Radiographic measurement of tibial joint angles in sheep

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Key words
Tibia, ovine, measurement, joint angles

Summary
The aim of this study was to establish normal reference values of anatomic and mechanical joint angles of the tibia in sheep at different age groups. Eighteen clinically healthy Santa Ines sheep were used. The animals were divided into three equal groups according to age: Group I – from six- to eight-months-old, Group II – 2-years-old, Group III – from three- to five-years-old. Anatomic medial proximal and lateral distal tibial angles, mechanical proximal and distal tibial angles, and anatomic caudal proximal and anatomic cranial distal tibial angles were measured from tibiae radiographs (n = 36). In the craniocaudal view, the mean values of the anatomic medial proximal, anatomic lateral distal, mechanical medial proximal, and mechanical lateral distal tibial joint angles were 89.6°, 86.6°, 91.4°, and 85.19° respectively. In mediolateral view, the mean values of the anatomic caudal proximal and anatomic cranial distal tibial angles were 64.55° and 105.69°, respectively. The joint orientation angles of the tibia in sheep showed similar values regardless of animal age for both anatomic and mechanical axes.

Introduction
The establishment of the parameters and limits of alignment and joint orientation are needed to understand normal anatomy and to facilitate preoperative planning in cases of deformities, misalignment and malorientation (1–8). By using radiographs in orthogonal planes, it is possible to measure the mechanical and anatomic axes of a long bone and joint angles (3, 7, 8). A straight line joining the joint centre points of the proximal and distal joints determines the mechanical axis, and one or two straight lines that follow the mid-diaphysis of a bone determines the anatomic axis (3). In addition, the joint orientation angle is established between the joint line and mechanical or anatomic axes (3, 7, 8). These parameters are well established in human orthopaedic surgery, but there are few studies in veterinary medicine (5–9).

In one report, normal anatomic axes of 20 radii and ulnae from medium- and large-breed dogs in frontal and sagittal radiographic planes were determined as a reference, and nine radial angular deformities in seven dogs were corrected by the use of dome osteotomies (5). The preoperative planning was based on neutral centres of rotation of angulation (CORAs) that were established by points of intersection between the anatomic axis of the radial diaphysis and joint segment axes (5). In another report, a segmental radiographic planning technique combined with the centre of rotation of the angulations’ method, computed tomography, and stereo lithography was used to successfully treat an antebrachial angular limb deformity in a dog (9).

Anatomic lateral distal and proximal femoral angles, mechanical lateral distal and proximal femoral angles, and femoral angles of inclination were measured in four breeds of dogs (Labrador Retrievers, Golden Retrievers, German Shepherds, and Rottweilers) using digital radiographic images performed for hip evaluation according to the orthopaedic foundation for Animals. A digital image measurement programme was used. The study showed that anatomic and mechanical femoral joint angles varied between the breeds and provided information on angular alignment of the normal femur in the frontal plane (8). In another study, the femoral varus angles and femoral torsion angles of nine canine cadaver specimens (n = 18 femora), free from orthopaedic disease of the pelvic limbs, were described using computed tomography, standard radiography, and anatomic preparation (6).

Proximal and distal mechanical joint angles of the tibia in frontal radiographic plane were studied in 70 Labrador Retriever dogs and 35 dogs of other breeds which had been diagnosed with cranial cruciate rupture (7). Besides establishing a reference range of these angles for this population of dogs, the study described a standardised method for measuring the tibial mechanical axis in the frontal plane.

Several orthopaedic studies have used sheep as an experimental model to test materials or surgical procedures for use on human beings, such as replacement or reconstruction of the cranial cruciate ligament (10–12) and the treatment of fractures and segmental bone defects using bone plates (13–16) and external fixators (17,18). However, the influence of the bone axial alignment and joint orientation on the support of bodyweight loads during locomotion is possibly a predisposing factor for osteoarthritis development or implant failure, and have not been evaluated in sheep. Therefore, the primary purpose of this study was to establish normal reference values of anatomic and mechanical joint angles, in frontal and sagittal radiographic planes, of the tibia in sheep due to their importance as an experimental model for studying orthopaedic conditions. A second purpose was to determine if age influences these measurements due to the time at which growth plate fusion is complete in this species.
Materials and Methods

This study followed the guidelines for the care and use of laboratory animals and was approved by the Ethics Committee of our Veterinary School.

Eighteen clinically healthy Santa Ines sheep were used. The animals, 12 males and six females, were divided into three equal groups according to age: Group I – from six to 8-months-old (mean weight 25 kg), Group II – two-years-old (mean weight 50 kg), Group III – from three to five-years-old (mean weight 55 kg). The sheep were numbered from one to 18, and three animals were housed per pens (2.5 m x 2.5 m). Sheep maintenance feed, hay and water were provided ad libitum.

Anaesthetic procedure and care of animals

Food and water were withdrawn 36 hours and 12 hours, respectively, prior to the radiographic examination. After premedication with acepromazine 0.03 mg/kg IV, dissociative anaesthesia was induced and maintained with 3 mg/kg ketamine and 0.5 mg/kg diazepam administered intravenously. Following radiography the animals were recovered from anaesthesia and return to the pens.

Radiographic evaluations

Green-sensitive film\(^a\) sized 30 X 40 cm and cassettes with screens were used. A focus-film distance of 90 cm was used with an exposure of 45 kV and 3.2 mAs for the mediolateral view and 50 kV and 3.2 mAs for the craniocaudal view. The film was processed with an automatic processor\(^b\).

Mediolateral and craniocaudal radiographs including the entire tibia, stifle and tarsus on a single film were obtained. Radiographic projections were made with the radiograph beam centred at the mid-diaphysis of the tibia. Mediolateral radiographs were taken with the animal positioned in both left and right lateral recumbency. The pelvic limb was maintained in an anatomic standing position with the stifle positioned at approximately 140º, and the hock positioned at approximately 150º.

Radiographs were considered acceptable when the femoral condyles were superimposed. For an appropriately aligned craniocaudal radiographs the animal was positioned in dorsal recumbency, and the limbs were drawn caudally until they were parallel to the examination table, which placed the hip and stifle joints in positions approaching maximal extension. The patellae were centred over the trochlear groove. The stifles were extended and rotated inwards, allowing the hocks to be in an extended position. Radiographs were considered acceptable when the calcaneus was superimposed on the distal tibia, and at least 75% of the proximal epiphysis of the tibia calcaneus was visualised overlapping the tibial diaphysis.

The radiographic measurements included proximal and distal joint orientation angles based on the mechanical and anatomic axes. In both mediolateral and craniocaudal views, the anatomic axes were defined as two separate straight mid-diaphyseal lines, one for the proximal tibia and one for the distal tibia. For this the tibial diaphysis was divided into two equal segments. A straight mid-diaphyseal line was determined at points 25% and 75% along each segment of the tibia through which the respective axes were drawn. The mechanical axis was defined as the straight line joining two joint centre points, one at the proximal tibia and the other at the distal tibia, in the craniocaudal view. The stifle centre point was established at the centre of the intercondylar eminences, and the centre point of the tarsocrural joint was established at the mid-width of the tibia (medial malleolus) and fibula (lateral malleolus) at the level of the plafond.

In craniocaudal radiographs, the proximal joint orientation line was drawn connecting two points on the concave aspect of the tibial plateau, and the distal joint orientation line was drawn connecting two landmarks established on the subchondral bone of the two arciform grooves of the cochlea tibiae (Fig. 1). In mediolateral radiographs, the proximal joint orientation line was drawn along the flat portion of the subchondral bone, and the distal joint orientation line was established connecting two points from the distal edge of the

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\(^a\) Kodak, New York, New York, USA
\(^b\) Macrotec MX2; São Paulo, Brazil
The joint orientation angles were formed by the intersection of the proximal or the distal joint line, and either mechanical (m) or anatomic (a) axis. The measured angles in the craniocaudal view were anatomic medial proximal tibial angle (aMPTA) (Fig. 3), anatomic lateral distal tibial angle (aLDTA) (Fig. 3), mechanical medial proximal tibial angle (mMPTA) (Fig. 4), and mechanical lateral distal tibial angle (mLDTA) (Fig. 4). The measured angles in the mediolateral view were the anatomic caudal proximal tibial angle (aCPTA) and the anatomic cranial distal tibial angle (aCrDTA) (Fig. 5).

The measurements were made by two independent investigators, and the data obtained were combined to obtain the average values. A transparent plastic goniometer was used to measure joint angles directly from the radiographs.

Statistical analysis

The values of anatomic and mechanical joint angles, expressed in degrees, were analyzed using one-way analysis of variance (ANOVA) and the Kruskal-Wallis test. The Shapiro-Wilk and Levene tests were used for presuppositions of normality and homocedasticity (equality of variances).

Results

For anatomic orientation angles values in craniocaudal and mediolateral views (Table 1), and for mechanical orientation angles (Table 2) the variation among the groups were not significantly greater than expected by chance (p>0.05).

The median values of the anatomic tibial joint orientation angles are reported in Table 1, and the mean values of the mechanical tibial joint orientation angles are reported in Table 2. The differences between the three groups in the anatomical and mechanical angles were not significant (p>0.05).

The mean angles for all animals are shown in Table 3. In the craniocaudal view, the mean values of the anatomic medial proximal, anatomic lateral distal, mechanical medial proximal, and mechanical lateral distal tibial joint angles were 89.6°, 86.6°, 91.4°, and 85.19° respectively. In the mediolateral view, the mean values of the anatomic caudal proximal and anatomic cranial distal tibial angles were 64.55° and 105.69°, respectively.

Discussion

The points established for the tibial joint orientation lines as well as mechanical and anatomic axes were based on those described by Paley in human patients (3). Using this system, the long-bone geometry can be described by axes (anatomic/mechanical), site (proximal/distal), and side (medial/lateral) (3, 19). However, some anatomic landmarks were different from those established measurements of proximal and distal mechanical joint angles in the frontal plane in dogs.
The centre of the proximal most aspect of the intercondylar fossa of the femur was the proximal landmark for the mechanical axis of the tibia in dogs (7) instead of the centre of the intercondylar eminences of the tibia as used in the present study.

In sheep the medial and lateral intercondylar eminences are well-defined and have similar sizes (20) which makes their localization easier. In humans, both methods define the centre of the knee joint (3). In addition, the distal intermediate ridge of the tibia was the distal landmark for the mechanical axis of the tibia in dogs (7) instead of the mid-width of the tibia (medial malleolus) and fibula (lateral malleolus) as used in the present experiment. In sheep the shaft of the fibula is vestigial, and its distal extremity constitutes the lateral malleolus (20, 21) representing an anatomic difference to dogs and humans. More studies are necessary to provide a better landmark for sheep according to the weight distribution in this joint.

The use of the mechanical or anatomic axis measurements depends upon a number of factors such as the magnitude, level, plane and direction of the deformity, surgical planning, and the type of treatment, among other factors (3–5, 7, 19). The mechanical axis is more often used for tibia evaluation since it corresponds to the static weight bearing axis (4, 7).

In dogs with cranial cruciate ligament rupture, a mean value of 93.3° was obtained for the mechanical medial proximal tibial angle (7) that was very similar to the mean value of 91.44° ± 2.5° observed in the sheep of the present experiment. These dogs had a mean value of 95.99° ± 2.7° for the mechanical medial distal tibial angle (7), the supplementary angle of which is similar to the mean value of 85.19° ± 3.2° for mechanical lateral distal tibial angle measured in the sheep.

In healthy humans the normal medial proximal lateral and distal tibial angles were 85°–90° and 86°–92°, in both the mechanical and anatomic axes (3). In the present study, the anatomic medial proximal and lateral distal tibial angles had a mean value of 89.61° ± 2.54° and 86.64° ± 2.26°, respectively, in the craniocaudal view. The variation of values between humans and sheep may be associated with radiographic positioning. In humans, the procedure is performed with the

### Table 1

<table>
<thead>
<tr>
<th>Anatomic Axis(1) Groups</th>
<th>G I</th>
<th>G II</th>
<th>G III</th>
<th>p* (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>aMPTA</td>
<td>89.0 (86.2; 90.0)</td>
<td>89.0 (88.0; 91.7)</td>
<td>90.0 (89.2; 90.7)</td>
<td>0.264</td>
</tr>
<tr>
<td>aLDTA</td>
<td>86.0 (83.5; 88.5)</td>
<td>87.5 (85.2; 89.0)</td>
<td>87.5 (85.2; 89.0)</td>
<td>0.415</td>
</tr>
<tr>
<td>aCPTA</td>
<td>64.5 (61.2; 67.5)</td>
<td>65.5 (58.2; 72.0)</td>
<td>61.5 (60.0; 67.7)</td>
<td>0.660</td>
</tr>
<tr>
<td>aCrDTA</td>
<td>107.5 (105.2; 109.7)</td>
<td>106.0 (103.2; 109.5)</td>
<td>107.5 (102.2; 109.5)</td>
<td>0.861</td>
</tr>
</tbody>
</table>

(1) Median values of the angles for both right and left pelvic limbs
(*) Kruskall-Wallis test (α = 0.05).

Key: aMPTA: anatomic medial proximal tibial angle; aLDTA: anatomic lateral distal tibial angle; aCPTA: anatomic caudal proximal tibial angle; aCrDTA: anatomic cranial distal tibial angle.
In conclusion, the joint orientation angles of the tibia and the orientation of knee joint surfaces, in the frontal plane (19). The measurements of tibial angles in human patients are usually used in cases of tibial osteotomy (2, 22, 26, 27), and total knee arthroplasty due to osteoarthritic knees or knee misalignment (28–30). As reported in dogs (5, 7, 8), reference ranges and method of measurement pattern are also important to other animals and may be useful for surgical planning in experimental or clinical studies. The differences between breeds should be also considered (8).

In sheep the measurements may be used in experimental studies that involve bone deformities and their correction, prosthesis development for stifle surgery, evaluation of metal implant that modify the bone axis, among others.

In conclusion, the joint orientation angles of the tibia in sheep showed similar values regardless of animal age for both anatomic and mechanical axes when viewed radiographically. Further studies must be done to compare these values with other sheep breeds and other quadrupeds.

References

Table 3 Mean of tibial joint angles of the anatomic and mechanical axes of all sheep.

<table>
<thead>
<tr>
<th>Anatomic Axis</th>
<th>Mechanical Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranio-caudal view</td>
<td>Mediolateral view</td>
</tr>
<tr>
<td>aMPTA</td>
<td>aLDTA</td>
</tr>
<tr>
<td>89.61 ± 2.5</td>
<td>86.64 ± 2.2</td>
</tr>
</tbody>
</table>

(1) Mean ± SD values of the angles for both right and left pelvic limbs. Key: aMPTA: anatomic medial proximal tibial angle; aLDTA: anatomic lateral distal tibial angle; aCPTA: anatomic caudal proximal tibial angle; aCrDTA: anatomic cranial distal tibial angle; mMPTA: mechanical medial proximal tibial angle; mLDTA: mechanical lateral distal tibial angle.

Table 2 Mean of tibial joint angles of the mechanical axis for each sheep group (G I: six-to-eight-months-old, G II: two-years-old, G III: from three-to-five-years-old).

<table>
<thead>
<tr>
<th>Groups</th>
<th>G I</th>
<th>G II</th>
<th>G III</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>mMPTA</td>
<td>91.41 ± 2.3</td>
<td>90.83 ± 2.8</td>
<td>92.08 ± 2.0</td>
<td>0.663²</td>
</tr>
<tr>
<td>mLDTA</td>
<td>85.08 ± 3.2</td>
<td>85.50 ± 2.0</td>
<td>85.00 ± 2.0</td>
<td>0.935²</td>
</tr>
</tbody>
</table>

(1) Mean ± SD values of the angles for both right and left pelvic limbs. Key: mMPTA: mechanical medial proximal tibial angle; mLDTA: mechanical lateral distal tibial angle.