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A COMPARATIVE ANATOMICAL STUDY OF THE HUMAN KNEE AND SIX ANIMAL SPECIES

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Abstract

Purpose—Animal models are an indispensable tool for developing and testing new clinical applications regarding the treatment of acute injuries and chronic diseases of the knee joint. Therefore, the purpose of this study was to compare the anatomy of the intra-articular structures of the human knee to species commonly used in large animal research studies.

Methods—Fresh frozen cow (n=4), sheep (n=3), goat (n=4), dog (n=4), pig (n=5), rabbit (n=5), and human (n=4) cadaveric knees were used. Passive range of motion and intra-articular structure sizes of the knees were measured, the structure sizes normalized to the tibial plateau, and compared among the species.

Results—Statistically significant differences in the range of motion and intra-articular structure sizes were found among all the species. Only the human knee was able to attain full extension. After normalization, only the pig ACL was significantly longer than the human counterpart. The tibial insertion site of the ACL was split by the anterior lateral meniscus attachment in the cow, sheep, and pig knees. The sheep PCL had two distinct tibial insertion sites, while all the other knees had only one. Furthermore, only in human knees, both lateral meniscal attachments were located more centrally than the medial meniscal attachments.

Conclusions/Clinical Relevance—Despite the relatively preserved dimensions of the cruciate ligaments, menisci, and intercondylar notch amongst human and animals, structural differences in the cruciate ligament attachment sites and morphology of the menisci between humans and animals are important to consider when selecting an animal model.

Keywords

Knee; Anatomy; ACL; PCL; Meniscus

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CONFLICT OF INTEREST STATEMENT

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INTRODUCTION

Injuries of the intra-articular structures of the knee - the cruciate ligaments, menisci, and cartilage - are becoming increasingly prevalent, and are often associated with severe long term consequences such as post-traumatic osteoarthritis¹⁻³. These facts illustrate the need for new and effective treatments for these injuries^{4, 5}. Currently, intensive research efforts have produced a considerable amount of basic science knowledge for cruciate ligament⁶⁻⁸, meniscal^{9, 10} and cartilage^{11, 12} injuries. However, before human patients can benefit from such data, translational work in large animal models is often necessary to comply with regulatory requirements and the principles of translational medicine¹³.

Large animal models provide a uniform, experimental platform for development and evaluation of the effectiveness and safety of novel treatments¹⁴. Most commonly, sheep, goats, pigs, dogs, and rabbits are used as models of the human knee to test implants or to discover determinants of disease progression¹⁵⁻¹⁹. However, there exists no study that systematically and quantitatively compares the anatomy of the intra-articular structures of these animals with that of the human knee joint. Hence, the objective of this study was to compare the intra-articular knee anatomy of the above mentioned six animal species and the human knee in a systematic and quantitative way to define best-practice models for experimental models in knee surgery.

METHODS

The study was designed to compare the anatomy and sizes of the intra-articular structures of the knees of six animal species: cow (n=4), sheep (n=3), goat (n=4), dog (n=4), pig (n=5), rabbit (n=5), with the human knee (n=5). All animal knees were retrieved from subjects undergoing euthanasia for IACUC-approved research studies. The cow specimens were from female adolescent Angus cattle, the sheep knees from female adult Columbia sheep and the goat knees from female adult Alpine goats. The dog knees were from four female adult large breed dogs, the rabbit knees from five adult female New Zealand white rabbits, and the pig knees from adult female Yorkshires. All animal knees were harvested within 2 hours of euthanasia. The human knees were obtained from a willed body program and were obtained from 4 females with an age range of 47 to 60 years. All specimens were frozen at the time of collection and maintained at -20°C until the time of analysis.

Before dissection, specimens were thawed overnight and placed in an upright stand. The passive range of motion was measured using a goniometer with 1° gradation (Quint Measuring Systems, Sam Ramon, CA). The arms of the goniometer were aligned with the femoral and tibial shafts. Prior to the measurement, the knee was moved through a full range of motion to determine the axis of the joint rotation; the center of the goniometer was then placed over this axis. All angles were measured relative to the neutral 0° axis in extension of the femur shaft. After the goniometer measurements, the surrounding skin and musculature of the knees was removed leaving the capsule intact. The dissection started anteriorly with the removal of the patella, patellar tendon, and fat pad. Extraneous capsular fascia, fatty tissue and ligamentum mucosum were removed to give a clear view of the anterior cruciate ligament (ACL) tibial insertion, posterior cruciate ligament (PCL) femoral insertion and anterior meniscal attachments. Next, the medial and lateral aspects of the knee including both collateral ligaments were dissected to reveal the medial and lateral meniscus. Removal of the posterior capsule exposed the tibial PCL origin, femoral ACL origin and the posterior meniscal attachments. Following this, the anterior attachments of the menisci were dissected from the tibia flush with the bone allowing an unobstructed view at the ACL insertion. The posterolateral meniscal attachment to the femur was transected flush with the bone to examine and remove the tibial origin of the PCL and expose the posterior insertion of the

medial meniscus. Finally, the menisci were separated from their skeletal attachments. Vernier calipers (steel, double scaled, Fisher Scientific, Hanover Park, IL) were used to measure the meniscal width midway between the anterior and posterior horn as the distance from the free edge to the former capsule; the meniscal length was defined as the anterior-posterior dimension of the meniscus. ACL and PCL length and width were determined before the ligaments were excised from the knee. The length of the ACL was measured as the distance between the anterior tibial and femoral attachments, while the length of the PCL was defined as the distance between the posterior aspects of the tibial and femoral attachments. The ligament widths were measured at the mid-level of the ligaments in the sagittal plane. ImageJ 1.44 (NIH, Bethesda, MD, www.nih.gov) was used to measure the area of the insertion sites of the cruciates and menisci in the transverse plane after all soft tissue had been removed. Tibial plateau width was defined as the widest extent of the plateau in the frontal plane. The intercondylar notch width was measured at half the height from the distal most point of the femoral condyles to the apex of the notch. Each structure was measured three times and the median value was reported.

In addition to the direct measurements, all measurements were also normalized by the width of tibial plateau to facilitate comparison between knees of different sizes. This ratio between the width of the tibial plateau and structure size was referred to as the Tibial Index. Both the measured values and the values normalized by the Tibial Index were used in the comparative statistical analysis. Differences between groups were determined using an analysis of variance (ANOVA), with significance levels set at $p < 0.05$ for the overall ANOVA and Bonferroni adjustment for post-hoc testing to determine the significance between groups. All these calculations were performed using Intercooled STATA 10 (Statacorp LP, College Station, TX, USA).

RESULTS

Passive Range of Motion (Table 1)

The passive range of motion of the knees revealed that only the human knee could be brought to full extension, whereas neither of the knees of the quadruped animals reached a neutral 0° angle (Table 1). A difference in the flexion angle could only be seen in dog and rabbit knees, which had a statistically significant higher flexion angle compared to the human knees.

Photographs of the cruciate ligaments, tibial plateau, and menisci are in Figure 1.

Anterior cruciate ligament (ACL)

Direct measurement (Table 2)—The human ACL was significantly *wider* than the dog and rabbit ACL ($p < 0.001$) and significantly *longer* than the goat, dog, and rabbit ACL ($p < 0.01$).

Tibial Index (Table 3)—No significant differences in the Tibial Index of the ACL *width* between the species were found, whereas the Tibial Index of the ACL *length* was significantly *smaller* in the human than in the pig specimens ($p < 0.001$).

Overall shape (Figure 1)—The femoral origin of the ACL was located at the posteromedial edge of the lateral condyle in all species. The tibial ACL insertion site varied among species. In the human and goat knees, the tibial insertion of the ACL was adjacent to the anterior insertion of the lateral meniscus. Cow, sheep and pig knees had the tibial insertions of the anteromedial and posterolateral ACL bundles separated by the anterior attachment of the lateral meniscus. The cow anteromedial bundle inserted across the anterior

slope of the intercondylar eminence while the posterolateral bundle inserted in the center of the eminence between the tibial spines. The sheep and pig anteromedial bundles inserted at the medial edge of the anterior slope of the intercondylar eminence while the posterolateral bundles inserted on the lateral edge of the medial tibial spine deep to the anteromedial bundles and anterior lateral meniscus insertion. The ACL insertion in the rabbit knee was on the center of the tibial intercondylar eminence, posterior to the anterior lateral meniscus attachment. The dog ACL tibial insertion was on the medial slope of the intercondylar eminence.

Posterior cruciate ligament (PCL)

Direct measurement (Table 2)—The human PCL was significantly *wider* than the PCLs of all other species ($p<0.01$) but significantly *longer* only compared to the goat, dog, and rabbit PCL ($p<0.001$).

Tibial Index (Table 3)—The normalized PCL *width* showed no significant differences across the species, whereas the normalized sheep and pig PCL *length* was significantly *larger* than the human ($p<0.001$).

Notch width

Direct measurement (Table 2)—The human notch width was not significantly different from the cow but was significantly *larger* than in the other species ($p<0.001$).

Tibial Index (Table 3)—The Tibial Index for the notch width was significantly *smaller* in the sheep, goat, pig and rabbit knees when compared to the human ($p<0.01$).

Medial meniscus

Direct measurement (Table 2)—The human medial meniscus *width* was significantly *smaller* than the cow ($p<0.01$) but significantly *larger* than the rabbit ($p<0.001$). With exception of the cow medial meniscus the human medial meniscus was significantly *longer* than the animal medial menisci.

Tibial Index (Table 3)—Relative to the tibial plateau width, the human medial meniscus *width* was significantly *smaller* than the cow and pig ($p<0.05$).

Overall shape (Figure 1)—The anterior medial meniscus bony insertion was the most anterior structure found in the knee in all species. It inserted on the anterior edge of the tibial plateau just above the tibial tuberosity in all species except the dog, where instead of individual insertions, an intermeniscal ligament connected the anterior-most sections of the medial meniscus to the lateral meniscus. The sheep and pig knees also had a small connection between the anterior medial and lateral meniscus insertions, but they did not obscure the distinct anterior insertion sites. The posterior horn of the medial meniscus inserted on the lateral edge of the posterolateral surface of the medial spine, just anterior to the PCL origin and was covered superiorly by the PCL (Figure 1, column B). The goat, dog, and rabbit insertion site areas were smaller than those noted in the human, cow, sheep, and pig knees.

Lateral meniscus

Direct measurement (Table 2)—The human lateral meniscus *width* was significantly *larger* than the rabbit but *smaller* than the cow ($p<0.001$). The human lateral meniscus was significantly *longer* than the animal lateral meniscus except for the cow ($p<0.001$ for all comparisons).

Tibial Index (Table 3)—Neither the Tibial Index for the lateral meniscus *width* nor lateral meniscus *length* was significantly different between the species ($p>0.001$ for all comparisons).

Overall shape (Figure 1)—The human lateral meniscus covered a smaller portion of the lateral tibial plateau when compared to all of the animal knees. Anteriorly, the lateral meniscus in human knees was attached to the lateral aspect of the lateral spine of the intercondylar eminence. The cow, sheep, and pig lateral meniscus split the ACL bundles, while the goat and dog lateral meniscus passed behind the ACL. All inserted close to the medial tibial spine. The rabbit anterior lateral meniscus was attached even more medial, adjacent to the anterior horn of the medial meniscus. Posteriorly, the menisco-femoral ligament connected the lateral meniscus to the lateral back wall of the medial femoral condyle more inferiorly in human than in the animal specimens. Human, sheep, goat, dog, and rabbit lateral meniscus had a menisco-tibial coronary ligament, attaching directly lateral to the PCL insertion, with the human, goat, and dog being less robust than the rabbit.

Other features

The cow, sheep, and goat knees did not possess a full-length fibula or proximal tibia-fibula joint. Instead a fused fibular head was attached to the lateral side of the tibial plateau and served as an attachment site for the lateral meniscus. Furthermore, all animal knees contained an intra-capsular, extra-articular, lateral long digital extensor tendon (LDET) that originated just inferior to the lateral edge of the patellar groove. The LDET was not found in the human knee. The function of the LDET appeared to be dorsiflexion of the forefoot especially during knee flexion.

DISCUSSION

In this study, significant quantitative and qualitative differences between the human intra-articular structures of the knee and the animal species were found. Quantitatively, the human ACL was longer than the goat, dog and rabbit ACLs and wider than the dog and rabbit ACLs, whereas after normalization by the tibial plateau width, only the pig ACL showed a significantly greater length when compared to the human. The human PCL was wider than all of the animal PCLs, but only longer than goat, dog and rabbit PCLs. After normalization, only the PCL length of sheep and pig differed from the human. Previous studies have quantified the length and width of the human PCL as 38 mm in length and 13 mm in width²⁰, measurements which are similar to those reported here of 40 ± 7 mm and 14 ± 5 mm, respectively. Only the cow knee had a notch width and medial meniscus length comparable to the human knee, whereas the medial and lateral meniscus width was closest to human in sheep, goats, pigs, and dogs. In prior studies of human menisci, the width of the mid-body of the medial meniscus and lateral meniscus as measured on MRI have been reported at 7.4 mm and 8.4 mm, respectively²¹. Those measurements were consistent with those reported here (9.5 ± 0.6 mm and 9.8 ± 0.7 mm for the medial meniscus and lateral meniscus, respectively)²². Qualitatively, the two bundles of the ACL (anteromedial and posterolateral bundles) and of the PCL (anterolateral and posteromedial) were not as well-defined in the human as they were in some of the animal knees. In the human and goat knees, the anterior insertion of the lateral meniscus adhered to the lateral side of the ACL which may have obscured the bundle separation in these knees. The cow, sheep, and pig knees had distinct bundles which were separated by the anterior insertion of the lateral meniscus. This is very important to consider when placing a tibial tunnel through the center of the ACL footprint while performing an ACL reconstruction on those animals, as the anterior horn of the lateral meniscus could potentially be injured. Likewise, a tibial tunnel placed posteriorly to the ACL insertion site in the goat model may also damage the anterior lateral meniscus.

insertion. The sheep PCL had two distinct tibial insertion sites, while all other species had only one.

Unlike the animal knees, the human knees had both horns of the lateral meniscus located more central than the medial meniscus attachments. The dog and rabbit knees did not have the anterior insertion of the lateral meniscus connecting to the ACL or separating the ACL bundles; however, it is certainly possible that these species do have cruciate bundles that are mechanically distinct even though they were not identified anatomically in this study. The posterior attachment of the lateral meniscus via the posterior menisco-femoral ligament is similar to that previously reported in dog and sheep knees²³. In that study, the menisco-femoral ligament was also present in both of these species, caudal to the PCL and more oblique, features noted in our study as well. None of the four human knees in this study had anterior intermeniscal ligaments, which have been well characterized in past cadaver studies^{24, 25}. However, in this study, the intermeniscal ligament was identified in three of the four dog knees. While the intermeniscal ligament in the human is supplemental to the bony anterior insertion sites of the menisci²⁴, this ligament was the only anterior attachment for the medial menisci in several of the dog knees in this study. Thus, the division of an intermeniscal ligament in the dog model may destabilize the medial meniscus as the knee does not have separate bony attachments for these structures. In a prior study about the anterior insertion of the human medial meniscus, the insertion site was found to have four variations. Type I insertions were located in the flat intercondylar region of the tibial plateau; Type II occurred on the downward slope from the medial articular plateau to the intercondylar region; Type III occurred on the anterior slope of the tibial plateau; there was no firm bony insertion of the anterior horn in Type IV²⁶. In our examination of four human knees, all the knees had Type I insertions, as did all the animal knees, with the exception of several of the dog knees which had a Type IV insertion. The variability in the insertion site anatomy in the animal species and humans may thus be important in translational studies of medial meniscus pathology.

Our measurements of the passive range of motion (Table 1) of all knees show an inherent functional difference of the knees of the quadruped animal models compared to the human knee. All animals had a physiological limit of extension at about 40° to the neutral 0° axis in extension of the femur shaft (only rabbit knees were significantly more extendable to 22°). Although this significant difference in the range of motion occurs in all the common animal models for the knee joint and therefore is less of a factor when determining the optimal animal model for the human knee, it is crucial to keep this difference in mind when translating animal data to the human case.

Limitations of the study were the exclusive study of female specimens. While this selection bias prevented our contributing to the known gender-based differences in human knee anatomy, biomechanics, and cell biology^{27, 28}, it likely did result in a reduction of variance. Given the relatively high prevalence of knee injuries and specifically ACL ruptures in women compared to men³ was another reason to study the female knee. Another limitation in our study is the small number of specimens in each of the seven groups. A reliable statement can be given for the statistically significant comparisons, whereas not all non-significant comparisons have a power >80% and allow a correct interpretation. Apart from the specific limitations of this study, a general concern is the use of quadruped animals as knee models for the bipedal human, particularly given their range of motion differences noted in this study.

The disappearance of many of the observed differences in the cruciate and meniscal anatomy after normalization with the tibial plateau width suggests an overall conservation of relative size among species for the cruciates and menisci. Nonetheless, differences in the

absolute size of the structures exist, which results in considerable changes in the load and shear the intra-articular structures are subjected to.

The overview in Table 4 evaluates these characteristics, and can act as a guideline for choosing the right model for a certain structure. Sheep and cow specimens were the best match for the human ACL in size and proportion, but had their tibial ACL insertion split by the anterior lateral meniscus, whereas the goat ACL was shorter than the human ACL, but had a similar tibial insertion site. Based on anatomy alone, sheep, cows and goats may therefore make the best models for ACL injury treatment.

Interestingly, there was less conservation of PCL dimensions among the species studied. Only the cow PCL was comparable to the human PCL in absolute length, normalized values, and anatomy of the insertion sites, whereas the human PCL was significantly wider than all of the animal specimens. This may be attributed to differences in the range of motion of bipeds compared to quadrupeds. Since the PCL prevents the knee from overextending, it might have to sustain a higher load in the human knee at full extension, in comparison to the quadruped knees which are limited in their extension (Table 1).

The size and proportion of the human medial meniscus was most similar to the sheep and goat specimens. The human lateral meniscus was most similar in size to the sheep, goat and pig specimens; however, the anatomy of the tibial insertion sites of the lateral meniscus in the goat was most comparable to that of the human knee. Considering both the medial and lateral meniscus, the animal model with the closest anatomy to the human knee was the goat.

CONCLUSION

Large animal models are a very valuable tool for developing and testing new surgical procedures. Choosing an appropriate large animal model for a certain surgical procedure, or development of a new treatment, is essential for the correct interpretation of the outcome and translation into the human model. The results of this study provide information on size and morphology of the cruciate ligaments and menisci and thus will hopefully provide some guidance on this aspect of selection of appropriate animal models for intra-articular knee surgery development.

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Figure 1. Different aspects of the knees of the seven species

Column A shows the anterior aspect of the knees with the medial side being on the left and the lateral side on the right. Noticeable is the small band attaching the intermeniscal ligaments to the tibial plateau in the dog knee (6A). The anterior attachment of the lateral meniscus courses between the anteromedial and posterolateral bundles of the ACL in the cow, sheep, and pig knees (2A, 3A, 5A).

Column B represents the posterior aspects of the knees. In all knees the medial meniscus passes behind the PCL. In the human knees, the posterior meniscofemoral ligament inserts more inferiorly on the medial femoral condyle (1B). Note the posterior thickening of the

menisco-tibial coronary ligament between the lateral meniscus and tibial plateau in the sheep, goat, dog, and rabbit knees (3B, 4B, 6B, 7B).

Column C shows the different tibial attachments of the knees. Notice the splitting of the tibial ACL insertion by the anterior lateral meniscus in the cow, sheep, and pig knees (2C, 3C, 5C). The lateral meniscus attachments are located central to the medial meniscus attachments in the human knee (1C).

Column D shows the morphology of the menisci with the medial meniscus on the left, the lateral meniscus on the right and the anterior horns facing down. In the human knee (1D) the posterior horn of the lateral meniscus attaches anteriorly to that of the medial meniscus, a feature not seen in any of the six animal species examined.

(ACL = anterior cruciate ligament; ALM = anterior lateral meniscus; AMM = anterior medial meniscus; PCL = posterior cruciate ligament; PLM = posterior lateral meniscus; PMM = posterior medial meniscus)

Table 1
Direct measurement of the passive range of motion of the knee (in degrees)

Statistically significant differences ($p < 0.05$) to the human values are marked **bold**. All angles are goniometrically measured relatively to the neutral 0° axis in extension of the femur shaft. Only the human knee could be brought to full extension. All quadrupeds showed a physiological extension deficit. This general difference could not be seen in the flexion angle, where only the dog and rabbit knee had a statistically significant *larger* flexion angle than the human knee. v

	PASSIVE RANGE OF MOTION	
	EXTENSION [in degrees]	FLEXION [in degrees]
Human	2.5 ± 2.9	137.5 ± 9.6
Cow	35 ± 5.8	145 ± 7.1
Sheep	40 ± 5	146.7 ± 2.9
Goat	45 ± 9.1	145.5 ± 8.7
Pig	42 ± 4.5	144 ± 5.5
Dog	34 ± 4.2	160 ± 3.5
Rabbit	22 ± 2.7	161 ± 2.2

Table 2
Direct measurement of the medial and lateral menisci, anterior (ACL) and posterior cruciate ligaments (PCL), and notch (in mm)

Statistically significant differences ($p<0.05$) to the human values are marked **bold**. (ACL = anterior cruciate ligament; PCL = posterior cruciate ligament) The human ACL is significantly *wider* than the dog and rabbit ACL and *longer* than the goat, dog, and rabbit ACL. The human PCL *width* is significantly *larger* than in all of the animals, but only *longer* than goat, dog, and rabbit specimens. The human medial meniscus is significantly *narrower* than the cow, *wider* than the rabbit, and *longer* than any animal medial meniscus except the cow specimens. The same is true for the lateral meniscus except the cow lateral meniscus being significantly *longer* than the human. The human notch is significantly *wider* than all the animal specimens except the cow.

	DIRECT MEASUREMENT									
	ACL		PCL		Medial Meniscus		Lateral Meniscus		Notch	
	Width [mm]	Length [mm]	Width [mm]	Length [mm]	Width [mm]	Length [mm]	Width [mm]	Length [mm]	Width [mm]	Length [mm]
Human	12.73 ±1.35	37.78 ±3.17	14.23 ±5.17	40.30 ±7.45	9.5 ±0.71	39.8 ±3.71	9.83 ±0.69	33.28 ±3.53	21.9 ±5.0	
Cow	9.28 ±2.1	42.65 ±0.55	7.45 ±1.93	45.4 ±2.8	15.1 ±2.23	39.55 ±2.56	16.0 ±2.42	39.25 ±1.78	24.58 ±1.56	
Sheep	9.27 ±2.53	31.77 ±0.25	6.67 ±0.76	37.03 ±1.67	9.33 ±0.29	25.63 ±1.7	9.63 ±1.21	26.03 ±0.9	9.5 ±0.50	
Goat	10.65 ±1.62	24.2 ±2.56	5.33 ±0.82	26.6 ±3.0	8.80 ±3.4	23.18 ±1.75	8.65 ±0.35	22.0 ±3.57	8.1 ±1.09	
Pig	10.86 ±1.08	37.0 ±2.8	8.2 ±0.94	39.68 ±2.45	10.44 ±2.15	25.32 ±3.77	10.26 ±1.65	25.60 ±2.43	11.12 ±1.21	
Dog	5.45 ±1.21	21.2 ±2.97	5.33 ±1.08	22.8 ±4.4	6.33 ±0.95	16.83 ±1.61	6.85 ±1.4	16.3 ±1.16	9.7 ±2.07	
Rabbit	4.84 ±1.24	10.6 ±1.38	4.34 ±1.27	10.0 ±1.52	2.4 ±0.35	9.2 ±0.4	4.06 ±0.47	10.0 ±1.17	3.88 ±0.51	

Table 3
Tibial Index values of the medial and lateral menisci, anterior (ACL) and posterior cruciate ligaments (PCL), and intercondylar notch

Statistically significant differences ($p < 0.05$) to human values are marked **bold**. (ACL = anterior cruciate ligament; PCL = posterior cruciate ligament) The Tibial Index was calculated by dividing the directly measured structure size by the maximal width of the tibial plateau in the frontal plain. After normalization to the tibial plateau width, the human ACL is significantly *shorter* than the pig ACL, the human PCL significantly *shorter* than the sheep and pig PCL. The human medial meniscus shows proportionally a significantly *smaller width* than the cow and pig specimens, the human lateral meniscus a *smaller width* than the cow and dog specimens. The human notch is proportionally significantly *wider* than the notch of the sheep, goat, pig and rabbit specimens.

	TIBIAL INDEX									
	ACL		PCL		Medial Meniscus		Lateral Meniscus		Notch	
	Width	Length	Width	Length	Width	Length	Width	Length	Width	Length
Human	0.18 ±0.01	0.54 ±0.02	0.2 ±0.06	0.57 ±0.07	0.14 ±0.01	0.57 ±0.04	0.142 ±0.02	0.48 ±0.03	0.31 ±0.06	
Cow	0.13 ±0.02	0.63 ±0.06	0.11 ±0.03	0.66 ±0.06	0.22 ±0.02	0.58 ±0.06	0.23 ±0.02	0.57 ±0.06	0.36 ±0.02	
Sheep	0.18 ±0.05	0.6 ±0.01	0.13 ±0.01	0.7 ±0.03	0.18 ±0.01	0.49 ±0.032	0.18 ±0.02	0.49 ±0.02	0.18 ±0.01	
Goat	0.24 ±0.03	0.55 ±0.05	0.12 ±0.01	0.61 ±0.07	0.2 ±0.05	0.53 ±0.03	0.2 ±0.02	0.5 ±0.04	0.18 ±0.01	
Pig	0.21 ±0.01	0.72 ±0.03	0.16 ±0.02	0.78 ±0.04	0.2 ±0.04	0.49 ±0.07	0.2 ±0.03	0.5 ±0.04	0.22 ±0.02	
Dog	0.15 ±0.02	0.57 ±0.07	0.14 ±0.02	0.62 ±0.09	0.17 ±0.02	0.46 ±0.02	0.19 ±0.04	0.44 ±0.02	0.26 ±0.04	
Rabbit	0.28 ±0.1	0.6 ±0.04	0.25 ±0.1	0.57 ±0.06	0.14 ±0.01	0.52 ±0.06	0.23 ±0.05	0.57 ±0.07	0.22 ±0.02	

Animal Model Selection Guide illustrates levels of structural resemblance to the human anatomy

(+) good, (o) fair, (–) no resemblance in direct, normalized value and anatomical comparisons. (ACL = anterior cruciate ligament; PCL = posterior cruciate ligament) Cow and sheep specimens were the best match to the human ACL in size and proportion but had their tibial ACL insertion split by the anterior LM, whereas the goat ACL was shorter but had a similar tibial insertion site. Sheep, cows and goats may therefore make the best models for ACL injury treatment. A preferred animal model for PCL injury treatment couldn't be found. The size and proportion of the human MM was embodied best by the sheep and goat specimens. The lateral meniscus has the best size equivalence to the human counterpart in sheep, goat and pig specimens; the anatomy was most equivalent in goats. Overall, the preferred animal model for meniscus injury treatment may be the goat.

	ANIMAL MODEL SELECTION GUIDE				
	ACL	PCL	Medial Meniscus	Lateral Meniscus	Notch
Bovine	+	o	–	–	o
Ovine	+	–	o	o	o
Caprine	+	–	o	+	–
Porcine	o	–	–	o	–
Canine	–	–	–	–	o
Lapine	–	–	–	–	o