Arthroscopy of the normal cadaveric ovine femorotibial joint: a systematic approach to the cranial and caudal compartments

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Summary
Objectives: Preclinical studies using large animal models play an integral part in translational research. For this study, our objectives were: to develop and validate arthroscopic approaches to four compartments of the stifle joint as determined via the gross and arthroscopic anatomy of the cranial and caudal aspects of the joint.

Methods: Cadaveric hindlimbs (n = 39) were harvested from mature ewes. The anatomy was examined by tissue dissection (n = 6), transverse sections (n = 4), and computed tomography (n = 4). The joint was arthroscopically explored in 25 hindlimbs.

Results: A cranio-medial portal was created medial to the patellar ligament. The cranio-lateral portal was made medial to the extensor digitorum longus tendon. The medial femoral condyle was visible, as well as the cranial cruciate ligament, caudal cruciate ligament and both menisci with the intermeniscal ligament. Valgus stress improved visibility of the caudal horn of the medial meniscus and tibial plateau. To explore the caudal compartments, a portal was created 1 cm proximal to the most caudal aspect of the tibial condyle. Both femoral condyles, menisci, caudal cruciate ligament, the popliteal tendon and the menisco-femoral ligament were visible. The common peroneal nerve and popliteal artery and vein are vulnerable structures to injury during arthroscopy.

Clinical significance: The arthroscopic approach developed in this research is ideal to evaluate the ovine stifle joint.

Introduction
Sheep stifles are commonly used models for translational orthopaedic research since they are of similar size with comparable anatomy to the human knee (1–4). They consist of four articulations: the femoropatellar, femorotibial, femorofibular and tibiobifular compartments that share a common synovial lining (5). The femoropatellar and femorotibial (medial and lateral) regions have the most clinical significance since they are used for investigations of articular cartilage repair, joint resurfacing and tissue engineering (6–11).

Arthroscopy is considered the gold standard for diagnosis and treatment of meniscal and cartilage pathology in humans (12–17). One of the advantages of arthroscopy is that it is minimally invasive, allowing researchers the opportunity to perform second-look evaluations of a joint. This can be particularly valuable when evaluating the performance of an in situ tissue engineered construct.

Clinical injury to the caudal horn of the medial and lateral menisci is well described in humans (18–21). Since the ovine stifle is commonly used for translational meniscal research, it is important that arthroscopic approaches provide access to the entire ovine menisci (22–26). A previously described arthroscopic approach to the ovine femorotibial joint provided limited visibility and accessibility for diagnosis and treatment of cranial compartments (27). In addition, there was restricted examination of the axial aspects of the menisci, and structures such as the abaxial aspect of the caudal horns of both menisci and the caudal cruciate ligament could not be assessed using the previously described approach. Due to the relevance of the ovine stifle in translational meniscal research, and the paucity of information in the literature regarding complete arthroscopic exploration of the ovine femorotibial joint, further considerations of arthroscopic approaches are needed. Therefore, the objective of this study was to develop arthroscopic approaches to the cranialateral, craniomedial, caudolateral, and caudomedial aspects of the ovine stifle joint.
this joint as determined via gross, computed tomographic, and arthroscopic anatomy of the femorotibial joint. We hypothesized that well placed portals on the cranial aspect of the femorotibial joint would reliably provide access to the axial aspect of the caudal horn of the medial meniscus, and caudal compartments of the femorotibial joint could be accessed from a caudomedial or caudolateral approach, allowing a more complete examination of the caudal structures of this joint.

Materials and methods

Cadaveric hindlimbs (n = 39) were used from 32 Polypay mature sheep euthanatized in other unrelated studies. All animals were older than two years old, with weights ranging from 45 to 71 Kg (mean 61.3 Kg). Limbs were disarticulated at the coxofemoral joint in four limbs (28). Limbs were maintained in partial flexion (approximately 120°) to permit equal distribution of the injected plastic across caudal and cranial aspects of the joint. A needle (1.6 mm x 38 mm) was inserted into the craniomedial femorotibial joint, approximately 1 cm cranial to the medial collateral ligament, and approximately 1 cm proximal to the patellar. An egress needle was also inserted in the suprapatellar pouch, on midline, approximately 0.5 cm proximal to the patella. Approximately 30 ml of plastic was injected into the femorotibial joint, until resistance was encountered, and the plastic exited the egress needle. After 30 minutes (time for the plastic to become solid), one limb was immediately dissected, one limb was imaged using CT as described below, and two limbs were frozen at −20°C and later cut in approximately 5 mm transverse cross-sections to establish the extent of joint distention (29). Transverse cuts of frozen limbs, parallel to the tibial plateau with the stifle in partial flexion (approximately 120°), were made from mid femur to the proximal third of the tibia using a band saw. Slices were photographed and maintained at −20°C for future reference.

Computed tomography

To further study the three-dimensional relationship of the stifle and its relation with bone and soft tissue structures, CT imaging was performed on five limbs. One of the limbs previously injected with plastic as described above, was scanned before gross dissection, to see if the plastic could serve as a useful contrast agent. In the remaining four limbs, survey CT scans, without any contrast injection, were performed. Medial femorotibial joints of these four limbs were then injected with a commonly used contrast agent (barium sulfate), using the technique described above for plastic injection. A 30 ml syringe was loaded with 15 ml of barium and 15 ml of tap water and injected until an increase in resistance was noticed at about 28 ml. Computed...
tomography imaging commenced immediately after completion of the injections, and 2.5 mm slices were imaged in transverse, coronal and sagittal planes.

Arthroscopy

Arthroscopic explorations of 25 stifles were performed (14 cranial and 11 caudal compartments).

Anatomical knowledge gained during other stages of this study described above was considered and portals were created through trial and error. Gross dissection was performed after each arthroscopic examination to ensure correct identification of intra-articular structures and to determine extent of iatrogenic damage created. A portal was considered optimal when most of the joint could be examined, combined with minimal iatrogenic damage. Special attention was paid to maximizing examination of the menisci.

A 1.9 mm 30° arthroscope\(^d\) attached to an arthroscopy tower\(^d\) was used to explore joints and record images. Prior to portal creation, palpation of anatomical landmarks identified during dissection was performed and joints distended with 30 ml of tap water. Intra-articular pressure was maintained with tap water at 206.84 kPa (kilopascal) throughout the procedure.

To explore the cranial femorotibial joint, limbs were placed with the caudal aspect down and the proximal femur attached to a custom-made jig, to mimic dorsal recumbency and facilitate flexion and extension during arthroscopic procedures. To distend the joint, stifles were positioned in partial flexion (approximately 120°) and a 1.2 mm x 38 mm needle was placed into the joint halfway between the medial tibial plateau and medial femoral condylar ridge, approximately 1 cm cranial to the medial collateral ligament. Intra-articular distension was easily appreciated on the craniolateral aspect, over the synovial sheath of the extensor digitorum longus tendon and peroneus tertius. A single arthroscopic portal was created in each one of the cranial compartments via a 4 mm stab incision with a No. 11 scalpel blade through skin, subcutaneous and joint capsule. No egress portal was created to explore the cranial compartments.

To explore caudal compartments, limbs were placed in partial flexion (approximately 120°), with the lateral or medial surface down, depending upon which caudal compartment was explored. To distend the joint, we used the same approach described for the cranial femorotibial joint. A single arthroscopic portal was created to each of the caudal compartments via a 4 mm stab incision with a No. 11 scalpel blade through skin and subcutaneous tissue only. No egress portal was created to explore the caudal compartments.

In order to ensure correct identification of anatomical structures seen arthroscopically, spinal needles (0.9 mm x 77 mm) were placed into each tissue under arthroscopic guidance, and tissue identity was confirmed with subsequent gross dissection. To determine limits of the field of vision of each arthroscopic portal, reference marks were made with a sharp trocar under arthroscopic guidance. Once familiar with which intra-articular anatomical structures could be examined arthroscopically, a spinal needle (0.9 mm x 77 mm) was used to locate the ideal location for instrument portals. Images of procedures were recorded. Articular cartilage and neurovascular structures were evaluated for iatrogenic injury during subsequent gross dissection.

Results

Gross anatomy

For cranial compartments of the femorotibial joint, gross dissection confirmed no vital neurovascular structures were at risk for being injured during arthroscopic portal creation. A large infrapatellar fat pad fills the cranial portion of the femorotibial joint, proximal to the tibial tuberosity (5). Even though all articulations of the ovine femorotibial joint share the same synovial lining, there is a thin membrane that, together with the fat pad, partially separates the cranialateral from the craniomedial compartment of the femorotibial joint. This membrane is attached to the cranialateral aspect of the synovial lining proximally, and courses axially from its attachment on the distal aspect of the lateral femoral trochlea until it reaches the intercondylar area (Figure 2A).

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Figure 2 Gross dissection of the right ovine stifle. A) Cranial view after removal of the patellar ligament (PL) and joint capsule to show the thin membrane (black arrow) in the cranialateral aspect of the femorotibial joint. B) Lateral view after removal of the biceps femoris to show the location of the common peroneal nerve (white arrow) on the lateral aspect of the lateral head of the gastrocnemius muscle (LG). The common peroneal nerve is located approximately 4 cm caudal to the lateral collateral ligament (LCL) at the level of the tibial plateau. The most caudal aspect of the lateral tibial condyle is indicated on the picture by the white circle. EDL: extensor digitorum longus tendon; MFC: medial femoral condyle; LFC: lateral femoral condyle.
In the caudal compartments of the femorotibial joint, the common peroneal nerve and popliteal artery and vein were identified as important neurovascular structures during gross dissection. The common peroneal nerve traces across the lateral head of the gastrocnemius muscle, deep to the biceps femoris muscle to reach the region of the head of the fibula (30, 31). It is a vulnerable structure for iatrogenic injury during portal creation and arthroscope placement due to its location, approximately 2 cm caudal to the most caudal aspect of the tibial condyle, at the level of the tibial plateau (▶Figure 2B). The popliteal artery and vein lie in the axial septum in between the caudo-lateral and medial compartments, cranial to the popliteal muscle (▶Figure 3A and B) (32). They are vulnerable structures for iatrogenic injury during portal creation if the scope is allowed to penetrate too deep and punctures through the axial aspect of the joint capsule.

Based on gross dissection and transverse sections, the craniomedial approach utilized to inject the stifle allowed adequate distention throughout all aspects of the joint. There was an even distribution of the injectable plastic across the cranio-lateral and medial compartments of the femorotibial joint (▶Figure 3 A and B). However, the caudomedial compartment was always larger when compared to the caudolateral compartment in a craniocaudal orientation (▶Figure 3 A). The popliteal tendon, which originates from the lateral femoral epicondyle, passes intra-articularly under the lateral collateral ligament and exits the joint in the caudolateral aspect of the femorotibial joint. The popliteal muscle divides the caudolateral compartment into distal and proximal pouches and inserts diffusely on the caudal aspect of the tibia (▶Figure 3B) (5).

**Computed tomography**

Survey images without contrast (n = 4) or images created after intra-articular injection of plastic (n = 1) were not useful for highlighting joint distension. However, acquired images after intra-articular injection of barium sulphate revealed the entire three-dimensional extent of the joint. Computed tomography findings complemented and supported findings described above upon gross dissection and transverse sectioning of anatomical specimens (▶Figure 3C). In addition, the popliteal artery and vein could be observed (▶Figure 3D).

**Arthroscopy**

**Cranial compartments**

Optimal arthroscopic portal location for a craniolateral portal was approximately 0.5...
cm medial to the extensor digitorum longus tendon and directly distal to the extensor fossa of the femur with the stifle in approximately 100° flexion (Figure 4A). Through this portal, the arthroscopic sleeve and blunt trocar should be advanced towards the intercondylar eminence of the tibia. The joint can then be gently extended and the sleeve advanced proximally through the thin membrane, which partially separates the craniofemoral from the craniofemoral compartments (Figure 2A), continuing proximally between the articular surface of the patella and the trochlear groove, towards the suprapatellar pouch. There was no increase in resistance while passing the sleeve through the previously described thin membrane.

Using this craniofemoral approach, the femoropatellar region, including the trochlear groove and trochlear ridges, as well as the suprapatellar pouch could be inspected thoroughly (Figure 5A and B). The arthroscope can then be retracted and passed along the medial femoral condyle into the craniofemoral femorotibial joint. The mediolateral femoral condyle, cranial aspect of the medial meniscus, a small segment of the cranial cruciate ligament, the caudal cruciate ligament and the intermeniscal ligament could all be seen. However, the most cranial aspect of the cranial cruciate ligament and most of the intermeniscal ligament were consistently covered by the infrapatellar fat pad. Therefore, a craniofemoral instrument portal was required to facilitate debridement of the fat pad. The best location for this instrument portal was identified using a 0.9 mm x 77 mm spinal needle placed approximately 1 cm medial to the patellar ligament, at the same level as the arthroscopic portal (Figure 4A). A full radius 4.5 mm resector was then introduced in the instrument portal and the infrapatellar fat pad removed to increase exposure of the cranial cruciate and intermeniscal ligaments (Figure 5C and D). Flexion of the stifle joint (approx. 80–90°) provided further and closer inspection of the proximal aspect of the caudal cruciate ligament, directly axial to the medial femoral condyle (Figure 5E). Valgus stress with the stifle in partial flexion (approx. 120°) improved inspection of structures located caudally in the medial femorotibial joint. This stress enabled examination of the tibial plateau and the axial aspect of the caudal horn of the medial meniscus (Figure 5F).

To explore the craniofemoral femorotibial joint, portals were then reversed such that the arthroscope was placed in the craniofemoral portal, and the craniofemoral portal was used for instruments. The cranial cruciate ligament, intermeniscal ligament, popliteal tendon, EDL tendon, lateral femoral condyle and cranial aspect of the lateral meniscus could all be seen (Figure 6A and B). To improve examination of the lateral meniscus and tibial plateau, the limb was partially extended (approx. 130°) and varus stress applied. However, the visibility of the caudal horn of the lateral meniscus could not be improved with this stress.

Caudal compartments

The optimal arthroscopic portal to explore the caudomedial femorotibial joint was located approximately 1 cm proximal to the most caudal aspect of the medial tibial condyle (Figure 4B). The arthroscopic portal was created and a sleeve with a blunt obturator introduced into the joint, aiming towards the axial aspect of the lateral femoral condyle. The caudal aspect of the medial femoral condyle, caudal abaxial aspect of the caudal horn of the medial meniscus (Figure 7A), and the cranial cruciate lig-
Arthroscopy of the ovine femorotibial joint. The amount of soft tissue on the lateral aspect of the limb made identification of landmarks more difficult, especially when exploration of the caudomedial compartment had already been performed, due to fluid leakage. To approach the proximal pouch of the caudalateral compartment, a sleeve with a blunt obturator was introduced into the joint aiming towards the axial aspect of the medial femoral condyle, parallel to the tibial plateau. To explore the distal pouch, the same incision was used, but the sleeve with blunt obturator was directed slightly distally (approx. 30°). Even though the caudalateral proximal pouch was small, the popliteal tendon, caudal aspect of the tibial plateau, lateral femoral condyle, lateral meniscus and meniscofemoral ligament could be examined (Figure 7C, D and E). In the distal pouch, which was even smaller than the proximal pouch, the distal aspect of the popliteal tendon and the articular proximocaudal aspect of the tibial plateau were seen (Figure 7F).

**Discussion**

This study defined the arthroscopic anatomy of the ovine stifle and permitted identification of optimal portal sites through trial and error based on anatomical considerations. The cranialateral and craniomedial arthroscopic approaches to the cranial compartments provided good visibility of cranial structures of the femorotibial joint and femoropatellar joint, as well as the axial surface of the medial meniscus, a prime region of interest in translational research (33–38). Carson described a cranial approach just proximal to the tibial tuberosity, which in our experience makes exploration of the most distal aspect of the joint (menisci and tibial plateau) very difficult because once the joint is flexed, portals tend to move further proximal, decreasing the range-of-motion of the arthroscope (39). It also makes the beginning of the procedure more difficult since it directs the surgeon into the infrapatellar fat pad making visual examination difficult, increasing the chance for iatrogenic damage to the menisci during portal creation (39). In humans, the infrapatellar fat pad can vary from a thin cord to a complete sheet, but is consistently large in the ovine stifle, which limits initial arthroscopic examination (40). Therefore, we agree with other authors that resection of the infrapatellar fat pad is ideal (27). With our approach, resection allowed more complete examination of the distal insertion of the cranial cruciate ligament and the meniscofemoral ligament than without resection.

In order to obtain better observation of the axial meniscal meniscus, a valgus stress was applied to the tibia in relation to the femur, as reported in humans (39, 41, 42). As observed in Figure 5F, this allowed observation of the entire axial meniscal meniscus using the described cranialateral portal and fat pad resection. Although the lateral compartment is more lax than the medial, and the lateral meniscus is more moveable and has closer horns than the medial meniscus, we were unable to completely view the axial caudal horn of the lateral meniscus with or without applied varus stress (5, 39, 42).

Caudal approaches to the caudo-medial and lateral femorotibial joint described in this study did not cause damage to neurovascular structures or femoral condyles. During gross dissection, the common peroneal nerve appeared to be approximately 2 cm caudal to where the lateral arthroscopic portal would be placed. However, once the femorotibial joint was distended, the common peroneal nerve displaced even further caudally. Distention of the joint prior to arthroscopic portal creation made exploration of the caudalateral compartment safe and feasible from the caudolateral portal and fat pad resection. Although the sleeve with blunt obturator was directed slightly distally (approx. 30°), even though the caudalateral proximal pouch was small, the popliteal tendon, caudal aspect of the tibial plateau, lateral femoral condyle, lateral meniscus and meniscofemoral ligament could be examined (Figure 7C, D and E). In the distal pouch, which was even smaller than the proximal pouch, the distal aspect of the popliteal tendon and the articular proximocaudal aspect of the tibial plateau were seen (Figure 7F).
eral aspect. In order to facilitate arthroscopic exploration of the caudal compartments, we recommend starting with the caudolateral compartment followed by the caudomedial compartment to optimize distention. Arthroscopic exploration of the cranial compartments should be performed last, either by the craniomedial or lateral approach, since maintaining joint distention is not as critical as it is for caudal compartments.

The caudomedial approach allowed good observation of the structures on the caudomedial aspect of the joint, which could not be seen by either cranial approach. The caudolateral approach provided good visibility of the caudolateral compartment, even though the articular space was smaller when compared to the caudomedial compartment, as seen by CT and anatomical study. In addition, the caudolateral compartment is divided by the popliteal tendon into distal and proximal pouches. Exploration of the proximal pouch offered good visibility of the lateral femoral condyle, lateral meniscus and meniscofemoral ligament. The distal pouch was poorly explored due to its size, providing limited examination of the caudal tibial plateau and popliteal muscle behind the synovial lining. Due to the inevitable fluid leakage secondary to any arthroscopic exploration, we recommend examining either the proximal or distal pouch, depending upon the study.

While crossing from the caudomedial to the caudolateral compartment seems to be a possibility in the human knee, it is not an option in the ovine stifle (42). As previously reported in horses, crossing from the caudomedial to the caudolateral compartment is not safe due to location of the popliteal artery and vein in the septum between the caudal compartments of the femorotibial joint (43). We did not attempt to create a second portal in the caudal compartments, but want to make the reader aware that a second portal would offer limited options for instrumentation due to the small size of the joint. If a second portal is necessary for the caudolateral compartment, we recommend placing it 1 cm proximal to the previously described portal. Creating a second portal caudal to the first portal increases the risk of common peroneal nerve damage. On the other hand, a second portal can be safely placed 1 cm further caudal, if needed, in the caudomedial approach to the caudomedial compartment.

The 2.7 mm 25° and 30° arthroscopes, 175 mm long, have been suggested for exploration of the ovine stifle (5, 27). We used a smaller diameter and shorter arthroscope (1.9 mm, 30° and 60 mm) after failing to observe the axial, caudal horn of the medial meniscus with a 2.7 mm scope during our pilot study. Even though a longer scope would facilitate exploration of the caudolateral compartment by decreasing the contact of fluid inlet and outlet with the skin due to the large muscle mass, we believe that the diameter of the scope was ideal to achieve complete examination of the femorotibial joint. The caudal horn of the medial meniscus, could be reliably accessed independent of the size of the animal. Furthermore, the limited space in both caudal compartments, when compared to the cranial compartments, is a limiting factor for the use of a larger diameter scope.

Conclusions

The ovine femorotibial joint is a joint that requires knowledge of the gross anatomy, good arthroscopic skill, and practice for successful exploration. The current study describes a systematic arthroscopic approach to cranial and caudal compartments of the ovine femorotibial joint, with positioning to avoid damage to neurovascular structures. The cranial approach to the ovine femorotibial joint allowed inspection of the femoral condyles, articular surface of the patella, cruciate ligaments, both menisci and their ligaments. Despite our findings, explorations of both caudal compartments remain a challenge due to their size and anatomical features. The feasibility of using these approaches to create or repair lesions is lacking. In order to validate these approaches to facilitate minimally i-
vise studies of meniscal and osteochondral surgery, further studies need to be performed.

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Conflict of interest

None declared.

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