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Intra-articular stabilization of a dog stifle with polyester thread: an *ex vivo* evaluation

Rainer da Silva Reinstein[1*] **Franciéli Mallmann Pozzobon**[1]
Daniel Curvello de Mendonça Müller[2]

[1]Programa de Pós-graduação em Medicina Veterinária (PPGMV), Grupo de Cirurgia Ortopédica e Reconstrutiva (GCOR), Hospital Veterinário Universitário (HVU), Centro de Ciências Rurais (CCR), Universidade Federal de Santa Maria (UFSM), 97105-900, Santa Maria, RS, Brasil. E-mail: rainerreinstein@gmail.com. *Corresponding author.

[2]Departamento de Clínica de Pequenos Animais (DCPA), Programa de Pós-graduação em Medicina Veterinária (PPGMV), Grupo de Cirurgia Ortopédica e Reconstrutiva (GCOR), Hospital Veterinário Universitário (HVU), Centro de Ciências Rurais (CCR), Universidade Federal de Santa Maria (UFSM), Santa Maria, RS, Brasil.

ABSTRACT: The incidence of cranial cruciate ligament rupture (CCLR) in dogs is high, which is considered the main arthropathy in the species. Once diagnosed, surgical stabilization is recommended and different treatments are categorized as intracapsular, extracapsular, and osteotomies. There is still no consensus regarding the most optimal method of stabilization, and some studies have attempted to create or improve existing techniques, making them more effective. This study presented an intra-articular stifle stabilization technique using a synthetic polyester implant using 32 anatomical specimens from canine cadavers, which were separated by weight into two groups. The drawer movement was analyzed at three timepoints: intact cranial cruciate ligament (CCL), dissected ligament, and after surgical stabilization using the proposed technique. Results showed a mean cranial displacement of the tibia relative to the femur of 0.61 ± 0.08 millimeters before dissection (mm), 2.61 ± 0.08 mm after dissection, and 0.68 ± 0.08 mm after surgical stabilization ($P < 0.01$). In conclusion, the intra-articular stabilization technique with polyester thread was effective in stabilizing *ex vivo* dog stifles after CCL dissection at the immediate postoperative period.

Key words: arthropathy, ligament injury, therapeutics, canine.

Estabilização intra-articular de joelho de cães com fio de poliéster – avaliação *ex vivo*

RESUMO: A incidência de ruptura do ligamento cruzado cranial (RLCCr) em cães é alta, sendo considerada a principal artropatia na espécie. Uma vez diagnosticada, a estabilização cirúrgica é recomendada e diversos autores indicam diferentes tratamentos, sendo divididos em intracapsulares, extracapsulares e osteotomias. Ainda não há consenso sobre a melhor forma de estabilização e estudos tem sido desenvolvidos buscando criar ou aprimorar técnicas existentes, tornando-as mais eficazes. O objetivo deste trabalho é apresentar técnica de estabilização intra-articular de joelho, utilizando implante sintético de poliéster. Para isso, 32 peças anatômicas oriundas de cadáveres caninos foram separadas em dois grupos, conforme o peso do animal. Analisamos o movimento de gaveta, em três momentos: ligamento cruzado cranial (LCCr) íntegro, ligamento desmotomizado e pós estabilização cirúrgica pela técnica proposta. Os resultados demonstram deslocamento cranial médio da tíbia em relação ao fêmur antes da desmotomia de 0,61 ± 0,08 milímetros (mm), 2,61 ± 0,08 mm após a desmotomia e 0,68 ± 0,08 mm após estabilização cirúrgica ($P < 0.01$). Concluímos que, no momento pós-cirúrgico imediato, a técnica de estabilização intra-articular com fio de poliéster é eficaz em estabilizar a articulação de modelo *ex vivo* de cães após desmotomia do LCCr.

Palavras-chave: artropatia, lesão ligamentar, terapêutica, canino.

INTRODUCTION

The cranial cruciate ligament (CCL) prevents cranial movement of the tibia relative to the femur, internal rotation of the tibia, and stifle hyperextension (DECAMP et al., 2016). It is considered the main stabilizer of this joint (NANDA & HANS, 2019), and function loss results in inevitable joint destabilization, with cranial tibial translation relative to the femoral condyles and subsequent osteoarthritis (WITSBERGER et al., 2008).

Despite several studies on cranial cruciate ligament rupture (CCLR), the pathogenesis was not fully understood in the past (HAYASHI et al., 2003). According to VASSEUR (2003), this rupture occurred when joint forces exceeded the tension capacity of the ligament, either intact or weakened by chronic degeneration. However, more recently, GRIFFON (2010) and ICHINOHE et al. (2015) reported that the causes are interconnected, as the ligament is more susceptible to injury when weakened by degeneration. They also highlighted that the high incidence of CCL failure is often preceded by underlying causes of premature cruciate ligament degeneration. Rupture may be complete, with clear or partial instability to a lesser degree. In both cases, untreated animals present joint changes within a few weeks and severe changes within a few months (DECAMP et al., 2016).

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Several techniques have been reported for surgical correction in dogs, including intra- or extra-articular procedures and osteotomies (NELSON et al., 2013; DECAMP et al., 2016; SPINELLA et al., 2021). However, no current surgical technique prevents/decreases/ceases the onset or progression of degenerative joint disease (DJD), which is expected to develop less or at a slower rate with surgical stabilization than without treatment (DECAMP et al., 2016).

The tibial plateau leveling osteotomy technique, described by SLOCUM & SLOCUM (1993), is one of the most used, which is the preferred treatment option by current surgeons (VON PFEIL et al.,2018). However, it requires good radiological studies of the joint, in addition to special equipment and materials (SLOCUM & SLOCUM, 1993; TATARUNAS et al., 2008).

Intra-articular reconstruction consists of anatomically replacing the CCL by inserting autogenous tissue or synthetic material through holes previously drilled in the femur and/or tibia (TATARUNAS & MATERA, 2005). An *in vitro* examination of several methods indicated that intra-articular repair results in closer-to-normal joint motion than extra-articular techniques (DECAMP et al., 2016), as the implant more accurately simulates the CCL position and biology (BARNHART, 2016).

The intra-articular stabilization technique proposed by MÜLLER et al. (2010) provides good resistance and partially stabilizes joints with both cruciate ligaments ruptured using bone tunnels and polypropylene mesh. With this, there is a minimal cranial drawer movement that allows joint degeneration progression. Thus, intra-articular techniques may fail to restore normal stifle kinematics in dogs due to improper graft choice and incorrect tunnel location, especially when using bone tunnels (BISKUP & CONZEMIUS, 2018).

The present study proposed a new approach for intra-articular femorotibial patellar stabilization using a synthetic surgical polyester implant, based on a technique modification described by MÜLLER et al. (2010). For this purpose, the implant was reduced in size and diameter, joint perforations were reduced, and isometric points were searched for CCL replacement.

MATERIALS AND METHODS

This study analyzed pelvic limbs (left and right) of adult (≥12 months old) cadaver dogs (*Canis familiaris Linnaeus, 1758*) whose cause of death was not related to orthopedic conditions from the University Veterinary Hospital of the Federal University of Santa Maria. The limbs were sectioned at the hip joint, presenting no macroscopic anatomical changes. Both pelvic limbs were excluded from the study when the femorotibial patellar joint presented DJD during the procedures or in case of previous CCLR. Thus, 32 pelvic limbs from 16 dog cadavers were selected.

The anatomical specimens were distributed into two experimental groups (G1 and G2), each group containing 16 pelvic limbs. G1 was composed of specimens from animals with ≤ 15 kg of body weight (7.73 ± 3.09 Kg) and G2 was composed of specimens from animals with > 15 kg of body weight (22.43 ± 4.42 Kg). The sample included the same number of left and right pelvic limbs (16 each), with no distinction between sexes and breeds to mimic the reality of treating patients diagnosed with CCLR.

After selection, the anatomical specimens were refrigerated (7 °C) for 24–36 h, frozen in a horizontal freezer (-20 °C), and thawed in a climate-controlled environment (24 °C) 24 h before the procedures. After thawing, the specimens were washed in running water and 4% chlorhexidine digluconate solution (Riohex®, Rioquímica, São José do Rio Preto, SP, Brazil) to remove dirt and reduce the microbiota. The specimens were widely shaved on the entire femorotibial patellar joint.

Standardized drawer movement testing

The standardized drawer movement test was based on the study by KEMPER et al. (2013) and consisted of a lateral parapatellar incision, as described by LATORRE et al. (2012), and localization of the lateral collateral ligament (LCL) (Figure 1A). Subsequently, two 1.0-mm Kirschner wires (Cão Médica®, Campinas, SP, Brazil) were inserted, one in the proximal region (in the femur) and the other in the distal region (in the tibia) of the LCL insertion (Figure 1B). These wires were used as references to measure tibial displacement relative to the femur in the cranial drawer movement.

To standardize the study, all surgical specimens were positioned with the medial side on the surgical table, and a 20-cm goniometer (Fibra Cirúrgica®, Joinville, SC, Brazil) was used to angle the joint at 135° (femur in relation to tibia) (Figure 1C). A caliper (MTX®, ToolsWorld, Guarulhos, SP, Brazil) closed in a right angle to the LCL (guided by the previously inserted 1.0-mm Kirschner wire) was used to test the tibial cranial drawer movement in relation to the femur in order to read the distance between wires (Figure 1D). This displacement was the caliper drag caused by the wire (in millimeters) after the test was performed. Measurements were repeated three times at all analyzed times (intact CCL, ruptured [dissected] CCL, and reconstructed CCL) and the arithmetic mean of the three readings was considered. All measurements were performed by the same evaluator and filmed using the same equipment, at a standardized distance, to evaluate the results.

After preparation of the anatomical specimens and reading of the drawer sign test with intact CCL, the femorotibial patellar join underwent arthrotomy followed by medial dislocation of the patella and CCL identification. The cranio-medial and caudo-lateral bands were excised using a scalpelblade 11, completely sectioning the ligament. The patella was anatomically repositioned, the joint capsule was sutured with mononylon (Atramat® Nylon, Atramat, Mexico City, Mexico) in a single continuous pattern, and the drawer motion test was performed again as described above.

Joint stabilization

Joint stabilization was performed based on a modification of the technique described by MÜLLER et al. (2010). The proposed procedure consisted of joint capsule opening, medial dislocation of the patella, joint inspection, and removal of the cranial fragment of the sectioned CCL. The implant was fixed by transverse drilling of the distal femoral diaphysis in the latero-medial direction, approximately 10 mm distant from the femoral trochlea, measured using a Castroviejo marker (Cão Médica®, Campinas, SP, Brazil) with a 1.5-mm orthopedic drill bit (Cão Médica®, Campinas, SP, Brazil), through which a folded n. 2 cerclage wire (Atramat® Stainless Steel, Atramat, Mexico City, Mexico) was passed. Polyester thread (Sertix®, Shalon, Goiânia, GO, Brazil) was anchored through the loop formed on the lateral side, while the ends of the cerclage thread returned, one dorsal and the other ventral to the femur, being closed over the implant.

The polyester thread was passed between the lateral and medial condyles of the femur using instruments developed to facilitate surgery (Figure 2A), until intra-articular emergence (Figure 2B). For a better understanding, passage of the intra-articular wire and the use of the instruments are shown in a polymer-printed articular bone model (Figure 2C)

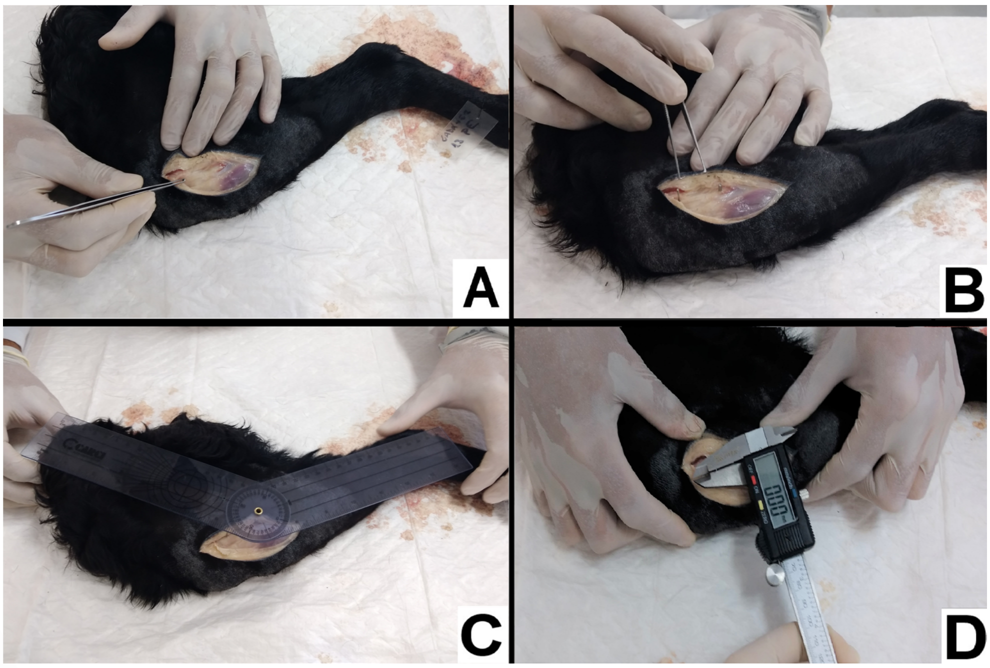

Figure 1 - Lateral collateral ligament location (A). Placement of a Kirschner wire in each CCL insertion (one in the femur and another in the tibia) (B). Positioning of the anatomical specimen at a 135° angle using a goniometer (C). Drawer sign test of the tibia in relation to the femur to verify the degree of displacement (in mm) using a closed pachymeter at right angles to the CCL (guided by the previously inserted 1.0-mm Kirschner wires) (D). Source: Personal file.

(Figure 2D). G1 limbs received n. 2 non-absorbable surgical polyester multifilament (Sertix® Polyester, Shalon, Goiânia, GO, Brazil) and G2 limbs received the same thread, but in size n. 5 (same manufacturer).

The proximal tibia was perforated in the center-medial direction (between the CCL insertion and the tibial crest) with a 2-mm drill (Cão Médica®, Campinas, SP, Brazil), avoiding the menisci; and subsequently, passing the folded polyester thread through the bone tunnel. After the patella was returned to the trochlear groove and the articular capsule was sutured with mononylon (Atramat® Nylon, Atramat, Mexico City, Mexico) in a simple continuous pattern, the proximal tibial metaphysis was perforated twice with a 1.5-mm drill in the latero-medial direction with a 5-mm distance between perforations. One of the polyester threads was passed through the proximal perforation in the medial-lateral direction and then returned through the other perforation (lateral-medial). The femorotibial patellar joint was placed at 135°, followed by a minimal lateral rotation. In this position, the polyester thread was occluded with its own ends. For a better understanding, the technique is presented in a polymer-printed articular bone model (Figure 3). After the procedure, the measurements were repeated using the standardized drawer movement test.

Statistical analysis

The Shapiro–Wilk normality test was performed, and the analysis of variance considered the group (light [≤15 kg] and heavy [>15 kg]), limb location (right and left), time of the procedure (before rupture, after rupture, and after surgical reconstruction) and its interactions as fixed effects, and the animals (canine cadavers) and the residue as random effects, using the MIXED procedure. A covariance structure selection test was performed using the Bayesian information criterion. In case of differences, the means were compared using the lsmeans function adjusted for the Tukey's test. Power analysis was performed using the POWER procedure. The SAS® statistical software version Studio (SAS Institute Inc., São Paulo, SP, Brazil) was used for all statistical analyses. Differences were considered significant when $P < 0.05$. Sample sufficiency was proven by the power analysis, which showed probability values above 0.99 for the variable drawer sign response.

RESULTS AND DISCUSSION

Results showed that joint stability after the proposed surgical procedure is equal to the stability before ligament rupture, regardless of the animal weight (Figure 4) (Table 1). This may be related to the good results previously obtained by MÜLLER et al. (2010) and VOGEL et al. (2020). Comparatively, the proposed technique has the advantage of replacing the 0.5-cm-thick polypropylene mesh and the large-caliber bone tunnel drilling, both described in the original technique (MÜLLER et al., 2010) with a surgical polyester thread, which has excellent low-caliber strength (ABNT, 2003), decreasing implant thickness, suppressing one perforation, and reducing the tibial bone tunnel caliber.

VOGEL et al. (2020) implemented a similar technique, using surgical polyester thread as an intra-articular implant in cranial and caudal cruciate ligament rupture in a cat to neutralize the tibial drawer movement. Intra-articular patellar tendon grafting has been the gold standard surgical treatment for anterior (cranial) cruciate ligament rupture in humans since 2008 (MATIOLA, 2022), in contrast to veterinary medicine, in which joints are stabilized using osteotomies and extra-articular sutures to correct CCLR (DUERR et al., 2014). The human tibial plateau has a natural angulation between 7° and 10° (MOZELLA et al., 2012), forming an angle close to 90° with the patellar tendon (LAFAVER et al., 2007), and resulting in dynamic stability in the support phase even with CCLR, a relatively easy surgical repair compared to the canine tibial plateau, which has a mean natural angulation close to 22.6° (SLOCUM & DEVINE, 1983).

Respectively, extra-articular osteotomies and sutures have the advantage of being used in arthroscopy or mini-arthrotomy for joint inspection (TATARUNAS et al., 2008) compared to the proposed technique that requires arthrotomy and medial dislocation of the patella, mainly because of the need to perforate the proximal tibia in the center-medial direction.

Although, innovative materials with improved biocompatibility and excellent strength are available in the market (GOMIDE et al., 2019), several studies have reported on the use of intra-articular synthetic polyester implants to replace ruptured ligaments (ROOSTER et al., 2001; SELMI et al., 2002; PRZĄDKA et al., 2017; PRADA et al.,2018), with a higher incidence of complications related to inefficient surgical technique than to material biocompatibility, according to PRADA et al. (2018). The main advantages of braided multifilament surgical polyester thread include non-absorption and load capacity maintenance over time (MÜLLER et al., 2016); in contrast, due to its characteristics, it

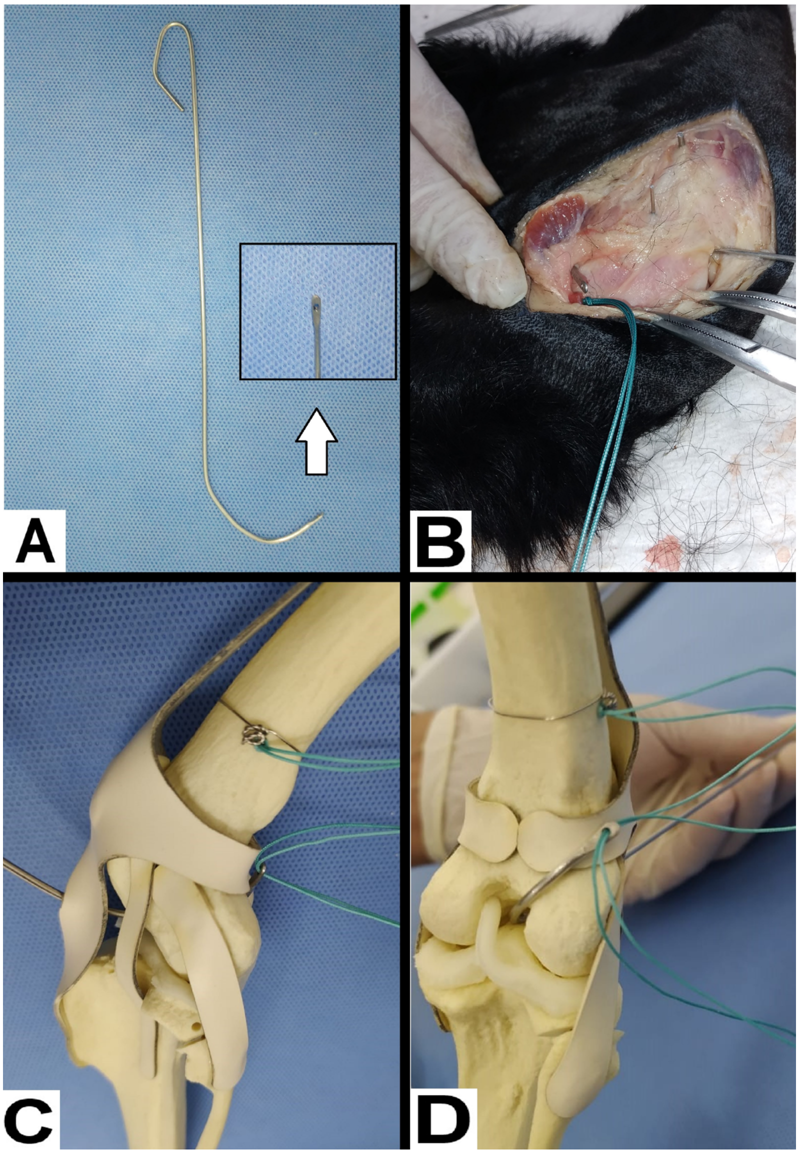

Figure 2 - Instruments developed to facilitate surgical execution and details of the blunt tip with a hole for passing the surgical thread (A). Use of the instrument to pass the polyester thread between the lateral and medial condyles of the femur until intra-articular emersion (B). For a better understanding, the instruments used for polyester suture passage through the femoral condyles in a polymer-printed articular bone model (Nacional Ossos®, Code AV252D). Lateral image of the joint (C). Caudal image of the joint (D). Source: Personal file.

triggers moderate tissue reaction with a 3-week peak followed by reduction (ESENYEL et al., 2009). A folded cerclage was passed through the bone tunnel to anchor the polyester thread next to the femoral diaphysis. The use of bone cerclage is associated with several complications such as fracture collapse, stability loss, and thread loosening; thus, its use is not recommended (HAYASHI et al.,2019). However, according to KOWALESKI et al.(2017), loop-shaped cerclage is a good anchoring option for grafts in orthopedic surgery. The present study analyzed the use of a polyester thread with two different thicknesses in cadaver dogs according to body weight. This difference followed the indication of load

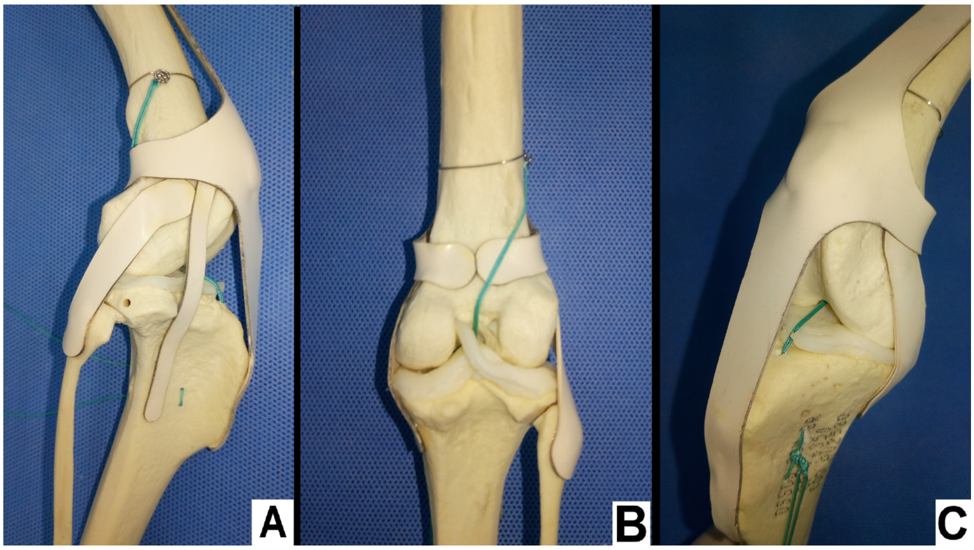

Figure 3 - Technique performed in an articular bone model printed in polymer (Nacional Ossos®, Code AV252D). Lateral image of the joint (A). Caudal image of the joint (B). Oblique cranial image of the joint (C). Source: Personal file.

resistance for thread rupture, as predicted by GOMIDE et al. (2019).

The drawer movement should be tested on the orthopedic examination of dogs with suspected CCLR either using the direct drawer test or the indirect tibial compression test. Both tests are based on detecting tibial displacement relative to the femur (DECAMP et al., 2016). Test sensitivity increases considerably when performed under anesthesia, reducing the risk of false-negative results (CAROBBI & NESS, 2009). The drawer test was used to analyze andmeasure tibial displacement by performing a passive movement. Although, the tibial compression test simulates the active weight-bearing movement by the limb, being influenced by the bone-muscle set (DECAMP et al., 2016), by annulling the drawer movement, the movement triggered by tibial compression is also annulled. However, the inverse is not evidenced.

In this study, the use of cadaver limbs previously thawed and prepared for the evaluations

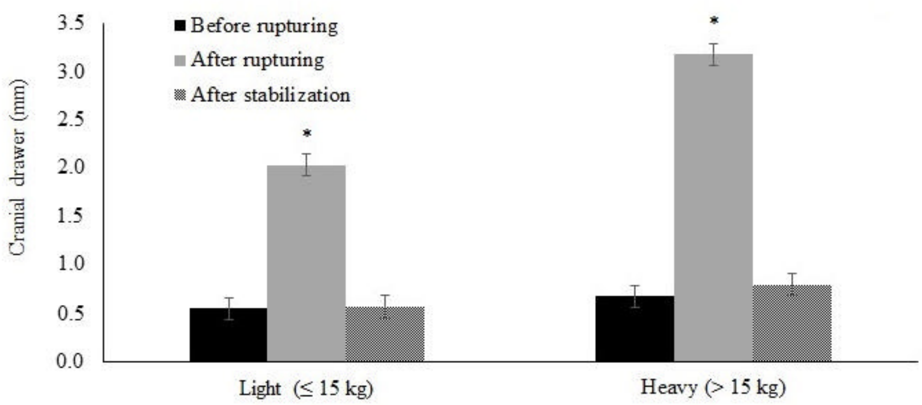

Figure 4 - Drawer movement in the different procedures for each group. There is no significant drawer movement difference between the pre- and postoperative moments in the groups. *indicates significant difference. Source: The author.

Table 1 - Cranial drawer movement in canine cadavers by group, limb location, and time of the procedure.

Responses	Cranial drawer movement (mm)	SEM*	Probability
----------Groups----------			
Light animals (≤ 15 kg)	1.05b	0.09	< 0.01
Heavy animals (> 15 kg)	1.55 a		
----------Location----------			
Left limb	1.29	0.07	0.73
Right limb	1.31		
----------Moment----------			
Before rupture	0.61b	0.08	< 0.01
After rupture	2.61 a		
After stabilization	0.68b		

SEM = Standard error of the mean.

standardized the drawer test after iatrogenic ligament rupture. The standardization occurred both by the execution team and by the conditions of the anatomical specimens. All limbs were tested at a 135° angle, based on DENNLER et al. (2006) and KIM et al. (2008), who reported that this angle is the standard for the canine stifle joint in the support phase of gait. The tibial displacement relative to the femur was 32.2% greater in cadavers with more than 15 kg of body weight than in lighter cadavers after CCL dissection ($P < 0.05$; Table 1). The literature does not cite this relationship, and it may be associated with the anatomically larger ligament-meniscus-articular capsule set.

The evaluated side, left or right, had no effect on the drawer movement, with a mean of 1.30 ± 0.07 mm ($P > 0.05$; Table 1). The interaction between limb location (right or left) and procedure moment was not significant ($P = 0.39$), showing that limb location has no influence on the drawer movement response at different procedure timepoints.

A significant interaction was foundbetween the group and the amplitude of the drawer movement ($P < 0.01$). After CCLR, the group of heavier animals presented a drawer movement (3.18 ± 0.15 mm) greater than the group of lighter animals (2.03 ± 0.14 mm). As an anatomical reference, the wire inserted next to the LCL in the tibia showed a mean displacement of 98.55% greater than the wire inserted next to the LCL in the femur in the group of heavier animals than in the group of lighter animals. These results corroborated with the literature (SCHULZ et al.,2019); however, obtaining reliable data on the cranial displacement of the tibia relative to the femur after CCLR is difficult, probably related to the force applied by the evaluator during examination.

Regarding joint stabilization evaluation after the proposed correction, no differences were reported in the tibial displacement before dissection and after surgical restoration ($P > 0.05$; Table 1). This demonstrated that the limb returns to a cranial tibial displacement after the surgical procedure which is similar physiologically. According to SHIMADA et al. (2020), no current surgical technique ensures complete joint stability after CCLR which will inhibit DJD progression mainly due to postoperative residual instability. In general, as long as instability is present, DJD will progress, resulting in meniscal injury, synovitis, articular cartilage degeneration, periarticular osteophyte development, and capsular fibrosis (PELISSON et al., 2010).

In this proposal, the drilling of large-caliber bone tunnels in the femur and tibia is suppressed by passing the wire through the femoral condyles, mimicking the CCL anatomy and obtaining a location close to the isometric point for implant fixation.

Intra-articular techniques using prosthetic ligament are described as a form of primary replacement of the ruptured ligament and/or as a method to expand an implanted biological graft (MASCARENHAS & MACDONALD, 2008). According to MURRAY et al. (2007), several techniques are expected to be replaced by intra-articular implants containing stem cells. These implants would act as biological scaffolds for ligament reconstruction, mechanically protecting the tissue while the CCL reaches structural integrity. This proposed technique can be the first step toward future biological substitution, as it efficiently and anatomically mimics the CCL and excludes intra-articular bone perforation to induce bone formation after the use of stem cells.

One of the main limitations of this study is the evaluationmethod, with the direct drawer movement test being an operator-dependent subjective analysis of displacement. However, it is a widely used technique to diagnose CCLR and for measurements that was used in other studies (KEMPER et al., 2013). Different materials may have affected displacement test measurements. However, the threads used in this study were made of polyester and without elasticity, but with different diameters according to the indication for use considering the animal weight. Thus, expected differences between the groups would include thread rupture during the evaluation, which was not observed in any of the tests. No differences were found between tibial displacement before dissection and after surgical restoration ($P > 0.05$; Table 1). The joints were not anatomically measured, which would make it possible to identify individual differences between the groups.

Results presented here show that future biomechanical tests and subsequent *in vivo* studies would help delineate limitations and restrictions of the proposed technique, as well as to evaluate the clinical progression of the patients by associating medium- and long-term imaging tests, claudication score, and evaluation of the joint range of motion.

CONCLUSION

The proposed technique is effective in stabilizing the stifle joint after CCL dissection in dog specimens, neutralizing the tibial drawer movement at physiological levels.

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DECLARATION OF CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the manuscript.

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