition of femoral anatomical axis (FAA), the femoral length was first defined as the vertical distance between lesser trochanter tip and midpoint of TEA (Fig. 2A). Thereafter, a best-fit circle in least-square sense was applied to the outline of femoral diaphysis, from 10% to 90% of femoral length, with 5-mm increments and the centroid of each circle were determined. FAA was defined as the best-fit 3D line of those centroids.

Femoral TEA anteversion was defined as the angle between TNA and TEA while femoral PCA anteversion was defined as the angle between TNA and PCA, projected onto a plane perpendicular to FAA, respectively. Neck shaft angle (NSA) was defined as the 3D angle between TNA and FAA. The horizontal femoral offset (HFO) was defined as the perpendicular distance between FHC and FAA. Vertical femoral offset (VFO) as the vertical distance between FHC and the tip of lesser trochanter. Bow angle was defined as the 3D angle between two tangent lines connecting the proximal and distal end of FAA (10% and 90% of femoral length respectively) (Fig. 2C). Neck long (L) and short (S) diameters were calculated at the isthmus level, defined as the smallest cross-section area perpendicular to the TNA and at the femoral head-neck junction. The femoral head center difference was defined as the distance in 3D space between left and right-mirrored femoral head center (Fig. 1).

2.4. Repeatability analysis

Manual digitization was involved for the determination of the centroid of femoral neck base, the tip of lesser trochanter, TEA and PCA. Therefore, intra-observer and inter-observer reliabilities of the measurements were evaluated with two independent blinded observers (D.D. and T.-Y.T.) using single-measure intraclass corre-
lation coefficients (ICC) with a two-way random-effects model for absolute agreement.

2.5. Statistical analysis

All parameters were tested with Kolmogorov-Smirnov test for normality. When the criteria for normality were met, a two-tailed paired t-test was used, otherwise the Wilcoxon signed-rank test was applied to assess side to side differences. Significance level was set at α = 0.05. The confidence interval (95%) of the difference was calculated based on the left minus right femur. Multiple linear regression was performed for every morphologic parameter studied to evaluate whether the side-to-side difference in that parameter, was correlated with demographic factors such as height, weight, gender, BMI and side-to-side difference in other proximal femur measurements. The reduced models consisted only of variables that were statistically significant (α = 0.05). Percent asymmetry was defined as the ratio of absolute left-right difference to the average value of left and right multiplied by 100 (Percent asymmetry = 100 × |left−right|/average of left and right).

3. Results

Intraobserver ICC and interobserver ICC ranged from 0.87 to 0.97, and 0.85 to 0.96, respectively (Table 1). In side-to-side comparison of the femurs, statistically significant differences (P<0.01) were found for femoral anteverision, horizontal offset, and the diameter of femoral head (Table 1). Within the same subject, right femur was more antverted on average and had a larger femoral head and neck diameter, while the left femur had larger horizontal offset and femoral length (Table 1).

In this cohort, the average femoral anteverision for the entire sample was 12.0±8.3° (range: −7.2° to 40.1°) and 18.4±8.5° (range −9.6° to 33.9°) when PCA and TEA were used as a reference, respectively (Fig. 3A, B). The average absolute left-right difference in PCA anteverision was 4.3±3.8° (range: 0.2 to 17.3°) (Fig. 4A). The absolute side difference in femoral anteverision was correlated (R² = 0.79, P=0.01) with femoral neck diameter at the ishmus and at the head-neck junction (Table 2).

The average horizontal and vertical offset for the entire sample was 37.0±5.0 mm (range: 28.6 mm to 49.6 mm) and 48.8±5.1 mm (range: 36.2 mm to 62.2 mm), respectively (Fig. 3C, D). The average absolute difference was 2.5±2.1 mm (0.1 to 10.3 mm) for the horizontal offset and 2.1±1.8 mm (range: 0.2 to 7.8 mm) for the vertical offset (Fig. 4B). The absolute side difference in horizontal offset was correlated (R² = 0.72, P<0.05) with BMI, gender and the side difference in femoral head diameter (Table 2). With regards to femoral head, the average femoral head diameter was 45.5±3.1 mm (range: 40.1 to 53.8 mm) for the entire sample (Fig. 3E). The average absolute difference in femoral head diameter and femoral head center was 0.57±0.4 mm (range: 0 to 1.8 mm) and 7.1±3.8 mm (range: 0.5 to 19.4 mm), respectively (Fig. 4C, D). The absolute side difference in femoral head diameter was correlated (R² = 0.81, P<0.001) with the side difference in femoral neck diameter at the head-neck junction (Table 2). The side difference in femoral head center was correlated (R² = 0.82, P<0.05) with absolute difference in femoral anteverision, horizontal offset and neck shaft angle (Table 2).
The average neck-shaft-angle was $126.7 \pm 4.7^\circ$ (range: 106.8° to 137.5°), while neck diameter exhibited an average long and short axis diameter of 19.1 ± 1.4 mm (range: 16.6 to 23.2 mm), and 17 ± 1.7 mm (range: 14.6 to 21.6 mm) at the head-neck junction and 16.8 ± 1.7 mm (range: 13.3 to 23.7 mm) and 13.8 ± 1.4 mm (range: 10.8 to 18.9 mm) at the neck isthmus, respectively (Fig. 3F). The absolute side difference in neck shaft angle was 2.3° (range: 0.2 to 14.9°) while the absolute side difference in the neck diameter was less than 0.52 mm at both head-neck junction and the neck isthmus (Fig. 5).

4. Discussion

The current study used 3D modeling technique to accurately quantify the side-to-side difference between proximal femur anatomy and establish the baseline asymmetry [11]. The results support that significant side-to-side variation exists in femoral anteversion, horizontal offset and femoral head center within subjects (Fig. 5).

Side-to-side anteversion difference is important, when evaluating the torsional deformities following femoral shaft fractures. Bräten et al. [12] using ultrasound found a mean 3.8° (range: 0° to 13°) while Reikeras et al. [13] using biplanar radiography found a mean 4.9° (range: 0° to 15°) side-to-side anteversion difference, in normal population. In agreement with the literature, the average anteversion side difference was 4.3° – range (0° to 17.3°) – the right femur being more anteverted (Fig. 4A). The data suggest that baseline anteversion asymmetry may be large, and therefore should be considered whenever the contralateral femur is used as reference.

Accurate horizontal offset reproduction is one of the primary goals during surgical reconstruction of the hip, as it affects implant stability, component longevity and patients function. Lecerf et al. [14], using plain X-ray, reported great variability of the horizontal offset in the normal population with a mean of 39.7 mm (range: 25 to 60 mm). Similarly, Krishnan et al. [15] reported a mean horizontal offset and side-to-side difference of 39.2 mm and 2.54 ± 2.31 mm, respectively. In accordance with the literature, we found an average femoral offset side difference of 2.5 ± 2.1 mm (Fig. 4B). To put these values in context, Sorial et al. [16] demonstrated that 15% reduction (~5 mm) in horizontal offset compared to the preoperative value can generate abductors weakness and detectable alteration in the gait.

The femoral head center (FHC) is an important biomechanical parameter as it affects the calculation of hip and knee joint rotation, moment and force results [17]. The femoral head center is commonly calculated by regression equations from data derived from skin markers, placed on palpable body landmarks, and assume

| Table 2 |
| Results of the multiple linear regression of the side-to-side difference. |

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Independent variable</th>
<th>Coefficient</th>
<th>P-value</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head diameter difference</td>
<td>Neck diameter at head–neck junction (L) difference</td>
<td>0.5</td>
<td>&lt;0.001</td>
<td>0.81</td>
</tr>
<tr>
<td>Femoral anteversion</td>
<td>Neck diameter at head–neck junction (L) difference</td>
<td>−3.2</td>
<td>0.01</td>
<td>0.79</td>
</tr>
<tr>
<td>difference</td>
<td>Neck diameter isthmus (S) difference</td>
<td>4.6</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Horizontal offset</td>
<td>Head diameter difference</td>
<td>−1.6</td>
<td>0.01</td>
<td>0.72</td>
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<tr>
<td>difference</td>
<td>BMI</td>
<td>0.17</td>
<td>&lt;0.001</td>
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<tr>
<td></td>
<td>Gender</td>
<td>1.6</td>
<td>0.03</td>
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<tr>
<td>Femoral head center</td>
<td>Femoral anteversion difference</td>
<td>0.2</td>
<td>0.03</td>
<td>0.82</td>
</tr>
<tr>
<td>difference</td>
<td>Horizontal offset difference</td>
<td>0.9</td>
<td>&lt;0.001</td>
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<tr>
<td></td>
<td>Neck-shaft angle difference</td>
<td>0.5</td>
<td>0.04</td>
<td></td>
</tr>
</tbody>
</table>

L: short diameter; S: long diameter. Dependent and independent variables refer to the multiple linear regression analysis model.
Side-to-side symmetry in regards to FHC [18]. Lanaerts et al. [19] showed that when the subject specific FHC location (derived from CT) was included in the model, the position of the FHC was shifted 30.3 mm more anterior and 20.9 mm more proximal compared to the model that included only subject-specific hip geometry (femoral anteverision, neck-shaft angle, neck length). Our study demonstrated an average 7.1 mm (range: 0.5 to 19.4) side difference within the same subject (Fig. 4C). Furthermore, FHC asymmetry was correlated with the asymmetry in many femoral parameters such as femoral anteverision, horizontal offset and neck-shaft angle (Table 2). Therefore, our results support the concept of subject-specific FHC model as side-to-side variation can be large and difficult to predict.

Side-to-side asymmetry was correlated with asymmetry in immediately adjacent segments of the femur and demographics. Subjects with differences in head diameter tend to have differences in neck diameter at head-neck junction but not at the ischium level. This finding was also supported by Noble et al and Young et al who demonstrated that proximal femur asymmetry did not occur in isolated segments [6,20]. Furthermore, we found that femoral neck diameter side difference was correlated with femoral anteverision side difference, whereas head diameter side difference was correlated to horizontal offset side difference (Table 2). This data implies that patients with asymmetry in femoral head and neck may demonstrate asymmetry in femoral anteverision and horizontal offset, respectively.

This study should be evaluated in light of several limitations. First, only non-arthritic subjects were included. Thus, results do not represent the majority of patients requiring operative hip treatment. However, the purpose of this study was to establish the baseline side-to-side asymmetry of non-diseased femurs. Secondly, there was no ethnic or race variability in this study. Although, Young et al. [6] showed that race does not affect side-to-side asymmetry in femoral head and neck diameter, the race effect on femoral anteverision, hip joint center and femoral offset asymmetry are still unknown [6]. Thirdly, we have used the distal femur as reference to calculate the FHC difference. Although the 3D deviation analysis showed excellent symmetry between right and left distal femur, it is possible that some degree of measurement error was introduced by the mirroring technique. Fourthly, due to the retrospective nature of this study, we were unable to retrieve information regarding limb dominance and activity level, factors that could potentially correlate with femoral asymmetry. Lastly, although the restoration of leg length is one of the goals of THA surgery, based on the variation observed, it is beyond the scope of the current study to state the potential clinical implications of this finding as the leg length discrepancy is multifactorial and its clinical tolerance by patients vary greatly. However, our study has quantified the side-to-side difference and the results demonstrate that the “assumption” of side-to-side symmetry should be done with a caution.

In conclusion, this study reported that significant side-to-side asymmetry exists for femoral anteverision, horizontal offset and femoral head center. Our results imply that caution should be exercised whenever the contralateral femur is used as reference, as the side-to-side variation may be large. Significant side difference in head and neck diameter, parameters easily measured on plain x-ray, may help identify femoral anteverision and femoral head center asymmetry.

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**Disclosure of Interest**

The authors declare that they have no competing interest.

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Nothing to declare.

**References**