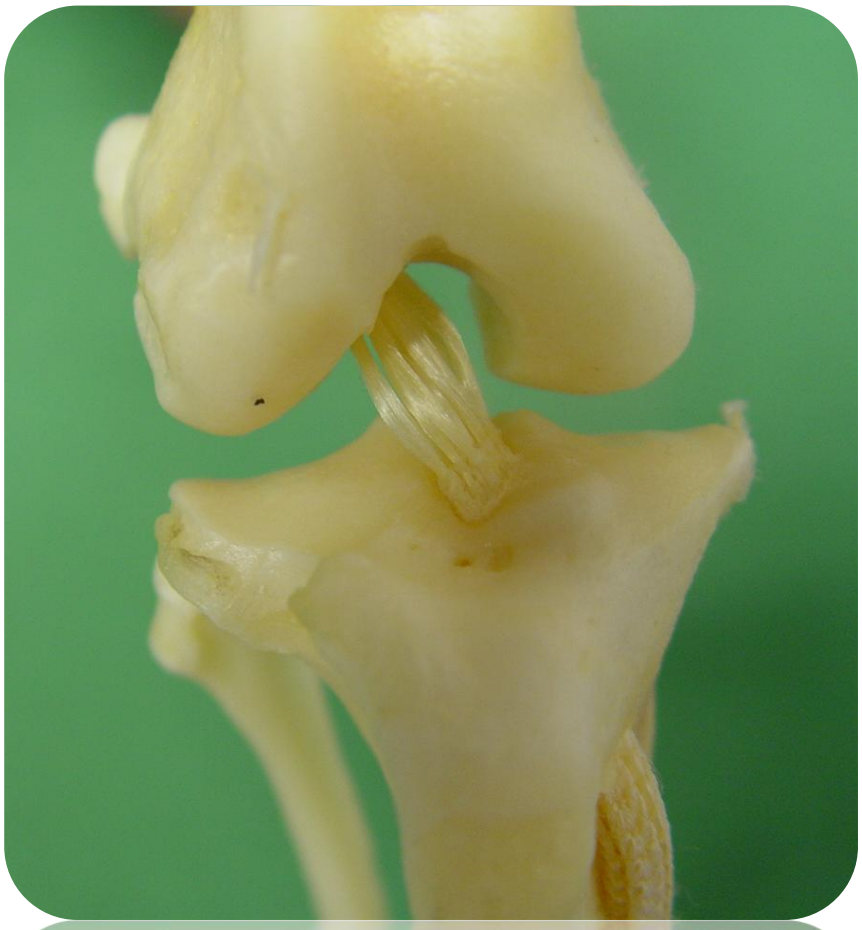
Treatment of cranial cruciate ligament rupture with the ligament augmentation and reconstruction system (LARS) in dogs: An in vitro study



Master research project

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Contents

Abstract

Objective: To describe the technique and to assess the efficacy of the ligament augmentation and reconstruction system (LARS) in treating cranial cruciate ligament (CCL) deficient stifle joints in dogs.

Study design: In vitro study.

Animals: Eight hind limbs from four canine cadavers.

Methods: Translation measurements in knee specimen at a standing angle of 135 degrees were performed. Translation of the tibial plateau was measured clinically with the drawer test and assessed radiographically with the use of the tibial compression test. In addition, the surgical procedure was evaluated by assessing the position of the bone tunnels in the femur and the tibia and comparing them with the anatomic origin and insertion of the CCL.

Results: Clinical tests showed decreased translation values after treatment with the LARS CCL implant in comparison with the CCL deficient stifles. Radiographic imaging showed a difference between the intact CCL and the LARS CCL implant in the distance between the centre of the humeral condyle and the centre of the tibial plateau. The LARS CCL implant did not result in a normal position of the tibial plateau. Scoring of the placement of the bone tunnels in the femur and tibia showed no difference between placement of the bone tunnels in the femur or tibia.

Conclusion: Despite the limitations of this study, it can be concluded that the surgical procedure of placing a LARS CCL implant is technical possible, but the procedure results in a small cranial displacement of the tibial plateau. The LARS CCL implant may prove to be of use in patients with CCLD but additional clinical in vivo studies are required.

Introduction

The most common cause of hind limb lameness in dogs is cranial cruciate ligament disease (CCLD). The disease is characterized by a chronic synovitis and progressive degeneration of the cranial cruciate ligament (CCL). In the healthy stifle, the CCL prevents hyperextension, cranial tibial displacement and internal rotation of the tibia relative to the femur(1,2) . Rupture of the CCL can be caused solely by trauma but the most common cause of CCL rupture in dogs is by a degenerative disease of the CCL of which the exact pathology is unclear(3). This degenerative disease of the CCL is often seen in young adult large breed dogs and frequently becomes bilateral within a year of the initial diagnosis. Rupture of the CCL leads to substantial tibial translation in the stifle during the stance phase of gait. Muscular forces are unable to compensate for the loss of stability provided by the CCL. This stifle instability leads to development of progressive stifle osteoarthritis and could even result in secondary meniscal injury(2).

Various treatment options are used to eliminate or correct the abnormal joint biomechanics caused by CCLD(4). The tibial plateau leveling osteotomy (TPLO) and the lateral extra capsular suture system(LESS)are most commonly used in veterinary practice. Besides these two procedures, the tibial tuberosity advancement(TTA) and the TightRope procedure(TR) are also popular techniques(5). TPLO was created to manage cranial tibial instability and eliminate cranial tibial thrust by leveling the tibial plateau slope. The procedure involves a radial osteotomy of the tibial plateau in combination with cranial rotation and leveling of the tibial plateau. A designated plate stabilizes the tibial plateau after osteotomy. TPLO gives a dynamic stabilization but the cranial drawer sign is not eliminated. Meniscal injury remains a common complication after TPLO(2). LESS is an extra capsular stabilization technique which involves a nylon leader line from the lateral fabella through a bone tunnel in the tibial crest which is secured by a stainless steel crimp. The LESS procedure eliminates cranial displacement and internal rotation of the tibia relative to the femur(4). TTA aims to eliminate cranial tibial thrust by altering the angle of the patellar ligament on the tibial plateau, and thus the force angle of the patellar ligament. TTA involves an osteotomy of the tibial crest and advancing the tibial tuberosity. The tibial crest is stabilized with a cage and a tension plate. TTA results in a stabile stifle joint dynamically eliminating the drawer sign. TTA alters not only the angle of the patellar ligament but also tensions the medial and lateral fascia of the stifle joint(2,6). The TR procedure is considered less invasive then TPLO and TTA. This procedure consists of drilling bone tunnels in the femur and tibia and then leading a multifilament artificial ligament through the bone tunnels to stabilize the CCL deficient stifle. The bone tunnels are drilled on the lateral side of the joint distal of the femorofabellar joint and just caudal of the tibial groove of the tendon of the long digital extensor

muscle. The TR procedure eliminates cranial thrust, the clinical drawer test and internal tibial rotation and is successful in restoring joint function(7,8). None of these treatment options restore normal joint mechanics and osteoarthrotic changes continue to progress even after successful surgery(4).

Restoration of normal joint mechanics can be best achieved by replacing the CCL. In humans, procedures to reconstruct the function of a ruptured CCL with an autograft are the golden standard in CCL reconstruction (9). In dogs, different autografts have been used but all of them had inferior results comparing to tibial osteotomy and extra-articular techniques. Autograft failure was due to the inability of the autografts to regain structural integrity of the original CCL and failure to duplicate the multiple bundle architecture of the CCL. The possibility of allografts was explored but these had been associated with an increased immune-directed inflammatory response and disease transmission and because of that, the development of allograft replacement of the CCL has been delayed. A prosthetic replacement for CCL could still be a good solution and it was hypothesized that the ideal prosthetic should act as a biologic scaffold for ligament differentiation and needs to mechanically protect in regenerating tissue(10).

Because research in human patients shows satisfactory results for the ligament augmentation and reconstruction system (LARS) when compared to conventional procedures(9,11-13), the LARS was used as an implant for CCL reconstruction in dogs in the present study. The LARS is a non-absorbable synthetic ligament made of polyethylene terephthalate (PET) and consists of two different parts. An extra-articular part which is made of longitudinal fibers held together by transverse knitted fibers and an intra-articular part which consists only of longitudinal fibers twisted at a 90 degree angle. The LARS CCL implant is highly cleaned to remove manufacturing residues and reduce reactive synovitis. The design of the LARS CCL implant is thought to favor ingrowth of surrounding tissue(9,11,14).

The aim of this study was to describe the surgical procedure for placing a LARS CCL implant in dogs, to determine if the LARS CCL implant effectively stabilizes the stifle joint with clinical tests and radiographs and to determine if the LARS CCL implant is suitable for treatment of CCL deficiency in dogs.

Materials and methods

Surgical procedure

The surgical procedure was performed on eight canine hind limbs and were all carried out by the same surgeon. A standard limited lateral arthrotomy was used leaving the lateral femoropatellar ligaments intact. The cranial cruciate ligament was identified and cut midway between femoral origin and tibial insertion. The lateral joint capsule was closed with interrupted sutures and tibial compression radiography of the stifle joint was performed.

A modification of the human LARS technique was used. The procedure was started after suture removal of the capsule using the same limited lateral arthrotomy. After identifying the origin of the cut cranial cruciate ligament in full flexion of the stifle a guide wire was drilled from the origin retrograde into the lateral part of femoral condyle, using a 60^0 angle exiting the lateral femoral cortex at the level of the entrance of the femoral trochlea. A mini approach to the lateral femoral cortex was performed to visualize the exiting point of the guide wire. The guide wire was withdrawn until the tip of the wire was just visible within the joint without limiting flexion and extension. A 5 mm cannulated drill was advanced over the guide wire normograde to create the femoral bone tunnel (figure 1). Completion of the femoral bone tunnel was checked by visualizing the drill tip exiting the femur within the joint. The bone tunnel was freed of debris by advancing and retracting the drill several times before removing the drill bit and guide wire from the femur.

Figure 1: Cannulated drill

The guide wire was reintroduced into the bone tunnel and the stifle was positioned in a 135^0 angle. The insertion of the cranial cruciate ligament on the tibial plateau just cranial of the tibial eminences was identified and used to position the guide wire. With the stifle in a 135^0 angle while avoiding external and internal rotation the guide wire was advanced through the tibia exiting the medial cortex at the level of the base of the tibial crest. A mini approach was performed to visualize the exiting point of the guide wire. The guide wire was withdrawn until the tip of the wire was just visible within the joint. A 5 mm cannulated drill was advanced over the guide wire retrograde to create the tibial bone tunnel. Completion of the tibial bone tunnel was checked by visualizing the drill tip exiting

the tibial plateau within the joint. The bone tunnel was freed of debris by advancing and retracting the drill several times before removing the drill bit and guide wire from the tibia.

A second bone tunnel was created from medial to lateral perpendicular to the long axis of the tibial diaphysis at the distal level of the tibial crest. A wire loop was introduced into the tibial plateau and femoral bone tunnels with the loop on the tibial side. The LARS was stabilized in the loop and the wire loop and LARS pulled through the tibial and femoral bone tunnels until exiting on the lateral of the stifle and advanced until the central part of the prosthesis was positioned within the joint. The LARS was stabilized within the femoral tunnel using a guide pin and 5mm cannulated interference screw(figure 2).

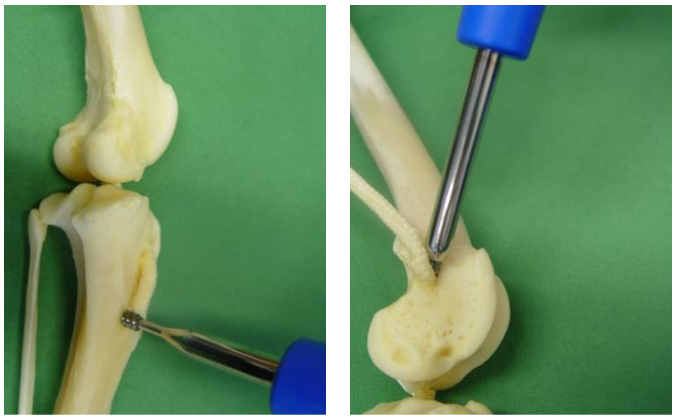

Figure 2: Insertion of the interference screws in the tibia (left picture) and the femur (right picture).

The LARS was tensioned manually on the medial side of the tibia and the stifle was cycled through full flexion and extension several times for settling and pretensioning of the LARS. Next the LARS was placed through the transverse tibial tunnel from medial to lateral. The stifle joint was again cycled through full flexion and extension, positioned in a 135^0 angle and the LARS was stabilized using a guide pin and 5mm cannulated interference screw in the distal transverse bone tunnel (figure 3). The joint capsule was closed with interrupted sutures and prepared for tibial compression radiography.

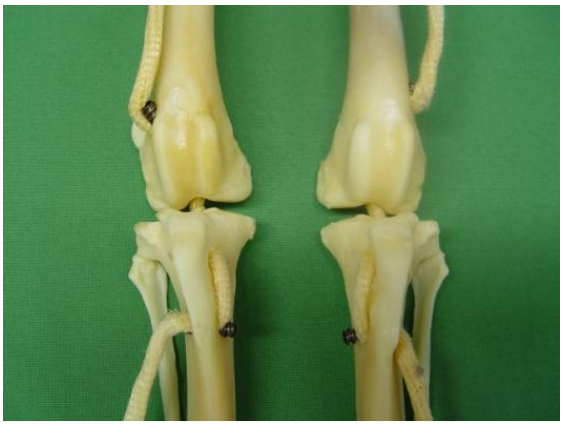

Figure 3: LARS CCL placement

Radiographs

Radiographs were taken of all legs with an intact CCL, after transection of the CCL and after placement of the LARS CCL implant. A template was used to control the stifle flexion angle more precisely during tibial compression radiography. All radiographs were made and assessed by the same surgeon.

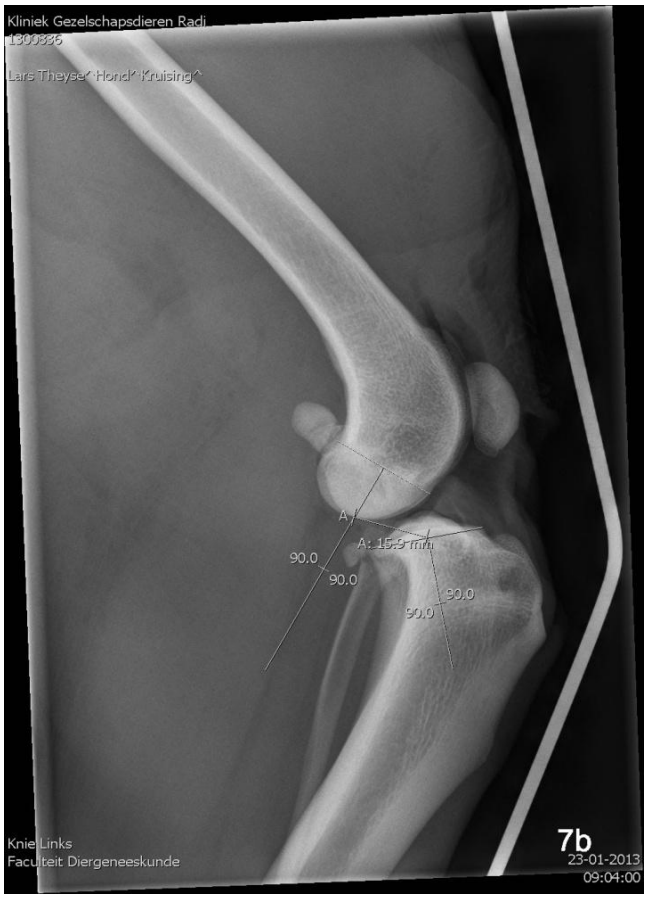

Figure 4: Drawing of the baselines and midlines used to determine the translation in the dog stifles. Line A represents the translation present in the stifle in milimeters.

In every radiograph the midline of the femoral condyle and the midline of the tibial plateau were determined using the imaging software (Impax, Agfa Healthcare, Bonn, Germany). The midline of the femoral condyle was determined by drawing a line from the junction of the femoral trochlea with the femoral condyle to the midlevel of the femorofabellar joint. A perpendicular line was drawn from the middle of this first line. Then the distance between the midpoint of the tibial plateau and the point where the perpendicular line of the femur dissected the condyle was determined to measure the amount of translation in the knee on the radiograph(Figure 4).

Bones

After surgery and radiographic imaging the bones of the eight hind limbs were harvested to determine if the insertion of the LARS CCL implant and placement of the bone tunnels were correct. All of the bones were assessed and scored by the same surgeon on placement of the bone tunnels and insertion place of the LARS CCL implant. The scoring system consist of 5 grades where a score of 0 means perfect placement, a score of 1 indicates a less than 25% deviation from the diameter of the bone tunnel, a score of 2 indicates a 25-50% deviation, a score of 3 indicates a 50-75% deviation and a score of 4 indicates a 75-100% deviation.

Data Analysis

A paired samples t-test was used to evaluate to the measurements on the radiographs (SPSS statistics 22, Armonk, USA). A Wilcoxon signed ranks test was used to assess the position of the bone tunnels.

Results

Clinical findings

After transection of the CCL, the drawer test and the tibial compression test were performed. For all eight legs the clinical drawer test was positive with a translation of 7 mm. Also, the clinical tibial compression test was positive in all eight legs. Post operatively, both tests were negative in all cases (table 1).

Leg	Pre-op DT	Pre-op TCT	post-op DT	post-op TCT
1	7	7	0	0
2	7	7	0	0
3	7	7	0	0
4	7	7	0	0
5	7	7	0	0
6	7	7	0	0
7	7	7	0	0
8	7	7	0	0

Table 1: Results of the clinical tests before transsection of the cranial cruciate ligament (pre-op) and after transsection of the cranial cruciate ligament (post-op). DT= drawer test, TCT= tibial compression test

Radiographic findings

Radiographs were taken from all eight legs with an intact CCL (group CCL intact), after transection of the CCL (group CCL defect) and after placement of the LARS CCL implant (group LARS CCL). The distance between the centre of the humeral condyle and the centre of the tibial plateau was measured in millimeter to determine the translation in the tibial plateau(table2). In the CCL intact group a mean translation of 6,36 millimeter was found. A mean translation of 16,46 millimeter was found in the CCL defect group and a mean translation of 10,65 millimeter was found in the LARS CCL implant group. A significant difference was found between all groups ($P<0,05$).

Leg	CCL intact (mm)	CCL defect (mm)	LARS CCL implant (mm)
1	5.9	14.7	9.6
2	5.9	17.3	10.2
3	6.1	17.3	11.4
4	6.1	15.6	11.4
5	6.2	15.9	9.0
6	7.1	17.2	12.0
7	7.4	17.3	11.4
8	6.2	16.4	10.2

Table 2: The translation in milimeters determined on radiographs in the canine knee joint. CCL= cranial cruciate ligament, LARS=ligament augumentation and reconstruction system.

Insertion of LARS

The placement of the LARS CCL implant was assessed giving a score in the range from 0-4. The LARS CCL implant was placed perfectly in the femur in 4 legs (50%) and within 25% deviation in the other 4 legs(50%). Placement of the LARS CCL implant in the tibia was perfect in 6 legs (75%), within 25% deviation in 1 leg (12,5%) and within 50% deviation in the last leg(12,5%). Placement of the LARS CCL was perfect in the femur in 75% (3 legs) of the right hind legs where it was placed perfect in only 25% (1 leg) of the left hind legs. Placement of the LARS CCL was perfect in 75% (3 legs) of the right legs and 75% (3 legs) of the left hind legs(table3). A Wilcoxon signed ranks test in SPSS statistics 22 showed that there was no significant difference between placement of the bone tunnels in the femur and tibia (P>0.05).

DOG	L/R	FEMUR	TIBIA
1	R	0	0
2	R	0	0
3	R	1	2
4	R	0	0
1	L	1	0
2	L	1	0
3	L	1	0
4	L	0	1

Table 3: Results of scoring the placement of the bone tunnels in the femur and tibia. 0= no deviation, 1= <25% deviation, 2= 25-50% deviation, 3= 50-75% deviaiton, 4= 75-100% deviation

Outcome

Clinical tests show decreased translation values between a defect CCL and the LARS CCL implant. Radiographic imaging shows a difference between an intact CCL and the LARS CCL implant in the distance between the centre of the humeral condyle and the centre of the tibial plateau, the LARS CCL implant did not result in a normal position of the tibial plateau. Scoring of the placement of the bone tunnels in the femur and tibia showed no difference between placement of the bone tunnels in the femur or tibia.

Discussion

The aim of this study was to describe the surgical procedure for placing a LARS CCL implant in dogs, to determine if the LARS CCL implant effectively stabilizes the stifle joint with clinical tests and radiographs and to determine if the LARS CCL implant is suitable for treatment of CCL deficiency in dogs.

Placement of the LARS CCL in the canine stifle was achieved by a modification of procedure for LARS placement in the human knee. This study showed that placement of a LARS CCL implant in the dog stifle is possible using this custom LARS technique. This technique is reproducible in vitro as shown in this study where the surgical procedure was performed successfully in all eight dog stifles. Placement of the LARS CCL implant and the bone tunnels in the dog stifle went as expected and no major difficulties occurred during surgery in vitro.

One of the modifications made to the human surgical procedure for LARS placement was that the insertion screw locking the LARS CCL implant into place in the tibia was not placed in the tibial bone tunnel. An extra bone tunnel was made to carry the interference screw locking the LARS CCL implant into place. Because graft failure in human patients was mostly attributed to shallow placement of bone tunnels(14) and there was insufficient bone left on top of the tibial bone tunnel in dogs, another solution had to be found. The shape of the tibia in dogs differs from the shape of the human tibia and because of that, guidelines for placement of the tibial bone tunnel in human patients may not be appropriate for future dog patients. An appropriate way to place the LARS CCL implant without the use of a second bone tunnel in dogs should be a subject in further research.

In this study, an open arthrotomy was used to place the LARS CCL implant. In human surgery, the LARS CCL implant is placed by arthroscopy(12,13). Placement of the LARS CCL with arthroscopy should result in a quicker recovery and lower complication rate than through open arthrotomy because arthroscopy is less invasive. The possibility of placement of the LARS CCL implant through arthroscopy needs to be evaluated but could prove to be very difficult. There is less space in the dog stifle joint compared to the human knee in arthroscopy.

A stifle distractor could be used to achieve a better overview of the dog knee during arthroscopy. A major disadvantage of using a distractor during placement of the LARS CCL implant is that the knee must be stabilized at a certain angle in order for the distractor to work. While using a stifle distractor

cycling through full flexion and extension is not possible, therefore limiting the change of correct placement of the LARS CCL implant(15,16).

After CCL transection, the clinical drawer test and the clinical tibial compression test were positive as expected. Both tests showed a translation of the tibia of 7 millimeters. After the LARS CCL implant was placed, both tests became negative. Placement of the LARS CCL implant results in a clinical stability of the stifle.

Radiographic imaging shows a difference between an intact CCL and the LARS CCL implant in the distance between the centre of the humeral condyle and the centre of the tibial plateau. Despite the fact that a clinical stability of the stifle was found, placement of the LARS CCL implant does not result in a normal position of the tibial plateau.

The LARS CCL cannot fully simulate the function of an intact CCL. This could be due to the differences in rigidness between the LARS CCL implant and the original CCL. A CCL has a rigid character even in relaxation but the LARS CCL implant is flexible when untensioned. The lack of rigidness could induce a lack of collaboration between the LARS CCL and the caudal cruciate ligament. This could result in a minor tibial cranial thrust as shown in the results from the tibial compression radiographs.

The strength of the LARS CCL implant varies between sizes and was determined by the manufacturer. A study in sheep however, showed that failure of the LARS CCL implant at maximum load occurred by slippage of the artificial ligament from the femoral or tibial bone tunnel(17). Failure of the LARS CCL implant occurs at the weakest point of the reconstruction which is the anchorage of the LARS CCL implant in the bone tunnels, suggesting the LARS CCL implant itself is strong enough to withstand mechanical loading within the stifle.

In human patients, ingrowth of CCL tissue in the LARS CCL implant has been hypothesized and confirmed(9). Because the cause of CCL rupture in humans is often a traumatic experience, the CCL tissue is mostly relatively healthy and the LARS CCL implant serves as a protective device encouraging CCL healing. In dogs, CCL rupture is mostly caused by a degenerative disease and ingrowth of CCL tissue in the LARS CCL implant is not expected(18). In sheep, ingrowth of tissue in the LARS CCL implant was observed 3 and 12 months post-operatively. After the sheep were euthanized, gross examination of the stifles showed that the artificial ligaments were covered by a connective tissue layer and the difference between native CCL tissue and the artificial ligament could not be distinguished. Histologic examination revealed that connective tissue ingrowth in the LARS CCL

implant also occurred in the intraosseus portion of the artificial ligament. The fibrovascular tissue layer between the bone and the LARS CCL implant was found to be denser in the stifles from sheep euthanized 12 months post-operatively than from sheep euthanized 3 months post-operatively (17). This suggests that over time, the LARS CCL implant becomes locked into place by tissue ingrowth in the bone tunnels. If tissue ingrowth in dogs with CCLD will occur in the intra-articular portion of the LARS CCL implant should be a subject of further studies.

The method used to measure the translation in the tibial compression radiographs has never been used before to our knowledge. This method could be used to determine exactly how large the translation in a stifle is and could find even minor forms of translation. This method can be used on greater scale but has to be validated first in order to contribute to other studies. For this study this method seemed to be appropriately showing us the difference between the three groups and allowing us to see that tibial cranial thrust is not entirely eliminated by the LARS CCL implant. This was never found by only using the cranial drawer test and tibial compression test without radiography because both were negative after placement of the LARS CCL implant. The difference in results between the clinical tests and the radiographic tibial compression test could be because the LARS CCL implant results into a slightly more cranial position of the tibial plateau, resulting in the positive findings on radiographic imaging, but it still eliminates further cranial tibial thrust resulting in a negative outcome in clinical testing.

In this study both the clinical tests and the radiographic tibial compression test were conducted with the use of a scaffold, placing the stifle at a 135 degree angle. Because of that, internal rotation was not observed or tested in this study. Dynamic testing should result in more information about the stability of the stifle after LARS CCL placement.

Despite the limitations of this study, it can be concluded that the surgical procedure of placing a LARS CCL implant is technical possible, but the procedure results in a small cranial displacement of the tibial plateau. The LARS CCL implant may prove to be of use in patients with CCLD but additional clinical in vivo studies are required.

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