Anteversion Angle Measurement in Suspected Torsional Malalignment of the Femur in 3-Dimensional EOS vs Computed Tomography—A Validation Study

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A B S T R A C T

Background: Computed tomography (CT) scan is the standard for assessment of femoral torsion. This observational study was conducted to evaluate the comparability of the EOS radiation dose scanning system (EOS imaging, Paris, France) and the CT scan in patients with suspected torsional malalignment of the femur.

Methods: Patients with suspected torsional malalignment of the femur were included in a study for surgical planning. The primary endpoint was to compare the 3-dimensional radiological (EOS) imaging system with the CT scan to determine femoral anteversion (AV) angle. Three independent raters performed measurements. Comparability of CT scan and EOS values was assessed by Pearson correlation, t test, interobserver reliability, and intraobserver reliability (Cronbach alpha).

Results: About 34 femora were examined. Interobserver reliability/intraobserver reliability was 0.911 of 0.955 for EOS and 0.934 of 0.934 for CT scan. EOS system revealed an AV angle of 12.2 ± 10.0° (−15.0° to 32.0°). CT examinations showed an AV angle of 12.6 ± 9.2° (−3.2° to 35.6°). About 11 hips featured physiological AV, 14 hips showed decreased AV (<10°) or retroversion (<0°), and 9 hips showed increased AV (>20°). Overall, a strong Pearson correlation of r = 0.855 and a highly significant correlation in the t test for both methods was seen. In patients with decreased AV, retroversion, or increased AV, Pearson correlation only resulted in a moderate/low correlation of r = 0.495 and r = 0.292. The t test showed no significant correlation at malrotation.

Conclusion: In torsional malalignment, EOS does not have correlation with CT measurements. In contrast to CT scan, EOS allows femoral torsion measurement independent of legs’ positioning.

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The anteversion (AV) angle of the proximal femur is an important parameter in planning and postoperative assessment of various surgical interventions [1–4]. Above all, knowledge of the individual AV of the femur is important for planning a total hip arthroplasty [5,6]. It is crucial regarding the restoration of an anatomic joint mechanism and the reconstruction of the center of rotation [5]. AV of the femur is also of particular importance when planning and performing corrective osteotomies in congenital hip dysplasia [7,8]. Gold standard for torsion measurements of the lower extremity is the computed tomography (CT) scan. Therefore, the CT scan is also used to determine the femoral AV angle [9,10].

The biplanar low-dose EOS system (EOS imaging, Paris, France) was developed to provide a low-radiation method for analysis of whole-body and whole-leg angles [11]. The operational principles of the EOS 2-dimensional/3-dimensional (3D) system are as follows. Perpendicularly vertical-moving X-ray tubes create very thin collimated X-ray beams, collected by unique line detectors. It is a
slot scanning system using ultralow radiation doses with the patient in an upright load-bearing position followed by 3D reconstruction of the skeletal system. A special software (SterEOS; EOS imaging, Paris, France) allows the generation of these 3D models from the biplanar EOS scanning images. Using these 3D models, torsion parameters such as the AV angle of the proximal femur and other angles can be calculated. There has been no study to date, validating EOS vs CT scan when measuring the AV angle in patients with suspected torsional malalignment of the femur. To our knowledge, this is the first study comparing these 2 measurement methods in case of suspected maltorsion of the proximal femur.

Materials and Methods

Patients with a suspected torsional malalignment of the femur and an indication for surgical treatment of hip joint osteoarthritis, patellofemoral instability, or unicompartamental knee joint osteoarthritis were included in the study. The suspicion of torsional malalignment of the femur was derived from the gait pattern, clinical examination of the hip rotation, patella position, and position of the foot. If available, existing X-ray images were evaluated. For ethical reasons, only patients with an indication for surgical treatment were included in the study to avoid unnecessary radiation exposure to other patients. As usual, a CT scan was carried out to determine the AV angle of the proximal femur. Then these patients underwent a biplanar low-dose EOS X-ray of the pelvis and leg statics for preoperative clarification and operative planning instead of the conventional leg full-length image and X-rays in 2 planes. There was no additional radiation exposure for the patient because the EOS whole-leg image was used to determine all axes and angles of the lower extremity, and no additional conventional X-ray image was necessary. A 3D model was created using the EOS software. The AV angles were then determined from this 3D model of the femur.

Exclusion Criteria

Condition after treatment with knee or hip arthroplasty, pronounced acetabular dysplasia, patient age younger than 18 years and older than 80 years, time after corrective osteotomy of the lower extremity and/or the pelvis, pregnant patients, patients who are unable to receive information or to consent, and pronounced post-traumatic malposition.

CT Measurement Method

The femoral torsion was determined in CT scan as the angle between the axis of the femoral neck and the tangent to the femoral condyles. The Lee method [12,13] (transversal method) was used to determine the AV angle (Fig. 1). The axis of the femoral neck was determined as a connecting line drawn from the center of the femoral head to the center of the femoral neck. The first axial section of the scan with a visible connection between the femoral neck and the greater trochanter was used for this. All CT measurements were carried out by 3 independent orthopedic surgeons with verified additional qualification in skeleton radiography and...
CT scan diagnostics. All measurements were repeated at a second time by the respective rater, without knowing the previous values.

**EOS Measurement Method**

A simultaneous scan in the anteroposterior (AP) and lateral directions was carried out in all patients. A whole-leg scan of both lower extremities was performed. The lower limb or the hip workflow was used to calculate the femoral AV. The following data were obtained when performing the hip workflow at the end of the measurement: femoral offset, cervicodiaphyseal angle (CCD), femoral neck length, diameter femoral head, femoral torsion, and femoral length. The workflow of SterEOS software encompasses the following steps. In step 1, when using the lower limb workflow, the 3 reference points of the femoral center, trochlea, notch, and femoral diaphysis are selected. This is done for the AP and lateral planes. In the case of the hip workflow, only the landmarks of the thigh are marked. In step 2, the previously selected points are manually fine tuned. The lateral and medial femoral condyles are marked. The tangent to the femoral condyles is then determined to calculate the AV angle. In step 3, the trochanter major is first marked in the AP view. In step 4, the femoral neck axis is defined using 2 reference points. In step 5, the last bony reference points are drawn. The lateral and medial as well as the ventral and dorsal cortex of the femoral diaphysis are determined in both planes. In step 6, it is again possible to manually adjust reference points. Here, improvements can be made in every area of the femur to define the later 3D model as precisely as possible. In step 7, the SterEOS software automatically calculates the data. The measurement parameters are then available according to the set workflow (Fig. 2). In the eighth step, it is possible to create a 3D model for visual inspection (Fig. 3). All measurements were carried out by 3 independent orthopedic surgeons with verified additional qualification in skeleton radiography. All measurements were repeated at a second time by the respective rater, without knowing the previous values.

Contraindications to the use of the hip and pelvis workflows in the Lee method are pronounced dysplasia, deformities, and the presence of a hip or knee arthroplasty. In these cases, a precise assignment of the required bony reference points is not possible.

**Statistics**

Statistical evaluation was carried out using the SPSS statistics program (version 26; IBM Corporation, Armonk, NY). Pearson correlation coefficient and the 2-sided t test of the mean values for matched samples were calculated to compare the 2 measurement methods. Based on the power calculation, when there was a correlation of $r = 0.47$, with a desired power of 80% and a bilateral significance level of 5%, a necessary number of 33 hips was calculated to obtain a statistically significant result when using the Pearson correlation to discover a correlation coefficient of $P \neq 0$. The intraclass correlation coefficient (ICC) was determined to calculate the inter-rater reliability between 3 independent raters. The intraobserver reliability was determined by Cronbach alpha. The primary endpoint of the study was the comparison of the measured AV of the femoral neck between the 2 measurement methods; EOS and CT in the Pearson product-moment correlation.
The study was approved by the Ethics Committee of the Albert-Ludwigs-University of Freiburg, Germany with confirmation from June 5, 2018, application number 586/17. All patients were informed that CT scan and EOS in combination are currently being used in combination with the clinical parameters to plan the optimal therapy and optimal analysis of complex malalignment. The radiation exposure of both methods was described. The aim of the study was explained. Patients were advised that participation in the study was voluntary. All information was provided, and consent forms were signed by the head of the study and respective patient. The institutional review board had been assured that there were no additional risks for patients as these were routine procedures. It had been clarified that it was the objective of the study to establish a method that would reduce the radiation exposure of future patients. Furthermore, it was assured that only patients with clinical suspicion of a suspected torsional malalignment of the femur and simultaneous indication for surgical treatment of hip joint osteoarthritis, patellofemoral instability, or unicompartamental knee joint osteoarthritis were included in the study. The power calculation was presented.

### Results

About 34 femora measured from 19 patients (15 women and 4 men) with an average age of 45.5 ± 19.8 years took part in this study. Both hips were measured in 15 patients. One-sided measurement was performed in 4 patients. In these patients, there were exclusion criteria for determining AV using EOS on the other extremity. Torsional malalignment was not confirmed in 11 hips. 14 hips showed a reduced AV (<10°) or retroversion (<0°), and 9 hips showed an increased AV (>20°) (Table 1).

#### Mean Values

Determining the AV angle in the EOS system resulted in a total mean value of 12.2° ± 10.0° (−15.0° to 32.0°). Slight differences were found in the comparison of the right and left sides with an EOS right mean of 13.4° ± 2.4° (−12.0° to 32.0°) and an EOS left mean of 11.1° ± 2.8° (−15.0° to 30.0°). The CT scan examinations showed overall mean values of 12.6° ± 9.2° (−3.2° to 35.6°). Differences from left to right with CT scan were revealed with a CT right mean of 13.5° ± 2.2° (−3.2° to 35.6°) and a CT left mean of 11.6° ± 2.1° (−2.8° to 29.6°). A comparison of the CT scan vs EOS showed an average deviation of 0.4° for the total mean value. Including all values that showed reduced AV (<10°) or retroversion (<0°) in either EOS or CT scan, 14 hips were measured with an EOS mean value of 4.2° ± 7.4° (−15.0° to 13.0°) and a CT scan mean value of 4.0° ± 3.8° (−3.2° to 12.5°). Including all values that showed increased AV (>20°), in either EOS or CT scan, 9 hips were measured with an EOS mean value of 25.4° ± 2.3° (19.0° to 32.0°) and a CT scan mean value of 24.2° ± 2.3° (17.2° to 35.6°).

#### Pearson Correlation Coefficient, Inter-Rater Reliability, and Intrarater Reliability

Pearson correlation coefficient for all hips was included in the study, and the hips with regular AV shows a strong correlation...
between the 2 measurement methods with \( \tau = 0.855 \) \((N = 34)\) despite some deviations. The correlation is significant at the level of \(.01\) (2-sided). The correlation of the measurements between EOS and CT for the determination of the AV angle with reduced AV \((<-10^\circ)\) including retroversion \((<-14^\circ)\) resulted in a moderate effect of \(\tau = 0.495 \) \((N = 14)\) in the Pearson product-moment correlation. The correlation of the measurements between EOS and CT for the determination of the AV angle in increased AV \((>20^\circ)\) gave a low effect of \(\tau = 0.292 \) \((N = 9)\) in the Pearson product-moment correlation (Fig. 4; Table 2). The inter-rater reliability by calculating the ICC for all 3 examiners when measuring the AV angle with the EOS system showed a strong agreement with an ICC of 0.911. The ICC for all 3 examiners when measuring the AV angle with the CT scan also showed strong agreement with 0.934. The ICC for all 3 examiners showed a strong intraobserver reliability with Cronbach alpha of 0.955 for EOS and 0.934 for CT scan.

### The 2-Sided t Test

The calculation of the correlation of the mean values for matched samples in the 2-sided \( t \) test showed a highly significant correlation considering all values \((N = 34; \ P < .001)\) and the values with physiological AV \((N = 11; \ P = .001)\). Taking into account the values with torsional malalignment, neither decreased AV and retroversion \((N = 14; \ P = .072)\) nor increased AV \((N = 9; \ P = .446)\) showed a significant correlation between the measured AV angles in EOS and CT scan.

### Table 1

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>CT Scan</th>
<th>EOS</th>
<th>Left hip</th>
<th>Right hip</th>
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<tr>
<td></td>
<td>Rater 1</td>
<td>Rater 2</td>
<td>Rater 3</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Lap 1</td>
<td>Lap 2</td>
<td>Lap 1</td>
<td>Lap 2</td>
</tr>
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<td>0.5</td>
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<td>2</td>
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<tr>
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<td>2.3</td>
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<td>31.4</td>
<td>34.4</td>
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<td>20.4</td>
<td>21.5</td>
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<td>7</td>
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<td>13.2</td>
<td>15.9</td>
<td>12.4</td>
</tr>
<tr>
<td>17</td>
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<td>-2.9</td>
<td>0.4</td>
<td>2.1</td>
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<tr>
<td>18</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>19</td>
<td>18.9</td>
<td>24.2</td>
<td>19.1</td>
<td>18.1</td>
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</tbody>
</table>

### AV, anteverision; CT, computed tomography; N/A, not available.
between the measured AV angles in EOS and in the CT scan. Alpha showed a strong intraobserver reliability of 0.955 for EOS and valid results in the inter-rater agreement with 0.911 in the EOS

Radiation Dose

According to previous studies [14,15], EOS showed significantly lower radiation dose compared with conventional pelvic X-rays with a factor of 0.6 for body mass index <25 (7 vs 10.7 dGy/cm²) and a factor of 0.3 for body mass index 30-40 (9.7 vs 30.1 dGy/cm²). The average radiation exposure of an EOS leg full-length image on both sides is many times lower than that of the CT scan needed to determine the torsion. The radiation exposure for the EOS is approximately 0.63 ± 0.13 mGy. The radiation exposure during the CT examination varies more, depending on how large the area to be scanned is set. Radiation levels of 8.4-15.6 mGy have been reported [16].

Technical Aspects of CT Scan

In the present study, the proximal femoral AV angle was determined on CT scan as the angle between the femoral neck axis and the most prominent aspect of the posterior knee condyles by the method of Lee (transversal method) [12]. According to this method, the femoral neck axis is determined by a connecting line between the center of the femoral head and the center of the femoral neck. The most proximal axial slice of the CT scan on which a connection between the femoral neck and the greater trochanter (neck confluence) is visible is used for the purpose. In contrast to this single-slice approach, other methods use multiple slices to determine the femoral neck axis and are therefore more sophisticated in terms of creating a spatial construction [17-20]. Most methods including the Lee method give the AV angle in relation to a tangent to the most prominent posterior knee condyles. In comparison to the values derived from conventional radiographs as described by Rippstein [21], the mean values of the femoral AV as determined by CT scan analyses are significantly higher. Furthermore, when applying different measuring methods for CT scans, there sometimes are large deviations especially in patients with increased or excessive femoral torsion [22]. In the head-neck method, AV values vary depending on the height of the scan and on the CCD angle. Other studies have shown that fluctuations up to 13° can result from the height of the CT scan and CCD angle when measuring the same femur [17,23]. In the head-neck-axis method, the average AV angles seem lower compared with the head-neck method [13,14]. Considering these aspects, the method of Lee has a proximal definition and seems a reliable method for measuring cases with torsional malalignment [12-14,21,22,24].

The setting of bony landmarks on CT slice images is known to depend on the position of the patient. This is particularly important for the tangent to the femoral condyles. In addition to measurements of AV, patellofemoral measurements (tuberosity tibial tubercle groove distance) that depend on the tangent to the femoral condyles are highly dependent on the position of the leg in the CT scan. Furthermore, defining the femoral neck axis in slice images is known to have high inter-rater variability. For 3D bone models reconstructed from CT data, validations for AV measurements have only recently become available. Unfortunately, these studies were predominantly conducted based on total femur scans of cadavers or saw bone models. Total femur CT scans require high radiation dosages, which definitively limits the application in a clinical routine. Furthermore, recent publications regarding anatomy assessment in 3D state that true 3D angle measurement for AV is not useful [25,26]. This is due to fact that the 3D angle between the femoral neck axis and tangent to the femoral condyles is not only determined by the AV but also strongly influenced by the CCD angle. To measure only the AV, the angle must be calculated in the XY plane of the 3D model, and the z value is set to 0. In the future, 3D modeling and measurement using torsional CT scan will be possible, but there is still a lack of a general definition of landmarks, angle measurements, and scientific validation. Therefore, 3D measurement using torsional CT scan was not included in the present study.

A weakness of the CT scan is that positioning of the lower extremity should be in a neutral position. In cases with pronounced torsional malalignment however, it is not very reliable to hold this position [22].

Technical Aspects of EOS

A major advantage of the biplanar EOS imaging to create a 3D model is the ability to determine a large variety of anatomic parameters. In conventional preoperative planning, a full-leg X-ray in 2 planes (AP and lateral) and a CT scan are necessary to determine the length, axis, and hip parameters including the angles. With EOS however, all these desired measurement parameters can be calculated using 1 X-ray scan. Because it is a spatial scanning system, it is not important to maintain a neutral rotation of the leg. On one hand, given the software capability of creating a 3D model, no further radiologic examinations are necessary for the planning of hip arthroplasties or correction osteotomies. In addition, recent studies demonstrated the potential value of EOS measurement in patients after total hip arthroplasty [4,5,27]. EOS is superior to plain X-rays and standing X-rays in the angle measurement of the acetabular cup and AV of the femoral component even after hip arthroplasty [28,29]. The EOS system, on the other hand, features limitations in patients who are unable to stand or hold the

Table 2

<table>
<thead>
<tr>
<th>AV Angle Measure</th>
<th>EOS</th>
<th>CT Scan</th>
<th>Pearson Correlation</th>
<th>Two-sided t Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV angle including all hips (N = 34)</td>
<td>12.2° ± 10.0° (-15° to 32°)</td>
<td>12.6° ± 9.2° (-3.2° to 35.6°)</td>
<td>r = 0.855</td>
<td>P &lt; .001</td>
</tr>
<tr>
<td>AV angle in reduced AV or retroversion (N = 14)</td>
<td>4.2° ± 7.4° (-15° to 13.0°)</td>
<td>4.0° ± 3.8° (-3.2° to 12.5°)</td>
<td>r = 0.495</td>
<td>P = .072</td>
</tr>
<tr>
<td>AV angle in increased AV (N = 9)</td>
<td>25.4° ± 2.3° (19.0°-32.0°)</td>
<td>24.2° ± 2.3° (17.2°-35.6°)</td>
<td>r = 0.292</td>
<td>P = .446</td>
</tr>
</tbody>
</table>

AV, anteverision; CT, computed tomography; SD, standard deviation.
appropriate position for the time of the examination. Movement artifacts do not allow precise evaluation of the EOS images.

The Present Findings

In patients featuring physiological AV angles of the femur, the present results reflect the findings by others in the current available literature. In the study by Folinia et al [30], the correlation showed a value of $\tau = 0.93$ in a total of 43 measurements of the AV angle. The inter-rater correlation also revealed very similar values. The inter-rater correlation was at 0.93 in the study by Folinia et al with a total of 3 examiners. This is nearly identical to the findings of the present study. Further similar values for a population of 35 patients were shown in the study by Buck et al [31]. The mean values for the femoral AV was 11.6° for EOS and 11.5° for CT scan; similar to values in the present study of 12.6° for EOS and CT scan. The study by Rosskopf et al [32] also shows results similar to the present trial regarding the comparability of EOS and CT scan. The results can also be confirmed in the study by Pomerantz et al [33]. The determination coefficient of both measurement methods was 0.83–0.84. A better agreement among the investigators was found with an ICC value of 0.98. Even after total hip arthroplasty, reliable results are achieved by EOS measurement. The average absolute differences between EOS and CT measurements were 4°±4° for femoral AV. Comparable to the current trial, intraobserver agreement was >0.75, respectively (Cronbach alpha, 0.90) for measurement of femoral AV using EOS imaging [27,29]. Similar observations were made by Tokunaga et al [34].

To date, high correlations of EOS measurements and the existing gold standard of CT scans have only been shown for hips featuring a physiological femoral torsion but not for torsional malalignment. Schmaranzer et al [22] compared 5 different CT-based measuring methods for determining the AV angle in patients with pronounced torsional malalignment. They found highly significant differences of the AV angle values across these CT scan measuring methods ($P < .001$). The method of Lee et al [12,17], for example, showed mean AV angles of $11°\pm1°$ (range, $-13°$ to $45°$) compared with $29°\pm13°$ (range, $-5°$ to $63°$) as revealed by the method of Murphy et al [22]. With increasing femoral torsion, the differences between the 2 measurement methods were even more significant. This illustrates the limitations of CT scans in determining the AV angle in patients with torsional malalignment. In the present study, the values of the AV angle for all patients measured in the CT scan by the method of Lee showed a strong Pearson correlation with the values measured by the EOS method ($\tau = 0.855$). At torsional malalignment, only a moderate Pearson correlation between EOS and CT scan was achieved. Taking all cases into account, a highly significant t test correlation ($P < .001$) was achieved. But at torsional malalignment, there was no significant correlation in the t test. The differences of the AV angle between EOS and CT scan are higher in patients with torsional malalignment compared with patients with physiological torsion. Regarding measuring methods for CT scans, there are sometimes large deviations in patients with increased femoral torsion. Neutral positioning of the leg is necessary for accurate CT scan measurement of AV angle determination, but neutral positioning of the leg may be difficult in these patients [22]. In EOS imaging, the problem of leg positioning was overcome by measurements on the reconstructed 3D bone model. This may be a sign that EOS could be more accurate in patients with torsional malalignment because neutral positioning of the leg is not relevant during EOS imaging.

This is the first study to show that the angles measured in the EOS system and CT scan do not correlate significantly in the case of maltorsion of the proximal femur. But they show a highly significant correlation in normal AV.

Weakness of the Study

It could not be ensured that the neutral position of the leg was fully maintained during the CT scan image acquisitions, which to some extent limits the precision and reliability of the CT scan values in patients with pronounced torsional malalignment.

Conclusion

Measuring the femoral AV angle, EOS imaging system enables a strong overall correlation with CT scan measurements as well as high intra- and inter-rater reliability. In torsional malalignment, EOS does not have correlation with gold standard CT measurements. Although CT scans require a neutral positioning of the legs, which could not accurately enough be assured in patients with pronounced torsional malalignment, EOS allows femoral torsion measurement independent of legs’ positioning. This independency may represent an advantage in patients with pronounced torsional malalignment. In addition, radiation dose of an EOS image is many times lower than that of the CT scan needed to determine the torsion.

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