Measurement of femoral antetorsion and tibial torsion by magnetic resonance imaging

B SCHNEIDER, MD, J LAUBENBERGER, MD, S JEMLICH, MD, K GROENE, MD, H-M WEBER, MD and M LANGER, MD

Departments of Diagnostic Radiology and Orthopaedic Surgery, University of Freiburg, Hugstetterstr. 55, 79106 Freiburg, Germany

Abstract. Several methods for measuring femoral and tibial torsion by CT have been described since 1980. Alternative methods of measurement to CT are needed to avoid irradiating young patients facing derotation osteotomy. In this study, MRI was used to quantify femoral and tibial torsion in normal adult volunteers, firstly with transverse sections analogous to those of CT in order to establish reference values; and secondly, with sections along the axis of the neck of femur to assess the influence of the orientation of the slices on the measured values. The images were acquired using fast T1 weighted gradient echo sequences in 0.2 and 1 T magnets. Average femoral antetorsion (CT-analogous method) was 10.4° (average side difference = 4.6°); average tibial torsion was 41.7° (average side difference = 6.1°). A steeply inclined slice along the axis of the femoral neck gave a mean measurement of the angle of antetorsion that was significantly higher than the mean obtained from either slightly inclined or transverse sections (16.7° vs 12.1° and 11.2°, respectively, p < 0.001). In conclusion, MRI provides an alternative to CT in the measurement of femoral and tibial torsion. MRI enables one to orientate the slice along the axis of the femoral neck, thus obtaining a single cross-section of the entire neck. However, the normal range of measurements will vary according to the plane of image.

Introduction

Tibial torsion is defined as the anatomical twist of the proximal versus the distal articular axis of the tibial bone around the longitudinal axis [1]. Femoral torsion is generally described as torsion of the proximal femur relative to the distal femur. However, different definitions of femoral antetorsion are given by different authors. While some describe femoral torsion as the angle between the axis through the femoral neck with reference to the tangent to the dorsal border of the femoral condyles [2] or to the transcondylar plane of the distal femur [3], Billing [4] defines femoral antversion as the angle between the condylar plane and the plane of anteversion. The plane of antversion is the plane that contains the long axis of the femur and the axis of the femoral head, which is defined by the centre of the femoral head and the centre of the base of the femoral neck. In contrast to the definitions of other authors Billing’s method is not influenced by the shape of the neck of femur.

Measurements of femoral torsion and tibial torsion are important in selecting patients for derotation osteotomy. The former has been measured since 1955, according to the method described by Rippstein [2], and the latter usually by goniometry [1]. Several methods of measurement using CT have been described since 1980 [1,3,5–11]. These methods differ slightly with regard to anatomical landmarks and the positioning of axes and have provided different normal values. All CT methods require at least four sections, although further sections may be required under special circumstances, for instance when there are different limb lengths. Alternative methods to CT need to be assessed in order to avoid irradiating young patients before derotation osteotomy.

Galbraith et al [12] and Baumann et al [13] performed MRI measurement of femoral torsion using transverse sections analogous to those of CT. Guenther et al [14], however, performed MRI measurement of femoral antetorsion using slices angled to the femoral neck.

In a preliminary study [15] we investigated the feasibility of MRI measurement in a small group of 10 volunteers and six patients. However, reference values for femoral antetorsion and tibial torsion have not been established in normals, and the influence of slice orientation on femoral antetorsion measurements has not been studied. We performed MRI in healthy adult volunteers to these ends. In the first part of this study transverse sections were acquired, as for CT. In the second part of the study the effect of the angle of section through the femoral neck on the measured values...
of antetorsion was studied. Altering the plane of section is not possible with conventional CT, but is routinely available with MRI and allows for a cross-section of the entire neck of femur.

Materials and methods

Femoral antetorsion and tibial torsion were measured in 98 lower limbs in healthy adult volunteers (mean age = 42 years). The comparison between different slice orientations in the femoral neck was performed in 42 lower limbs of healthy adult volunteers (mean age = 42 years). Examinations were carried out in a 1.0 T and a 0.2 T system (Magnetom Impact and Magnetom Open, Siemens, Erlangen, Germany) using a heavily $T_1$ weighted gradient echo sequence (flash 2D, TR = 98 ms, TE = 5 ms, $\alpha = 70^\circ$ and TR = 280 ms; TE = 15 ms, $\alpha = 40^\circ$). Slice thickness was 8 mm. A block of 10 slices was positioned in the region of the femoral neck, the knee joint and the talocrural joint. Patients were placed supine with their legs extended and parallel to the $z$-axis of the scanner. The region to be examined was always positioned in the centre of the magnetic field. Acquisition time was 12 s (1.0 T) and 1 min 22 s (0.2 T) per package.

The section through the centre of the femoral neck and the distal part of the femoral head was chosen when carrying out the CT analogous method. Additional sections were needed in volunteers with coxa valga. According to the method described by Jend [7], the line of reference in the proximal femur was defined as the line connecting the centre of the distal section of the femoral head and the centre of the distal femoral neck (Figure 1). In the distal femur the tangent to the dorsal border of the femoral condyles was taken as line of reference (Figure 2).

Using the method of Jend et al [8], the section of the proximal tibia is taken immediately distal to the femorotibial joint and proximal to the head of fibula. The line of reference from this section is the tangent drawn to the dorsal border of the tibia (Figure 3). In the distal tibia, the section immediately proximal to the talocrural joint was chosen. The distal line of reference was formed by joining the centre of a circle fitted to the pilon tibiale with the midpoint of a line across the fibular notch of the tibia (Figure 4). The angle between each line of reference and the horizontal plane was determined automatically. Femoral torsion and tibial

Figure 1. (a) Scout view of the proximal femoral region using a transverse slice orientation. (b) Resulting transverse section through the femoral neck with reference lines through the centre of the femoral head and neck.

Figure 2. Section through the femoral condyles. The reference line is a tangent at the dorsal margin of the condyles.

Figure 3. Section through the proximal tibia with reference line at the dorsal margin of the tibia.
MRI measurement of femoral antetorsion and tibial torsion

Wilcoxon test: \( p < 0.001 \); the difference between measurements taken from slightly angled sections and those from steeply angled sections was \( 4.6 \pm 2.9^\circ \) (Wilcoxon test: \( p < 0.001 \)). Measurements taken from transverse images and from slightly angled sections did not show a significant difference.

Femoral and tibial torsion (transverse slice orientation) were reevaluated in 22 lower limbs after 3 months by the same examiner (BS) using the same sections in order to determine intra-observer variability. The mean difference ± SD in femoral antetorsion was \( 2.4 \pm 3.17^\circ \); in tibial torsion the mean difference ± SD was \( 3.0 \pm 2.7^\circ \).

Discussion

Measurements of femoral antetorsion and tibial torsion are important in selecting patients for derotation osteotomy. Since 1980 several methods of CT measurement of femoral and tibial torsion have been described [1, 3, 5–11]. Direct comparison of CT and MRI measurements cannot be performed in healthy volunteers because of ethical reasons. In the first part of our study we performed MRI measurements of femoral antetorsion and tibial torsion in 98 lower limbs of healthy adult volunteers using a CT analogous method (transverse slice orientation) in order to establish reference values. Jend [7] performed CT measurements on 32 macerated femurs and found the average antetorsion was \( 15.25 \pm 11.9^\circ \), which was at the high end of the normal range. The average antetorsion was \( 10.4 \pm 6.3^\circ \) in the 98 lower limbs of healthy volunteers in the present study. The position of the femur in volunteers shows a downward tilt from hip to knee due to gluteal soft tissues, especially in obese persons. This difference in femur position, together with the different number of lower limbs examined, may explain the differences between mean antetorsion.

In our group average tibial torsion was

![Figure 4. Section through the distal tibia and fibula just above the talocrural joint. The reference line is a line connecting the centre of the pilon tibiale with the centre of a line across the fibular incision of the distal tibia.](image1)

![Figure 5. (a) Scout view of the proximal femoral region using a slightly inclined slice orientation. (b) Resulting section through the femoral neck with reference lines.](image2)
Figure 6. (a) Scout view of the proximal femoral region using a heavily inclined slice orientation adjusted to the tilt of the femoral neck. (b) Resulting section through the right femoral neck with reference lines.

Table 1. Mean femoral antetorsion and tibial torsion using a transverse slice orientation

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral antetorsion</td>
<td>10.4°</td>
<td>6.2°</td>
</tr>
<tr>
<td>Side difference</td>
<td>4.6°</td>
<td>3.3°</td>
</tr>
<tr>
<td>Tibial torsion</td>
<td>41.7°</td>
<td>8.8°</td>
</tr>
<tr>
<td>Side difference</td>
<td>6.1°</td>
<td>4.5°</td>
</tr>
</tbody>
</table>

SD, standard deviation; n = 98 extremities.

41.7° ± 8.9°. This corresponds well with the results of Jend et al’s CT study [8]. They measured a mean tibial torsion of 40° ± 9° in 70 limbs of healthy volunteers.

Repeated determination of femoral antetorsion by the same examiner (BS) after more than 3 months resulted in an average difference of 2.4° ± 3.2°. These findings correspond well with the results of Jend [7] who describes a mean difference of 2.83°. In Hernandez et al’s CT study of femoral antetorsion, mean intraobserver variation was 2° on average [3]. Repeated determination of tibial torsion showed an average difference of 3.0° ± 2.7°. Jend et al measured an error of repeated measurements of 1.1° at the proximal tibia and of 1.5° at the distal tibia [8]. Our results are also in agreement with the findings of Laasonen and colleagues [9], who studied a number of methods for CT measurement of tibial torsion and found an average error of 4.4°–4.5°. These results imply that visualization of osseous structures in MRI using a T₁ weighted gradient echo sequence is sufficient for the exact and reproducible positioning of reference lines. The use of CT, which is superior to MRI with regard to precise imaging of osseous structures, does not go along with a higher reproducibility of femoral and tibial torsion angles.

Transverse slice orientation in CT provides a cross-section through the whole length of the neck of femur in persons with coxa vara only. In persons with normal neck-shaft angles, and especially in persons with coxa valga, the three-dimensional axis of the femoral neck passes obliquely through the transverse section. Since a single image in the transverse plane can only provide a two-dimensional cross-section, theoretically it should not be used to determine the three-dimensional axis of the femoral neck [11]. MRI, however, enables us to orientate the slice along the axis of the femoral neck, thus obtaining a single cross-section of the entire neck.

This study demonstrates that femoral antetorsion angles measured depend on the degree of slice inclination in the region of the proximal femur. Antetorsion determined using a steeply inclined slice along the axis of the femoral neck was significantly higher than antetorsion determined using a transverse (Jend’s method) or slightly inclined slice orientation (16.7° vs 11.2° and 12.1°). These results were anticipated with regard to the findings of Murphy et al [11]. They reported on a new CT technique for measurement of femoral antetorsion. In the region of the proximal femur one section is made through the centre

Table 2. Femoral antetorsion measured using different degrees of slice inclination in the region of the femoral neck

<table>
<thead>
<tr>
<th></th>
<th>Transverse slice orientation</th>
<th>Slightly inclined slice orientation</th>
<th>Steeply inclined slice orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral antetorsion</td>
<td>11.2 ± 5.4°</td>
<td>12.1 ± 6.0°</td>
<td>16.7 ± 6.3°</td>
</tr>
</tbody>
</table>

SD, standard deviation; n = 42 extremities.
MRI measurement of femoral antetorsion and tibial torsion

of the femoral head, another section is made through the base of the femoral neck. The proximal line of reference is defined as a line connecting the centre of the femoral head and the centre of the femoral diaphysis at the base of the femoral neck. Antetorsion measured using this method was 10° higher on average than antetorsion measured using one single slice through the centre of the femoral neck. Moreover, antetorsion values determined using a single slice through the proximal femoral neck were 11.1° lower than antetorsion angles determined using a single slice through the distal part of the femoral neck. It appears, therefore, that for anatomical reasons, antetorsion angles measured increase if the line of reference passes through the base of the femoral neck. Obviously a single transverse slice through both the femoral neck and the distal part of the femoral head (as described by Jend) provides a cross-section through the proximal part of the femoral neck rather than through the base of the femoral neck and therefore results in an underestimation of femoral antetorsion angles.

In summary, our study shows that visualization of osseous structures in MRI using a $T_1$ weighted gradient echo sequence is sufficient for the exact and reproducible measurement of femoral and tibial torsion. The use of CT, which is generally superior to MRI with regard to precise imaging of osseous structures, does not go along with a higher reproducibility of femoral and tibial antever sion angles. A comparison between MRI and conventional radiological projection techniques [2] or ultrasound has not been performed in this study. The use of ultrasound is generally favourable because of its non-invasiveness and easy availability. Since ultrasound cannot penetrate bone, femoral antetorsion measurements in older children and adults can only be based on surface contours. The validity and accuracy of reported techniques are variable [14]. While some reports are encouraging [16] others question its usefulness [17, 18].

Altering the plane of section and adjusting it to the coronal plane inclination of the neck of femur is not possible with conventional CT, but is routinely available with MRI and allows for a cross-section of the entire neck of femur. The use of an inclined slice orientation along the neck of femur resulted in antetorsion values that were 5.5° higher than antetorsion values obtained using a transverse section through the femoral neck. These results agree with the findings of Murphy et al [11] and imply that antetorsion measurements using a single transverse section through the neck of femur tend to underestimate femoral antetorsion.

References