Measuring femoral and rotational alignment: EOS system versus computed tomography

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KEYWORDS
Computed tomography; EOS system; Lower limb; Femoral torsion; Tibial torsion; Rotational alignment

Summary
Introduction: Computed tomography (CT) is currently the reference standard for measuring femoral and tibial rotational alignment. The EOS System is a new biplanar low-dose radiographic device that allows 3-dimensional lower-limb modelling with automated measurements of femoral and tibial rotational alignment (torsion).

Hypothesis: Femoral and tibial torsion measurements provided by the EOS System are equivalent to those obtained using CT.

Materials and methods: In a retrospective analysis of 43 lower limbs in 30 patients, three senior radiologists measured femoral and tibial torsion on both CT and EOS images. Agreement between CT and EOS values was assessed by computing Pearson’s correlation coefficient and interobserver reproducibility by computing the intraclass correlation coefficient (ICC).

Results: Femoral torsion was 13.4° by EOS vs. 13.7° by CT (P = 0.5) and tibial torsion was 30.8° by EOS vs. 30.3° by CT (P = 0.4). Strong associations were found between EOS and CT values for both femoral torsion (P = 0.93) and tibial torsion (P = 0.89). With EOS, the ICC was 0.93 for femoral torsion and 0.86 for tibial torsion; corresponding values with CT were 0.90 and 0.92.

Discussion: The EOS system is a valid alternative to CT for lower-limb torsion measurement. EOS imaging allows a comprehensive evaluation in all three planes while substantially decreasing patient radiation exposure.

Level of evidence: Level III, case-control.
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Introduction

Rotational malalignment of the lower limbs is frequently idiopathic [1,2] and less often related to injury [3] or to disorders such as cerebral palsy [4]. Many studies have established that these axial-plane deformities of the lower limbs, regardless of their cause, can affect the development of...
various knee disorders such as patello-femoral instability [5,6], knee osteoarthritis [7–9], and hip osteoarthritis [10]. Rotational osteotomies may therefore be indicated to correct the deformity [2,11]. Consequently, the optimal management of lower-limb rotational malalignment requires accurate and reproducible measurements of femoral and tibial torsion.

Several clinical [12], sonographic [13], fluoroscopic [14], and magnetic-resonance-imaging (MRI) [15] methods for measuring lower-limb torsion have been described but none has gained predominance in everyday practice. The accuracy of clinical methods has been challenged [12]. The sonographic and fluoroscopic methods follow a variety of protocols and are difficult to use [13,14]. Finally, although MRI-based methods have been proven accurate [15], their use is hampered by the limited availability of MRI machines. Computed tomography (CT) measurement of lower-limb torsion has been well validated and is widely used as the current reference standard [16].

CT measurement of tibial torsion is generally reported to be both accurate and reproducible [17,18]. The measurements are classically taken on superimposed axial slices between the tangent to the posterior tibial-plateau rim and the bimalleolar axis. The best CT method for measuring femoral torsion remains debated. The main difficulty is determination of the femoral neck axis [19,20]. Although several reported methods use axial slices to assess femoral neck orientation, slice selection strongly influences the measured value [20,21].

The planar low-dose EOS system (EOS imaging, Paris, France) [22–24] has been used to develop a new method for clinical lower-limb analysis [25]. In the EOS system, two perpendicular X-ray beams are mounted on a C-arm, which moves vertically. The patient stands or sits in the middle of the scanning booth. All or part of the body is scanned, simultaneously producing projections in two perpendicular planes. The radiation dose to the patient is substantially lower than with conventional radiographs [23,26]. Dedicated software (ster EOS, EOS imaging, Paris, France) can be used to alter generic models of the femur, tibia, and fibula, thereby producing a 3D model of the patient’s lower-limb skeleton. From this model, the software automatically computes a set of 3D clinical lower-limb parameters, including femoral torsion and tibial torsion [25,27].

Here, our objective was to compare femoral and tibial torsion values measured using the new EOS-based method and the reference CT method.

Material and methods

Population

We retrospectively included all patients who underwent both CT measurement of lower-limb torsion and EOS imaging including at least the entire lower limbs, between November 2009 and March 2011. The imaging studies were performed as part of standard care, either for the preoperative work-up before total hip arthroplasty (in patients requiring an evaluation in the axial plane) or for an evaluation of implant position combined with an assessment of lower-limb alignment (with only the non-operated side being included in the study). EOS imaging as part of the preoperative work-up for total hip or knee arthroplasty provides information on overall body alignment and, more specifically, on alignment of the lumbar spine and pelvis, whose assessment is considered crucial prior to joint replacement surgery [24,28].

Computed tomography (CT) measurements

A helical CT machine was used (Somatom, Siemens, Definition AS 40-slice, Erlangen, Germany). Three acquisition zones (hip, knee, and ankle) were defined on an antero-posterior scout view. In each zone, 1.25-mm slices were acquired as recommended by the manufacturer. The lower limbs were extended, fixed in neutral rotation, and strapped to the table to prevent movements during acquisition. Measurements were performed using OSIRIX MD software (Osirix Foundation, Geneva, Switzerland) by three senior radiologists who had extensive experience in osteoarticular radiology. All measurements in a given patient were made using the same CT acquisition. Femoral torsion was measured as described by Reikeras al. [29] (Fig. 1). After recovery of the native images from our institution’s Picture archiving and communication system (PACS), each radiologist selected the slices to be used for the measurements. The femoral neck axis was determined by superimposing two slices, one through the centre of the femoral head and the other through the middle of the femoral neck (on which the anterior and posterior cortices were parallel to each other). Each radiologist created a superimposition then used it to determine the femoral neck axis as the line through the femoral head centre and the middle of the neck diameter. To determine the axis of the femoral condyles, each radiologist selected a slice through the most prominent point of the condyles. This point can often be identified based on the fabella, when present, or on the roman-arch shape of the intercondylar notch. The degree of femoral torsion was measured as the angle subtended by the femoral neck axis and the posterior bicondylar axis. This angle was given a positive value in case of anteverision and a negative value in case of retroversion. Tibial torsion was measured as described by Reikeras and Hoiseth [18] and validated by Liodakis et al. [30] (Fig. 1). Each radiologist selected two reference slices, one through the middle of the proximal tibial epiphysis above the proximal end of the fibula and the other tangent to the talar dome. Tibial torsion was measured as the angle between the line tangent to the posterior tibial plateau rim and the bimalleolar axis through the centres of the anteroposterior diameters of the medial and lateral malleoli.

EOS measurements

At the beginning of the study, the radiologists had been using the EOS system and its modelling software on a regular basis for 18 months. The native images were recovered from the PACS, and a single EOS acquisition per patient was used by all three radiologists. Each radiologist produced a 3D model of the lower limb using sterEOS software. On the model of the femur, the femoral neck axis (from the centre of the femoral head to the base of the neck) and the axis tangent to the posterior condyles were determined automatically. Femoral
Therefore, the torsion of the biplanar posterior/lateral plane projection of the bimalleolar landmarks was determined automatically. Tibial torsion was computed as the angle between the projections of these two axes in the transverse tibial plane (defined as the line perpendicular to the mechanical axis of the tibia) (Fig. 2).

Therefore, in our study the EOS and CT measurements were obtained using the same anatomical landmarks. Biplanar acquisition with the patient in the strict anteroposterior/lateral position would result in superimposition of the anatomical landmarks on the lateral view, precluding the production of a 3D model by the sterEOS software [25]. Therefore, as part of standard care, the patients underwent the following imaging procedures:

- either simultaneous anteroposterior and lateral imaging in the bipodal standing position with the entire body rotated 15° relative to the acquisition system (Fig. 3);
- or anteroposterior and lateral imaging in the unipodal standing position with the limb to be studied in the strict anteroposterior/lateral position and the contralateral limb on a support and flexed 70° to 90° (Fig. 3).

Between April and September 2011, the three study radiologists reviewed all EOS and CT measurements recovered from our PACS, specifically for our study, working independently from one another, and without knowledge of the measurements obtained during patient management.

Radiation dose

The radiation dose delivered by the EOS system was recorded directly from the device. The EOS doses were compared to published data on doses delivered by CT with the equipment and acquisition protocols used in the patients included in our study [31].

Statistical analysis

SPSS version 15.0 (IBM, Armonk, NY, USA) was used for all statistical tests. Descriptive data were computed on the overall dataset. Student’s t test was performed to determine whether the measured values differed significantly between EOS and CT. Agreement between these two methods was assessed by computing Pearson’s correlation coefficient.

Interobserver reproducibility of each method was evaluated based on the intraclass coefficient (ICC) [32]. Mean

Figure 1  a: computed tomography measurement of femoral torsion; b: computed tomography measurement of tibial torsion.
interobserver error with the corresponding standard deviation (SD) was computed.

Results

Population

CT and EOS studies of 43 lower limbs in 30 patients (25 females and 15 males; mean age, 53.2 ± 20.4 years) meeting our inclusion criteria were retrieved from our PACS and included in the study. EOS studies were obtained in the bipodal stance for 25 lower limbs in 17 patients and in the unipodal stance for 18 lower limbs in 13 patients.

Measured femoral and tibial torsion values

Table 1 reports the femoral and tibial torsion values obtained using EOS and CT. Torsion values differed between the right and left sides in the 16 patients with data on both lower limbs. Mean side-to-side difference in femoral torsion was 6.3° by EOS and 6.8° by CT (P=0.6); tibial torsion showed a mean side-to-side difference of 3.9° with both imaging modalities. By EOS, the ICC for interobserver reproducibility was 0.93 for femoral torsion and 0.86 for tibial torsion; corresponding values by CT were 0.90 and 0.92, respectively. Table 2 reports the ICC values for interobserver reproducibility and Table 3 the interobserver measurement error values. Time needed to assess torsion, including image acquisition and processing, was 10 to 15 minutes by CT and 15 to 20 minutes by EOS.

By EOS, mean radiation dose measured as air kerma was 0.18 ± 0.05 mGy for the anteroposterior view and 0.45 ± 0.08 mGy for the lateral view. The CT protocol used in our study has been reported to deliver 8.4 to 15.6 mGy to the skin, depending on the anatomic region being imaged [31].

Discussion

In this study, we describe a new 3D method for measuring femoral and tibial torsion on EOS images and we provide a comparison of this method to the current reference standard CT method. Femoral torsion values are heavily dependent on the level of the selected CT slices [21] (Fig. 4). Inaccuracies in the identification of femoral neck landmarks can lead to major measurement differences. In studies comparing several CT methods, Sugano et al. [19] and Liodakis et al. [30] found that the most accurate was that described by Reikeras et al. [29], which was therefore chosen for our study. For tibial torsion measurements, we chose the method of Reikeras et al. [18] based on evidence of its greater reproducibility compared to other methods [30]. The EOS and CT methods used in our study used identical anatomical landmarks for the measurements.

In our study of 43 lower limbs, mean femoral torsion in the overall sample was between 13° and 14° and mean tibial torsion was between 30° and 31°. Tibial torsion was slightly less than in previous studies conducted in asymptomatic individuals [17,34], whereas femoral torsion was within the reported normal range [29]. These data are difficult to interpret, however, given the heterogeneity of the diagnoses in our study.

Table 2 Interobserver reproducibility (intraclass coefficient, ICC) of torsion measurements using the EOS system and computed tomography (CT).

<table>
<thead>
<tr>
<th></th>
<th>EOS</th>
<th>CT</th>
<th>P value</th>
<th>EOS/CT Pearson’s correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral torsion</td>
<td>0.90</td>
<td>0.94</td>
<td>0.93</td>
<td>0.90</td>
</tr>
<tr>
<td>Tibial torsion</td>
<td>0.88</td>
<td>0.84</td>
<td>0.86</td>
<td>0.92</td>
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</table>

Table 1 Measurement of femoral and tibial torsion using the EOS system and computed tomography (CT).

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<th>EOS</th>
<th>CT</th>
<th>P value</th>
<th>EOS/CT Pearson’s correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral torsion</td>
<td>13.4° ± 9.1°</td>
<td>13.7° ± 9.4°</td>
<td>0.5</td>
<td>0.93</td>
</tr>
<tr>
<td>Tibial torsion</td>
<td>30.8° ± 8.8°</td>
<td>30.3° ± 9.6°</td>
<td>0.4</td>
<td>0.89</td>
</tr>
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</table>
population. The high prevalence of side-to-side asymmetry of about 6° for femoral torsion and 4° for tibial torsion was also consistent with earlier studies [18,29,34–36].

We found very close correlations between CT and EOS values for both femoral torsion ($r = 0.93$) and tibial torsion ($r = 0.89$). No significant bias was detected between the measurements obtained using these two imaging modalities.

Reproducibility of femoral torsion measurement seemed slightly better with EOS than with CT. However, with both modalities the ICC values were equal to or greater than 0.9, indicating a very strong correlation [37]. For tibial torsion, reproducibility seemed slightly better by CT, with an ICC of 0.92 compared to 0.86 by EOS. However, the ICC values for the two modalities remained very similar, with the ICC by EOS being at the high end of the range indicating a strong correlation (0.7–0.89) and the ICC by CT being at the low end of the range indicating a very strong correlation (0.9–1) [37].

The 3D modelling method used by the EOS system requires visibility on the lateral view of the landmarks of each lower limb. Chaibi et al. [25] described a position with shifted feet to meet this requirement. In our study, we evaluated two other positions, both used in everyday practice at

### Table 3 Interobserver measurement error with the EOS system and with computed tomography (CT).

<table>
<thead>
<tr>
<th>Interobserver error</th>
<th>EOS</th>
<th>CT</th>
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<tbody>
<tr>
<td></td>
<td>Unipodal</td>
<td>Bipodal</td>
</tr>
<tr>
<td>Femoral torsion</td>
<td>$2.7° \pm 4.5°$</td>
<td>$2.7° \pm 4.5°$</td>
</tr>
<tr>
<td>Tibial torsion</td>
<td>$2.9° \pm 2.3°$</td>
<td>$4.1° \pm 3.5°$</td>
</tr>
</tbody>
</table>

our institution. In our experience, these positions are associated with greater ease in differentiating the anatomical landmarks on the lateral view. Importantly, the 3D measurements obtained by the EOS system are independent from patient position during acquisition. Our data suggest better interobserver reproducibility with the bipodal stance for femoral torsion and with the unipodal stance for tibial torsion. However, sample sizes were too small for meaningful statistical comparisons.

In our study, both EOS and CT measurements were performed by senior radiologists who were specialised in ostearticular radiology. The influence of experience on measurement quality, although not evaluated in our study, probably deserves consideration. With CT measurements, for instance, great care is needed to identify the femoral neck landmarks. With EOS, automatic determination of the axes is influenced by the quality of bone contouring, which in turn is influenced by the degree to which superimposition of bone landmarks on the lateral view is avoided.

The EOS system is not appropriate for all patients. For biplanar X-ray acquisition of the lower limbs, the patient must stand without moving for about 10s to avoid motion artefacts. Therefore, patients who are unable to stand and those who are unsteady in the standing position are not candidates for EOS imaging of the lower limbs. Furthermore, the 3D modelling software relies on generic 3D models of the femur and tibia and therefore cannot be used after total hip or knee replacement for modelling the native acetabulum.

Marked deformities of the femoral head or knee may create specific challenges. Some of the anatomic landmarks may be difficult to identify in patients who have advanced hip osteoarthritis with femoral head deformity and florid osteophyte formation. This limitation similarly affects torsion measurement by EOS and by CT. Comparable challenges arise in patients with residual abnormalities due to major dysplasia, slipped capital femoral epiphysis, massive avascular necrosis of the femoral head, or hip luxation or subluxation.

Finally, the simultaneous acquisition by the EOS system of an anteroposterior view and a lateral view ensures very easy 3D modelling, which is useful for morphological analyses. However, the 3D model thus obtained is of limited relevance to the structural diagnosis, since it is based on generic models of the femur and tibia.

Conventional 2D goniometry also has a number of limitations. Only deviations in the coronal plane can be measured using this technique. Conventional 2D methods, even those involving digitisation, deliver larger radiation doses [26,38,39]. Isolated analysis of rotational malalignment is only very rarely performed. Until now, 2D goniometry had to be completed by CT, and vice versa, which considerably increased the radiation dose to the patient. The EOS system can be used for single-plane imaging to perform conventional 2D goniometry. However, we believe that 3D imaging is crucial in patients with major lower-limb deformities, particularly when several abnormalities exist in combination (e.g., rotational malalignment, fixed flexion, and lower-limb length discrepancy) (Fig. 5) [40].

EOS has been demonstrated to deliver far lower radiation doses than conventional radiological techniques. This advantage is ascribable to the use of the multwire chamber developed by Charpak (Nobel Prize in Physics, 1992). A 6- to 9-fold radiation dose decrease versus conventional radiographs has been reported for full-spine EOS imaging [26]. In a study involving an Alderson-Rando phantom (trunk and lower limbs) and lithium fluoride thermoluminescent dosimetry, Delin et al. [31] established that the radiation dose delivered to the patient during lower-limb torsion measurement was 4- to 23-fold higher with CT than with EOS.

A major advantage of the EOS system compared to CT is the collection of 3D data during a single scan. Thus, EOS images immediately provide a 3D analysis instead of a single-plane analysis. We demonstrated that torsion values measured using the EOS system correlated closely with CT values, without bias and with comparably satisfactory interobserver reproducibility. The EOS system may therefore constitute a valid alternative to CT for evaluating lower-limb torsion. The use of the EOS system substantially decreases overall radiation exposure, a major advantage in patients who often require extensive orthopaedic investigations involving multiple imaging studies over time.

Figure 4 Importance of slice selection level for computed tomography measurement. Depending on the level of the slices, femoral anteverision varied by 8°. a: identification of the femoral head centres; b: superimposition of maximum intensity projection slices down to the middle of the femoral neck: method described by Riekers et al. [29]; c: superimposition of maximum intensity projection slices down to the base of the femoral neck: method described Murphy et al. [33]. Femoral torsion is greater by 8° using level c compared to level b.
Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References


Model


D. Folinais et al.