VALERIA CRISTINA DA SILVA SILVEIRA

PREVALENCE AND OUTCOME OF MENISCAL TEARS IDENTIFIED DURING TREATMENT FOR CRANIAL CRUCIATE LIGAMENT DISEASE VIA TIBIAL TUBEROSITY ADVANCEMENT

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Universidade Lusófona de Humanidades e Tecnologias

Faculdade de Medicina Veterinária

LISBOA
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Dissertação defendida em provas públicas para a obtenção do Grau de Mestre em Medicina Veterinária, no curso de Mestrado Integrado em Medicina Veterinária, conferido pela Universidade Lusófona de Humanidades e Tecnologias, no dia 12 de Maio de 2022, perante o júri, com o Despacho de Nomeação n° 164/2022, de 28 de Abril de 2022, com a seguinte composição:

Presidente: Prof. Doutor Pedro Faísca por delegação da Prof[a.] Doutora Laurentina Pedroso
Arguente: Prof. Doutor João Martins
Orientadora: Prof[a.] Doutora Ana Santana

Universidade Lusófona de Humanidades e Tecnologias

Faculdade de Medicina Veterinária

LISBOA
2022

All our dreams can come true if we have

the courage to pursue them.

Walt Disney

To my lovely husband and son.

Thank you.

ACKNOWLEDGEMENT

First of all, I would express my gratitude to Faculty of Veterinary Medicine at Lusófona University of Humanities and Technologies, especially to Professors Laurentina Pedroso and Pedro Faísca whom helped me so many times since I started my studies at ULHT.

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The most special thanks go to my lovely husband who always gave me support and encouragement, even on the tough moments he was there to hold my hand and say that we were on that together and give up was not an option. To my little one Benjamin, a huge thanks as he could not understand properly why mum had been absent for a few months in a row. You two are the best family that I could ask for. Also, Paçoca, my four-legged daughter, deserves a big thanks for being by my side while I was studying, she gave me the best emotional support.

I am also so grateful to my friend Rita de Cassia Gutierrez who went through the same process as me and was always helping with my countless questions, advising me along the best pathway to follow.

At last, I would like to thank to my parents who always teach me to fight for my dreams. They always tell me that resilience is the key for a successful journey and now I can say that it is true. I am extremely grateful to have them as my parents and I cannot describe how happy I am when I see the proudness on their eyes.

ABSTRACT

Cranial cruciate ligament disease is a common condition of hindlimb lameness in dogs and it has a significant caseload on veterinary medicine. The objective of this study was to evaluate the prevalence of meniscal tears and its outcome after 4 weeks. This is a retrospective study based on 72 dogs where the prevalence of meniscal tears was 33% (24/72), being 83% (20/24) “bucket handle” tears. Those rates are comparable with recent literature reports. Breed, weight, age and preoperative PTA had a significant prevalence on cruciate disease and meniscal injury. Retriever breeds, overweight, middle-aged dogs and PTA over 100° were predisposing factors on this study. Meniscal tears were identified via arthrotomy, consequently caudal horn and internal tears of the medial menisci could have been misdiagnosed, explaining the outcome of higher rate of lameness on no concurrent tears (71%). MRI was not available on this study due to costs. Meniscectomy or hemimeniscectomy were the surgical treatment for meniscal tears, but the consequence of it on increasing contact pressure zone and alteration on biomechanical forces the osteoarthritis generally gets worse afterwards. For this reason, new researches have been done to improve cartilage and meniscal regeneration through tissue engineering with promising results.

Keywords: Cranial cruciate ligament, meniscal, tears, osteoarthritis, lameness.

RESUMO

A doença do ligamento cruzado cranial é uma das causas mais comuns de claudicação de membro pélvico em cães e tem uma casuística significante na medicina veterinária. O objetivo desse estudo restrospetivo de 72 cães foi avaliar a prevalência de lesão de menisco e os resultados após 4 semanas de pós-operatório. A prevalência de lesão de menisco foi de 33% (24/72), das quais 83% (20/24) eram do tipo “alça de balde”. Raça, peso, idade e PTA pré-cirúrgico apresentaram prevalência significativa em relação a lesão ligamentar e de menisco. Raças Retrievers, obesidade, cães de meia idade e PTA acima de 100° foram fatores predisponentes nesse estudo. As lesões de meniscos foram diagnosticadas via artrotomia, portanto as lesões no polo caudal ou no interior do menisco podem não ter sido diagnosticadas, o que explica a alta taxa de claudicação no período pós operatório (71%). A ressonância magnética não foi realizada nesse estudo devido aos custos. A meniscectomia ou hemimeniscectomia foram os tratamentos cirúrgicos para lesão de menisco, mas devido ao aumento do contato das zonas de pressão e alteração nas forças biomecânicas, a osteoartrite piorou após a cirurgia. Por esse motivo, novos estudos têm sido desenvolvidos com o objetivo de melhorar a regeneração da cartilagem e do menisco através de engenharia tecidual, com resultados promissores.

Palavras-chave: Ligamento cruzado cranial, menisco, lesão, osteoartrite, claudicação.

INDEX OF ABREVIATIONS AND SYMBOLS

® - Registered Trademark

^{0} – Degree

BHT – “Bucket handle” tear

BMAC – Bone marrow aspirate concentrate

CaCL – Caudal cruciate ligament

CBLO – Cora based levelling osteotomy

CCLD – Cranial cruciate ligament disease

CCLR – Cranial cruciate ligament rupture

CLB – Cranial lateral band

CMPS – SF - Short form composite measure pain score

CrCL – Cranial cruciate ligament

CT – Computed tomography

CTA – Computed tomography arthrography

CTT – Cranial tibial thrust

COX-2 – Cyclooxygenase-2

CWO – Closing wedge ostectomy

DTA – Distal tibia axis

ECM – Extracellular matrix

ECS – Extracapsullar stabilization

GAG – Glycosaminoglycans

IM – Intramuscular

IV – Intravenous

Kg – Kilograms

LCL – Lateral collateral ligament

LFS – Lateral fabellar suture

LM – Lateral meniscus

Mab – Monoclonal antibody

MCL – Medial collateral ligament

mg/kg – milligrams per kilogram

MM – Medial meniscus

MMT – Modified Maquet technique

MRI – Magnetic resonance imaging

MSCs – Mesenchymal stem cells

NGF – Nerve growth factor

NSAID – Nonsteroidal anti-inflammatory drug

PDO – Polydioxanone

PGP – Polyglycolic acid

PRGFs – Preparation rich in growth factors

PRP – Platelet-rich plasma

PTA – Patellar tendon angle or Proximal tibial axis

ROM – Range of motion

SC – Subcutaneous

TPA – Tibial plateau angle

TPLO – Tibial plateau levelling osteotomy

TR - TightRope®

TT- Tibial tuberosity

TTA – Tibial tuberosity advancement

TTO – Triple tibial osteotomy

µg/kg – Microgram per kilogram

TABLE OF CONTENTS

INDEX OF GRAPHICS

INDEX OF FIGURES

EXTERNSHIP REPORT

The Integrated Masters in Veterinary Medicine at Lusófona University of Humanities and Technologies requires a externship at the final year. I completed a 4-months training at Village Vets, Dublin, Ireland, from 13rd December till 14th March, in a total of 650 hours. The externship took place in the surgery sector, in which I already have a good experience as being a veterinary surgeon in Brazil for 13 years. I could improve my knowledge and also teach the new graduated vets in a wide variety of surgeries.

All animal admitted for surgeries were previously checked by a vet in case of non-routine surgeries, or by a nurse when routine surgery, as neutered, was booked. Preoperative bloodwork was always offered to the owner and it included haematology and biochemistry, however it was not mandatory, unless high-risk surgeries were going to be performed.

The surgeries performed along this time were soft tissue, ophthalmologic, orthopaedic and odontology surgeries. The imaging diagnostics were always done under sedation and it was a responsibility of the vet who was doing surgery on that day.

The caseload of soft tissue surgeries was exploratory laparotomy, splenectomy, cystotomy, urethrostomy, urethroplasty, gastropexy, gastrotomy, enterectomy and anastomosis, reconstructive surgery, lumpectomy, mastectomy, herniorrhaphy (including diaphragmatic hernia), brachycephalic airway syndrome surgery, total ear canal ablation and routine surgeries (ovariosalpingohysterectomy and castrations). Animals underwent routine surgeries did not receive antibiotics, but anti-inflammatory was always prescribed, being meloxicam the most common choice. The postoperative protocol regard to other surgeries was variable according to the procedure performed.

The ophthalmologic surgeries carried out were enucleation, cherry-eye surgery (Modified Morgan Pocket Technique), third-eyelid flap, corneal ulcer debridement, entropion and ectropion correction and eyelid mass removal.

Dentistry surgeries had a high caseload in Village Vets as scale and polish is recommended once a year in most of the veterinary practices around Ireland. Surgical dental extractions were performed when necessary and gingival flap was done to close the defect. Intraoral radiographs were taken before the extractions. Nerve dental blocks were performed according to the tooth that was going to be removed and consisted of infraorbital, maxillary and alveolar blocks. All blocks were done with lidocaine and bupivacaine.

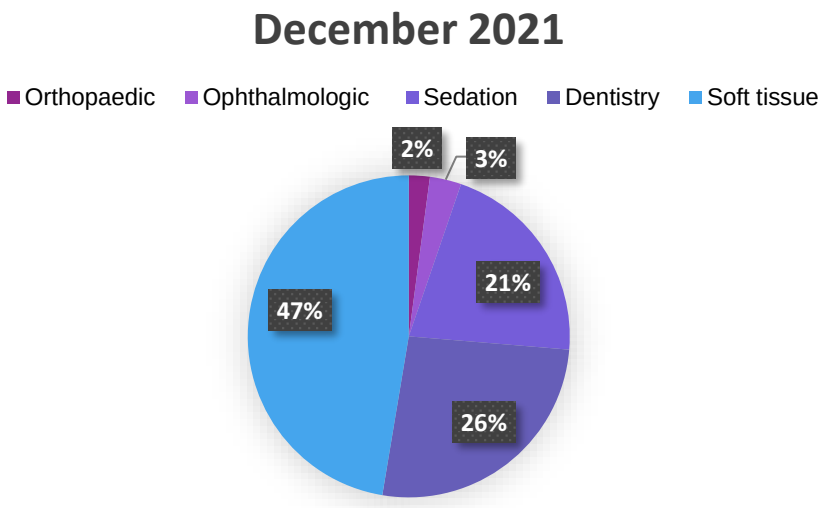
The orthopaedic sector is separated from the general surgeries. All orthopaedic cases were sent to the orthopaedic team in Village Vets, except for limb amputation. I had the opportunity to assist in lateral fabellar suture, femur head amputation and limb amputation. All

animal that underwent an orthopaedic procedure received cefuroxime 30 mg/kg/IV preoperatively and every ninety minutes. The analgesia protocol was chose based on patients pain score and it consisted of fentanyl patches, tramadol, gabapentin, meloxicam or robenacoxib. Most of the orthopaedic patients did not went home on oral antibiotics unless osteomyelitis was present. If so, amoxicillin with clavulanic acid or clindamycin were prescribed.

Sedation was performed for imaging diagnostic, flush ears, skin biopsy, wound debridement and bandage changing. The anaesthetic protocol was drawn up according to underlying disease and patient's needs.

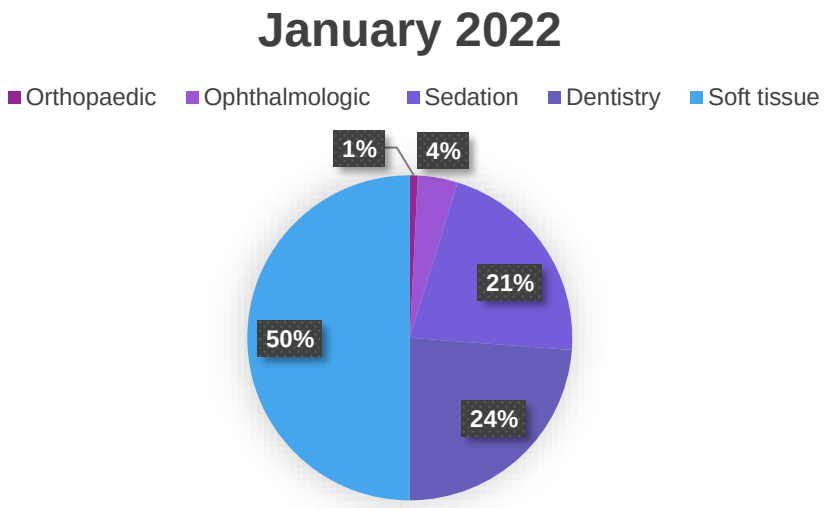
Postoperative check-ups were done at day 3, 7 and 15 or until the patient was fully recovered. Patients that underwent to orthopaedic surgery, especially tibial osteotomies for cranial cruciate ligament repair and osteosynthesis were seen again at 4 weeks for radiographs.

The total procedures in December were 95 (N=95, Graphic 1), with higher incidence of soft tissue surgery (47%), followed by dentistry (26%), sedation (21%), ophthalmologic surgeries (3%) and orthopaedic surgeries (2%).



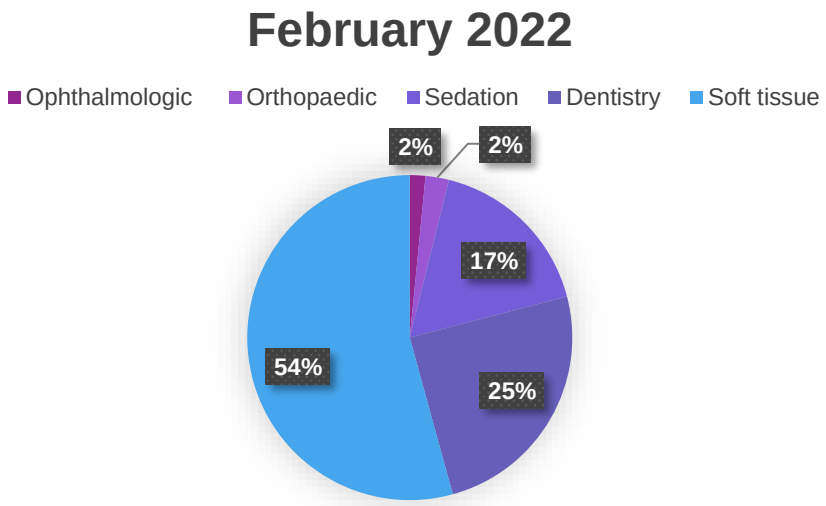
Graphic 1 - Classification and caseload of procedures in December/2021.

In January of 2022, 126 procedures were performed (N=126, Graphic 2), being 50% of soft tissue surgeries, 24% of dentistry, 27% of sedation, 5% of ophthalmologic surgeries, followed by 1% of orthopaedic surgeries.



Graphic 2 - Classification and caseload of procedures in January/2022.

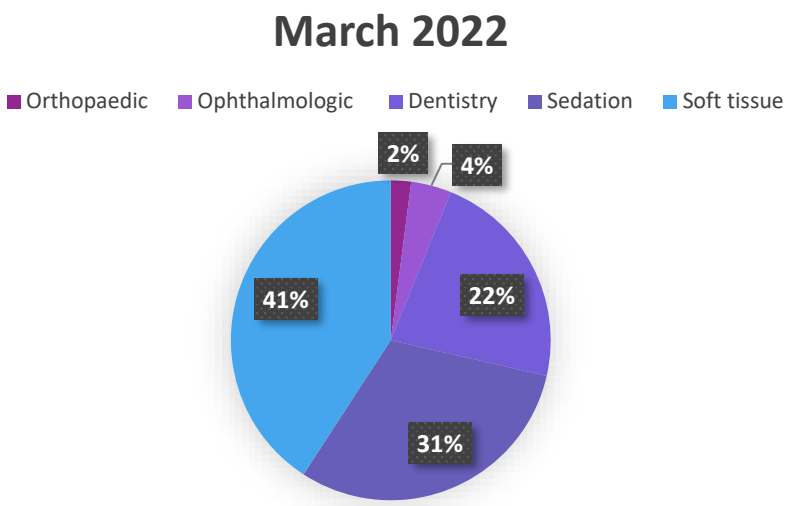
February was the busiest month, with 129 procedures in total (N=129, Graphic 3), being 54% of soft tissue surgery, 25% of dentistry, 17% of sedation, 2% of orthopaedic surgeries and 2% of ophthalmologic surgeries.



Graphic 3 - Classification and caseload of procedures in February/2022.

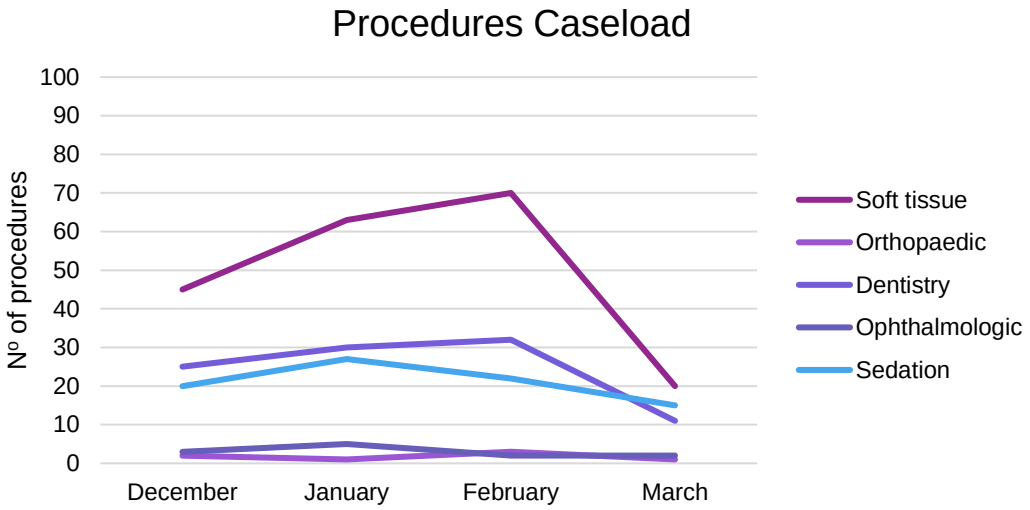
The externship ended on 14th of March, so the number of procedures was lower when comparing to the other months (N=49, Graphic 4). Soft tissue surgeries were still the highest

caseload (41%), followed by sedation (31%), dentistry (22%), ophthalmologic surgeries (4%) and orthopaedic surgeries (2%).



Graphic 4 - Classification and caseload of procedures in March/2022.

In conclusion, the soft tissue surgeries had a higher prevalence along the four months of externship. Dentistry had shown a gradual increase. Sedation showed a peak in the number of cases in January, but with a slightly decrease of caseload since then. Ophthalmologic and orthopaedic surgeries were always on the low numbers of surgeries, as most of them were sent to the internal specialist vets (Graphic 5). All procedures showed a sharply decreased in March, since the externship was finalised on the 14th so the caseload reported did not represent the entire month.



Graphic 5 - Procedures caseload along the four months of Externship.

In total, 399 procedures were performed, 198 soft tissue surgeries; 98 dentistry that included extractions and scale and polish; 84 sedations for imaging diagnostic and minor procedures; 12 ophthalmological surgeries and 7 orthopaedic surgeries. Village Vets has a high caseload of surgeries in general and it was a great experience acquired along the four months of externship.

I. INTRODUCTION

Cranial cruciate ligament disease (CCLD) is a common condition of hindlimb lameness in dogs**.** The CrCL is responsible for the stabilization of the canine stifle by neutralising cranial tibial thrust and also internal rotation of the tibia**.** Disruption of the CrCL has been shown to result in pain, lameness, osteoarthritis development in a long-term basis and secondary damage to the medial meniscus due to stifle instability (Schmutterer *et al*., 2021). The CrCL injury is commonly seen in large breed dogs and has an important economic impact, therefore continuing researches have to be done (Ferreira, 2013).

The CrCL is composed of two bundles - a craniomedial band and a caudolateral band. However, there is no sufficient studies in veterinary medicine that clarifies the real morphology and proper function of each bundle (Tanegashima *et al*., 2019) Cruciate ligaments prevents the tibia sliding against the femur, helps to stop over extension and internal rotation of the stifle (Fitzpatrick & Solano, 2010).

Injury of the ligament is characterised as partial, when only one of the bands that constitute the joint is injured and the lesion is present in the craniomedial band or total rupture, when both craniomedial and caudolateral bands are affected. The cranial cruciate ligament rupture results in instability, which can be associated with inflammation, cartilage degradation and meniscal injury (Fitzpatrick & Solano, 2010). The aetiology can be traumatic or degenerative (Fossum, 2002).

The menisci contribute to joint stabilization by aiding in shock absorption, load transmission, prevention of impact in between the synovial membrane from the femur and tibia, joint proprioception and lubrication (Guthrie, 2012). Concurrent medial meniscal injury is a common finding in partial or total cranial cruciate ligament rupture (Wow WW, 2020). The underlying aetiologies for meniscal tears in cranial cruciate ligament-deficit stifles remain unclear. Many patient factors have been linked to meniscal damage, including breed, body weight, age, degree of arthritis and effusion, duration of lameness and cranial cruciate ligament rupture (Laube & Kerstetter, 2020).

Several surgical techniques have been developed to give back the joint function and promote quality of life. The main goals are to alleviate pain, decrease instability and reduce the progression of osteoarthritis (OA). As research is kept on track, the complex pathophysiology has been clarified and the continuous search for better treatment option has been a target achievement for most of the veterinary orthopaedic surgeons around the world. Current techniques are focused on achieving mechanical stability instead of anatomical reconstruction of the ligament (Pinna *et al.,* 2020). The stability of the stifle is provided by extracapsular surgical techniques or tibial osteotomies (Muir *et al.,* 2018). Currently, tibial

osteotomy are most popular treatment, either by tibial plateau levelling osteotomy (TPLO), closing wedge osteotomy (CWO) or tibial tuberosity advancement (TTA). The goal of these techniques is to promote passive and active stabilization of the stifle by neutralizing the cranial tibial thrust (Pinna *et al.,* 2019).

This study aimed to describe the prevalence and outcome of medial meniscal tears in dogs associated with cranial cruciate ligament rupture which have been identified during tibial tuberosity advancement surgery.

1. ANATOMY AND BIOMECHANICS PARTICULARITIES OF THE STIFLE JOINT

1.2. GENERAL ANATOMY

The canine stifle is a compound condylar synovial joint formed by of three long bones: distal femur, proximal tibia, and proximal fibula (Figure 1); and four sesamoid bones (Evans & Lahunta, 2013). Patella is a sesamoid and considered to be the largest sesamoid bone in the canine body, followed by the lateral, medial, and popliteal sesamoids (fabellae) (Evans & Hermanson, 1993). The lateral and medial fabellae are located in the lateral and medial heads of origin of the gastrocnemius muscle, respectively. The popliteal sesamoid bone is the smallest one and sits within the tendon of origin of the popliteus muscle, articulating with the lateral condyle of the tibia. (Kowaleski *et al.,* 2018). The femoropatellar and femorotibial joints are two interdependent articulating components and communicates freely with each other. The medial and lateral menisci enhanced the congruity between the articular surfaces of the femoral and tibial condyles (Evans & Lahunta, 2013). The femorotibial joint is the primary weight-bearing articulation (Kowaleski *et al*., 2018).

The bones of the stifle joint play a major role in the overall mechanics of normal range of motion and provide processes for the insertion of muscles ligaments and tendons. Those bones have influence on the insertion points that potentialize the functions of the tendon and ligaments. (Pozzi & Kim, 2011).

The stifle has two major articulations characterised by the femoropatellar and femorotibial and they are formed by three articular surfaces. The first is where the patella articulates and it is called femoral trochlea, or patellar surface. The trochlea is a smooth, wide-grooved area located cranially to the femur and continuous with the articular surface of the femoral condyles. The groove of the medial ridge is thicker than the lateral (Evans & Hermanson, 1993). The articular surfaces of the distal femur are formed by the medial and lateral femoral condyles. The axial parts articulate with the tibial plateau, whereas, the abaxial articulate with the menisci (Robins, 1990). The condyles are divided by the intercondylar fossa

(ICF) and its caudal aspect where large bony prominences are found, the cranial cruciate ligament (CrCL) is originated (Fitch *et al*., 1995, Kim *et al.,* 2009).

The patella is ovate in shape, the round base faces proximally, and the pointed apex faces distally. The caudal articular surface is convex, smooth, and rides in the trochlear groove of the femur (Evans and Hermanson, 1993). The patella tendon inserts at the tibial tuberosity and it is also called patellar ligament in the literature. It can be utilized for extracapsular repair of the cranial cruciate ligament (Burks *et al.*, 1990) and is a reference point for proximal tibial osteotomies to promote the stifle stabilisation. The infrapatellar fat pad lies distally to the patella, within the fibrous layer of the capsule (Evans & Lahunta, 2013).

The proximal end of the tibia is flat and the articular surface is referred to as the tibial plateau. It is divided into medial and lateral condyles by a small non-articular strip and the intercondylar eminence. The medial condyle is oval in shape, whereas, the lateral condyle has a more rounded shape (Evans and Hermanson, 1993) There is a large process proximocranially called the tibial tuberosity that provides insertion of the patellar ligament . The has a significant importance nowadays for the osteotomies techniques. The tibial crest is formed at the cranial border of the tibia and extends distally from the tibial tuberosity (Kowaleski *et al.,* 2018).

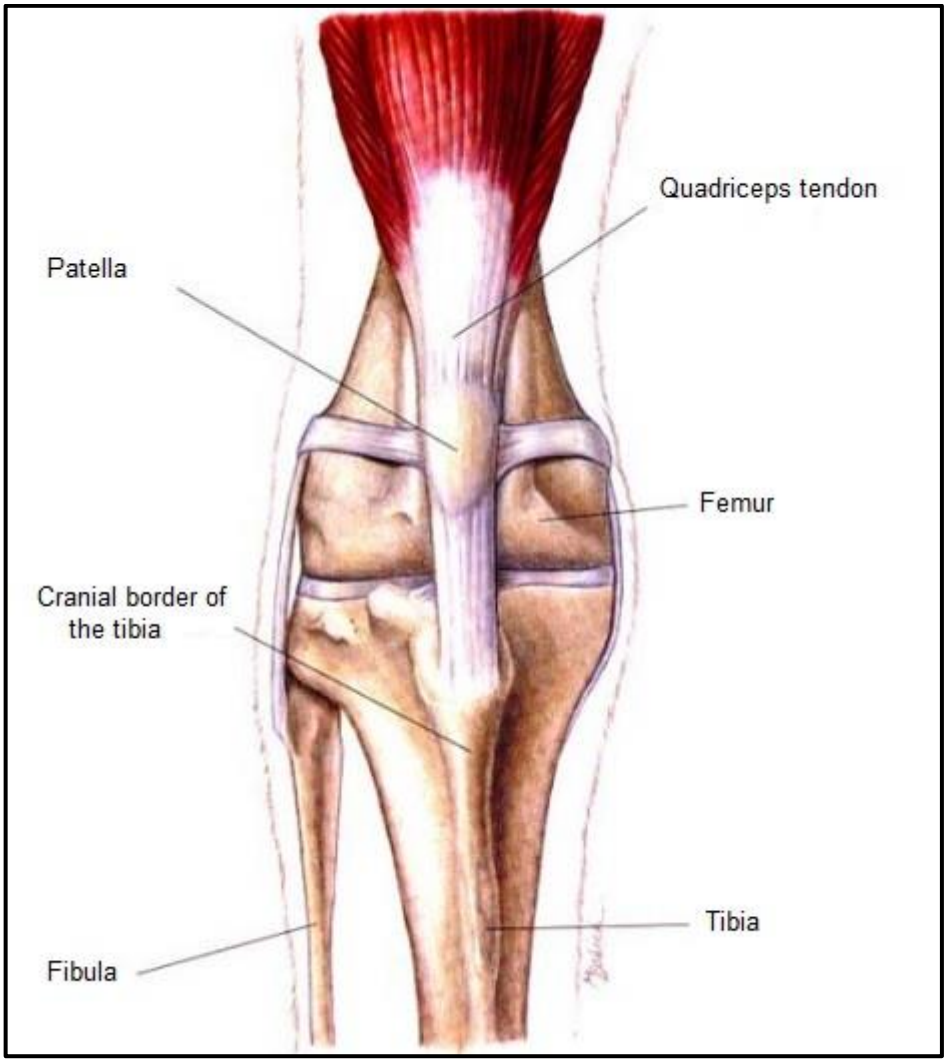


Figure 1 - Canine Stifle Anatomy

(*Atlas of Veterinary Clinical Anatomy*, Hill's Pet Nutrition, 2022)

The joint capsule is composed by an external dense fibrous layer, which attaches to the periosteum of the distal femur and proximal tibia, and an internal synovial membrane which is highly vascularized and provides the synovial fluid, a colourless and viscous liquid that is primarily composed of water and a strongly polymerised hyaluronic acid. The synovial fluid supplies lubrication, prepare the joint with nutrients and take out waste from the hyaline articular cartilage (Evans & Hermanson, 1993).

The bones of the stifle joint play a major role in the biomechanics of the stifle through insertion of muscles and ligaments on its prominences (Kowaleski *et al.,* 2018). The stifle joint is composed by 15 ligaments. The stability of the joint is mostly provided by four of them, the medial and lateral collaterals ligaments, and cranial, and caudal cruciate ligaments (Figure 2).

Of these the cranial cruciate ligament is widely discussed in veterinary medicine as being the most commonly ruptured (Pozzi & Kim, 2011).

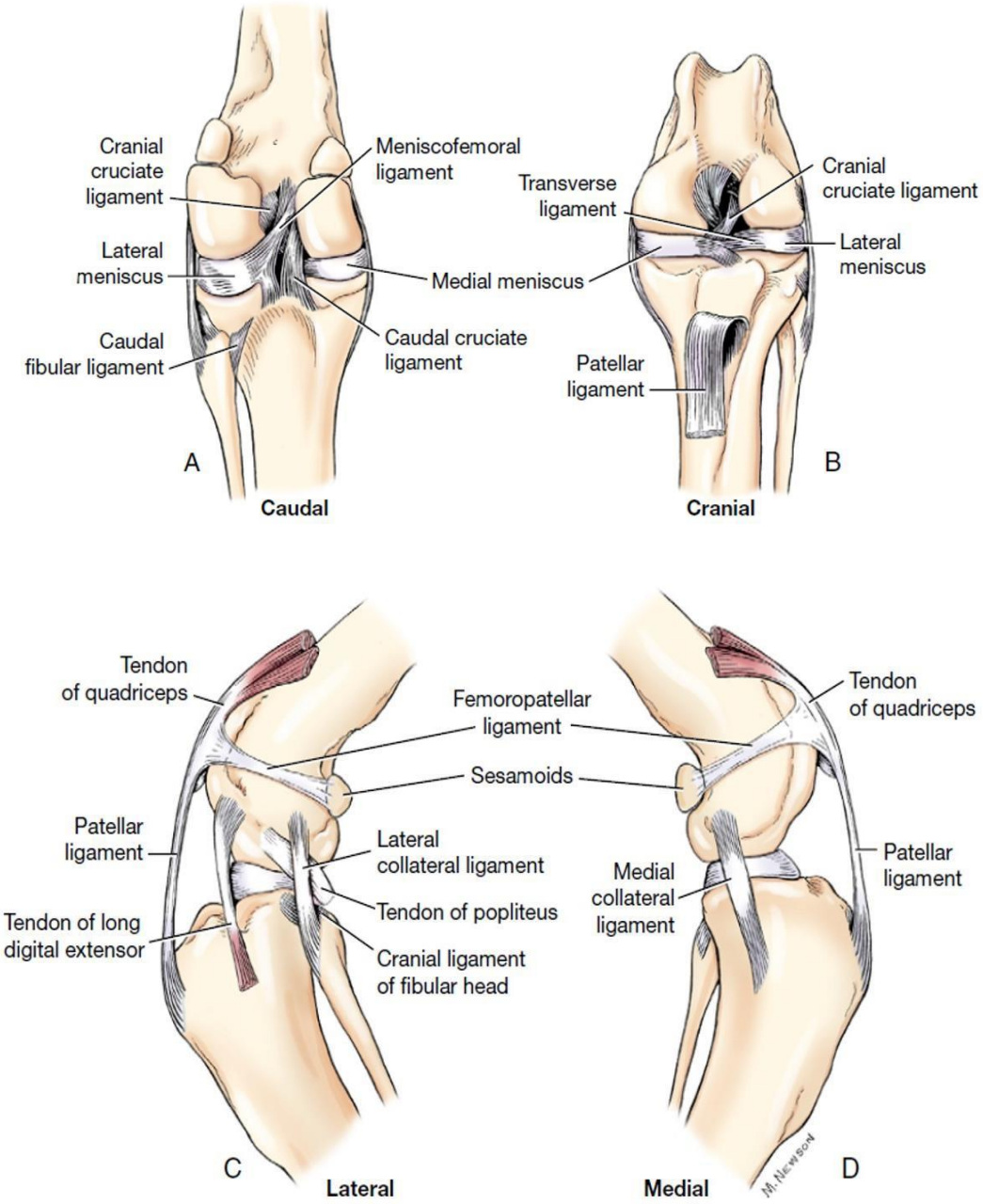


Figure 2 - Ligaments of the stifle joint

(From: Evans & Lahunta, 2010)

The lateral collateral ligament (LCL) originates in the lateral femoral epicondyle and inserts on the fibular head. The lateral femoral condyle freely moves in a caudal direction during flexion as it is loose and so internal rotation of the tibia happens, whereas in extension it is taut and the movement is limited. The LCL is attached to the joint capsule by loose connective tissue but there is no connection to the lateral meniscus (Vasseur & Arnoczky,

1981). The medial collateral ligament (MCL) has its insertion on the medial epicondyle of the femur and on the medial proximal area of the tibia. It is scientifically proved the MCL fuses with the medial meniscus after passing along the joint capsule (Vasseur & Arnoczky, 1981). A bursa is located between the ligament and the tibia and it is filled with fluid that reduces friction and improves the caudal movement of the MCL during flexion of the stifle joint (Pozzi & Kim, 2011).

The cranial and caudal cruciate ligaments are named by the position of their attachment at the tibia (Vasseur, 2003). The caudal cruciate ligament (CaCL) originates from a fossa at the intercondylar notch on the medial femoral condyle. The ligament runs on a caudodistal direction and crosses the cranial cruciate ligament (CrCL) medially. It inserts on the medial aspect of the popliteal notch of the tibia and is a bit longer and wider than the CrCL (Evans & Lahunta, 2013).The CrCL is comprised by two bands, a caudolateral band that is taut in extension but loose in flexion, and a craniomedial band that is taut in both position and one of its functions is to avoid the cranial drawer movement of the stifle (Figure 3) (Bojrab, 1993; Fossum, 2002). This is explained by having a look at the attachment points for the CrCL. Although they are not directly attached to the menisci, their femoral attachment may have fibers of the femoromeniscal ligament running together (Arnoczky & Marshall, 1977). The CrCL is attached on the medial side of the lateral femoral condyle, runs cranio-medio-distally, and attaches distally in between the tibial condyles, caudally to the medial meniscus and cranially to the lateral meniscus in a parallel direction to the meniscotibial ligament. The CrCL is narrow on its middle and disperse proximally and distally, and its length is proportional with the dog's body weight (Evans & Lahunta, 2013).

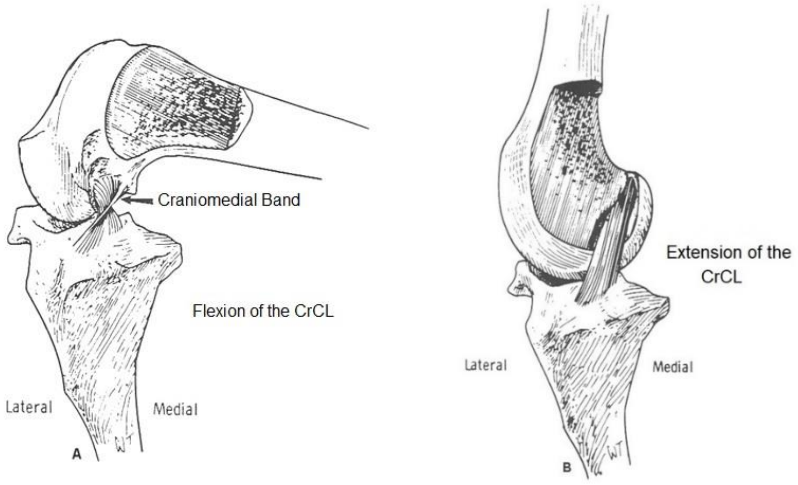


Figure 3 - Flexion and Extension of CrCL

A, Flexion of the CrCL with craniomedial band taut and caudolateral band loose. **B**, Extension of the CrCL with both bands taut.(Adapted from: Bojrab, M.J., 1993).

The medial and lateral menisci are two wedge-shaped fibrocartilaginous structures that sit between the convex femoral and tibial articulating surfaces (Figure 4) (Kowaleski *et al*., 2018). They are semilunar structures with thicker peripheral borders that provides stability and lubrication of the joint, reducing the incongruence of the tibial and femoral articular surfaces and avoiding concussion (Arnoczky, 1993). Water is their mainly composition (>64%) but also contain large percentage of collagen, glycosaminoglycans (GAG) and proteoglycans. The abaxial borders are thick and convex and it is where the joint capsule attaches, whereas the axial borders are thin and concave (Pozzi & Cook, 2010). The medial meniscus is smaller and thinner than the lateral. There are two ligaments (cranial and caudal) that attaches the menisci to the tibia (meniscotibial ligaments) and one that secure the lateral meniscus to the femur called meniscofemoral ligament. The cranial and caudal meniscotibial ligaments extend to the cranial and caudal intercondyloid area, respectively. The caudal meniscotibial ligament runs cranially to the CaCL and popliteal notch and caudally to CaCL on its insertion on medial and lateral meniscus (Robins, 1990; Evans & Hermanson, 1993). The lateral meniscus connects to the lateral surface of the medial femoral condyle through the meniscofemoral ligament , allowing the lateral meniscus to move plainly within the joint during motion. On the other hand, the medial meniscus has a very strict movement in the joint due to its attachment to the tibial plateau, medial collateral ligament and to the joint capsule via the coronary ligaments. The movement restriction of the medial meniscus results in often injury when compared to the lateral one. (Ritzo *et al*., 2014). There are several studies in human medicine that proves the meniscus carry 50% of the load transmission in the knee joint. In the dog, they also cover the tibial articular surface and provide better congruence of the femoral condyles on the tibial plateau, reducing the joint impact and improving the stifle biomechanics (Kaufman *et al*., 2017). Large portions of the menisci relies on diffusion of nutrients from the synovial fluid, however the major blood supply is provided by the medial and lateral genicular arteries, which also supply the joint capsule allowing the vessels to penetrate in an average of 20% of the width of the menisci. The same vascular synovial tissue that covers the cruciate ligaments is found around the horn of the meniscus (Ritzo *et al.,* 2014).

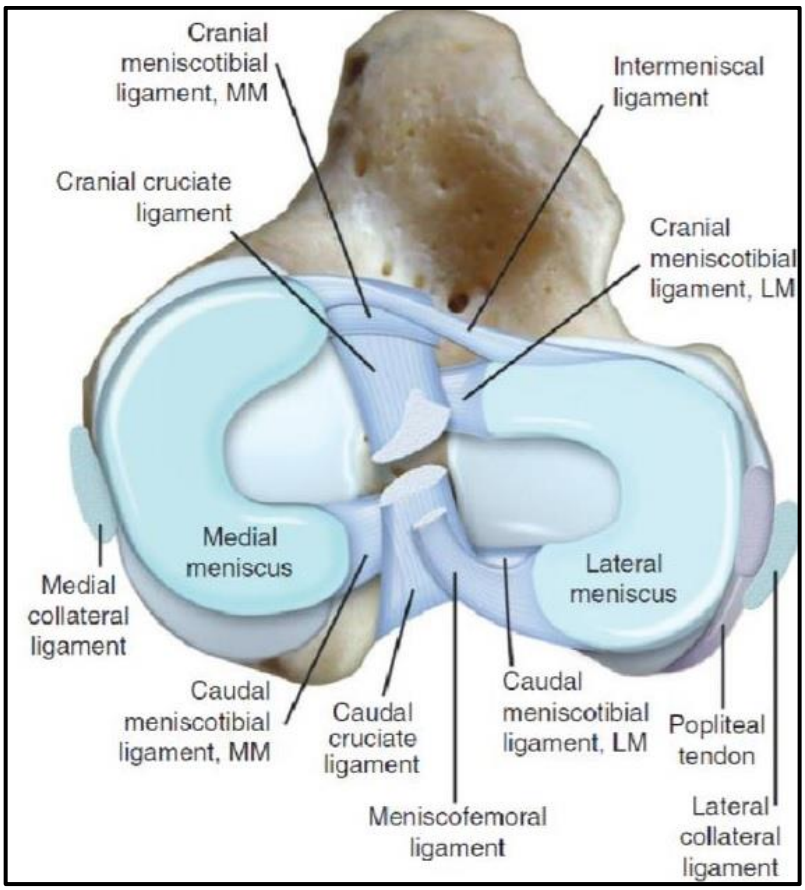


Figure 4 – Illustration of ligaments and menisci in a dorsal view of the stifle.

MM: Medial meniscos, LM: lateral meniscus. (From: Kowaleski, *et al.*, 2018)

1.3. MICROANATOMY AND NEUROVASCULAR SUPPLY

The CrCL is covered by a uniform fold of synovial membrane that consist mainly of dense connective tissue, small fibroblasts, and some adipocytes (Schulz *et al.,* 2019). By being protected by the synovial envelope and so considered extra synovial structures, the cruciate ligaments is not affected with degradative effects of the synovial environment, despite the fact they are intra-articular. The synovial envelope covering the CrCL comes from the intercondylar notch and progresses to the cranial aspect of the tibial attachment (Kowaleski *et al.,* 2018).

The canine cruciate ligaments is composed by a multifascicular structure, containing wavy fascicular subunits. Each fascicle may be composed of 1–10 subfascicles, subdivided by loose endoligamentous tissue. The subfascicles are formed by bundles of collagen fibers, which is not oriented isometrically during stifle joint motion. Different fibers are recruited when subtle 3-dimensional change occurs in stifle joint position. Those fibers orientate tangentially

to the joint surface, even when the cruciate ligaments start to twiddle about each other (Pozzi & Kim, 2011; Kowaleski *et al.,* 2018).

The genicular artery promote the major vascular supply to the centre of the stifle joint (Schulz *et al*., 2019) and it is originated from the popliteal artery. These vascularisation goes inside the caudal joint capsule, and penetrates craniodistally to the fossa intercondylaris, sitting on the cranial aspect of both cruciate ligaments (Figure 5) (de Vos and Simoens, 1992). The blood supply source to cruciate ligaments is predominantly of soft tissue origin, being the vascularized synovial membranes and the infrapatellar fat pad, creating an envelope around the ligaments (Figure 6) (Kobayashi *et al*., 2006; Kowaleski *et al*., 2018). The CaCL has a remarkable density of periligamentous and synovial vessels which explains a greater bloody supply than the CrCL (Kowaleski *et al.,* 2018).

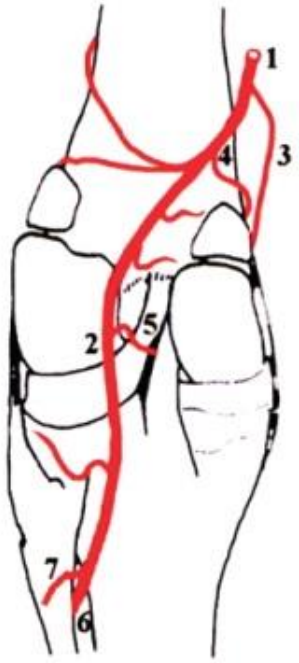


Figure 5 - Blood supply to the canine stifle joint.

Caudal view: (1) Femoral artery, (2) popliteal artery, (3) descending genicular artery, (4) proximal medial genicular artery, (5) middle genicular artery, (6) cranial tibial artery, (7) caudal tibial artery (de Vos and Simoens, 1992)

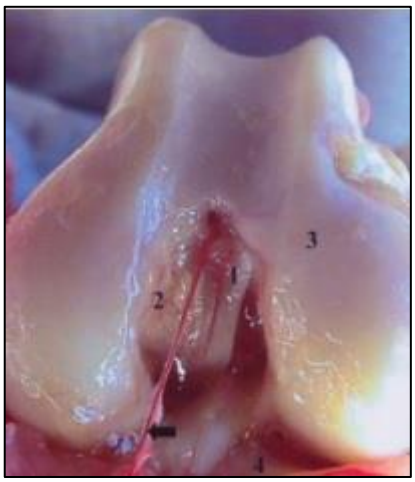


Figure 6 - Macroscopic view of stifle vascularisation in a canine cadaver specimen

(1) Cranial cruciate ligament (2) caudal cruciate ligament (3) lateral femoral condyle, (4) tibial plateau, (black arrow) artery originating from infrapatellar fat pad.
(Kobayashi *et al*., 2006)

There are three main articular nerves in the stifle joint – the medial, the lateral and the caudal articular nerve. The first one is the most important supplier to the stifle joint and the third one is commonly absent in dogs (Kowaleski *et al.*, 2018). Different sizes of nerves are located in the vascularized synovial tissue that covers the cruciate ligaments. Axons radiate to the centre of the ligaments from the peripheral synovium. The neurosensory network has an important role around the stifle joint, providing information about joint movement and position, hence proprioception may be affected when any moderate damage occurs in the femorotibial joint (Kowaleski *et al*., 2018)

1.4. BIOMECHANICS OF THE STIFLE

The movement of the stifle happens in three planes as the flexion-extension occurs, so the round femoral condyles articulate with the flat tibial condyles surface through a combination of rolling and gliding (Pozzi & Kim, 2011). The primary motion of the stifle joint consists of flexion and extension, and this occurs in the sagittal plane. Strict uniplanar motion does not occur on the stifle because of constraints imposed by the collateral ligaments, the cruciate ligaments, the menisci, and the cam-shaped geometry of the femoral condyles, therefore a slight tibial translation in a craniocaudal direction occurs during flexion and extension in the sagittal plane, characterising the secondary type of motion. In a transverse plane, there is a rotary movement of the tibia on the femur, which consist with the third type of motion (Kaufman *et al.,* 2017).

The normal range of motion (ROM) is approximately 140 degrees in flexion and extension. The average of flexion and extension angles measured by goniometry in Labrador Retrievers have been reported as 41 degrees and 162 degrees, respectively, providing a range of motion of 121 degree (Jaegger *et al.*, 2002; Mostafa *et al*., 2010). In extension, the medial and lateral collateral ligaments act as primary stabilizers to *varus* and *valgus* angulation of the tibia. However, in flexion, both collateral ligaments may also minimise these angulations since they are loosening in this position (Pozzi & Kim, 2011). When the stifle is in flexion, LCL is relaxed and internal rotation of the tibia occurs, by the lateral condyle moving caudally (Vasseur & Arnoczky, 1981). The "screw-home" mechanism is named as this due the internal rotation of the tibia that occurs over a ROM (Pozzi & Kim, 2011). Furthermore, the LCL represents the primary restraint in extension to limit the internal rotation of the tibia in respect to the femur, while the cruciate ligaments provide primary restriction during flexion (Slocum & Devine, 1983). Excessive internal-external rotation is limited by the CaCL, which also restrains caudal tibial translation. The caudolateral band of the CrCL acts as a primary restraint when the stifle is overextended and the CaCL is a secondary support (Pozzi & Kim, 2011; Kowaleski *et al*., 2018). When the stifle is at 90 degrees of flexion, all four femorotibial ligaments limit *valgus* angulation, whereas the lateral collateral, cranial cruciate, and caudal cruciate ligaments limit *varus* angulation (Evans & Lahunta, 2013).

All the scientific researches that have been done up to now describe that the CrCL has three basic biomechanical functions. The first one relies on the prevention of the cranial drawer movement of the tibia relative to the femur, the second one on avoiding overextension of the stifle and the third on controlling excessive internal rotation of the tibia in relation to the femur. During flexion, the craniomedial band of the CrCL gets long, preventing craniocaudal translation during flexion and the caudolateral band can get shortened in only one situation that is when the craniomedial band is damaged or severely stretched (Wingfield *et al.,* 2000). In opposition, the cranial translation restriction of the tibia thrust in regard to the femur are limited when both bands are taut (Kowaleski *et al.,* 2018).

The joint stability is provided by dynamic and passive stabilizers and they are needed because of the peculiar congruence between the femoral condyles and the tibial plateau (Pozzi & Kim, 2011; Hayes *et al.,* 2013). Dynamic stabilization of the stifle is mainly provided by the simultaneous contraction of the main muscle groups of the hind limbs (quadriceps, hamstrings, and gastrocnemius). The nervous system coordinates the accuracy of the muscle contractions and this is very important for joint stability. The soft tissues around the joint and in the intra-articular space provides passive stabilization. The mainly structures that are responsible for the passive stabilization are the femorotibial ligaments, the menisci, and the joint capsule itself (Pozzi & Kim, 2011; Hayes *et al.,* 2013). The role of the menisci as secondary stabilizer

depends on the integrity of the primary ones, especially the CrCL. The lateral meniscus slides caudally when the knee is flexed, whereas the medial meniscus has movement restrictions caused by its attachments to the medial collateral ligament and joint capsule (Pozzi & Kim, 2011; Hayes *et al.,* 2013).

2. CRANIAL CRUCIATE LIGAMENT DISEASE

2.1. EPIDEMIOLOGY

Rupture of the CrCL has been considered a multifactorial joint disease and its prevalence is getting higher on the last thirty years. It seems that mid age dogs, especially in between 7 and 10 years old, have a higher prevalence of cruciate disease (Witsberger *et al.,* 2008). Studies have demonstrated that female and neutered dogs, regardless of gender, are predispose to CrCL rupture. In regard to breed, Newfoundlands, Rottweilers, and Labrador Retrievers have higher chances of developing CrCL disease (Duval *et al*., 1999; Witsberger *et al.,* 2008). Furthermore, Miniature Dachshunds, Dachshunds, and Greyhounds apparently does not have a significant predisposition to the disease (Witsberger *et al.,* 2008). A study was done with Rottweiller and Greyhound comparing the CrCL biomechanic resistance according to body weight had shown Rottweilers have expressively less CrCL resistance, which may give the explanation to some extend the odds of this breed to CrCL disease (Wingfield *et al*, 2000). Patients over 20 kilograms have been presented with higher prevalence to develop CrCL rupture (Duval et al., 1999). Buote and colleagues (2009) proved that large breed dogs have an earlier onset with faster progression of CrCL degeneration and the disease course is more severe when compared to smaller dogs. The same study had also shown that contralateral rupture may occur in 22% to 48% of the dogs who already suffered from unilateral CrCL insufficiency.

2.2. PATHOGENESIS

Although is acknowledged that an acute CrCL rupture can occur due to trauma, the majority of the cases result from chronic degenerative changes within the ligament, resulting inflammation of the stifle joint, partial rupture and, finally, complete rupture of the CrCL. Microscopically, a chondroid metaplasia takes place to substitute the fibroblast cellularity of the damaged ligament with its replacement to epiligamentous tissue and total loss of the normal architecture of the extracellular matrix (ECM) (Hayashi *et al.,* 2004). These alterations on the ligaments structures lead with gradual degeneration and the initial partial rupture

becomes complete with worsening of the clinical signs. Scientists have done countless studies to understand the aetiopathogenesis of CrCL disease but it seems not be clear enough yet (Griffon, 2016). Multiple factors are associated with the disease that result in a cascade of abnormal biology and biomechanics, worsening of the osteoarthritis and general failure of the stifle joint (Cook, 2010; Griffon, 2016).

Denny and Butherworth (2000) suggested four main aetiologies, which include traumatic injury; degenerative disease in adult middle-ages dogs; rupture in young large breed dogs and inflammatory arthropathies. It was believed that traumatic injury was the most common cause of cruciate disease in dogs, however after so many studies on the last twenty years it is very well know that it can occur in cases of excessive internal rotation or severe overextension of the stifle joint but it is not routinely reported. On the other hand, degenerative disease in middle aged adult dogs is the most reasonable aetiology nowadays and it is followed by osteoarthritis changes since the very beginning (cartilage degeneration, osteophytosis, periarticular fibrosis, synovial hypertrophy and subchondral sclerosis) (Cook, 2010). Young large breed dogs may be predisposed to CrCL rupture when angular deformities is present, which modifies the stifle biomechanics. Immune-mediated arthropathies that lead with changes within the ligament is another reason of its rupture and hindlimb lameness.

The depth of the intercondylar notch (ICN) has been associated with hind limb conformational abnormalities and seems to be a risk factor for CrCL rupture (Comerford *et al.,*2006). It changes the distal femoral conformation and dogs in a higher risk of cruciate disease (Labrador, Rottweiler and Golden Retriever) was reported with a narrower ICN than dog classified as a low-risk breed (Greyhounds) (Comerford *et al.,* 2006; Lewis *et al.,* 2008). This anatomical particularity found on these breeds reduces the structural integrity of the CrCL, increasing the laxity and predisposes to its degeneration (Comerford, 2011).

The stifle biomechanics is compromised by the tibial slope. When an excessive caudal slope of the tibial plateau is present, the cranial tibial thrust is increased and the CrCL is kept under stress which leads with its rupture (Slocum & Devine, 1984, Cook, 2010). Also, the misalignment of the quadriceps and genu varum, normally associated with medial patella luxating is another reason of continuous stress over the ligament, contributing to its failure (Comerford, 2011). A greater TPA has been associated with CrCL injury (Morris & Lipowitz, 2001), however many studies have been done to correlate this finding and there is no evidence that either patellar tendon-tibial plateau angle (PTA) or TPA is definitely a risk factor for CrCL disease in canine patients (Cook, 2010; Arruda *et al.,* 2015). *Ex vivo* researches had shown when either of these two angles is considerate above the average based on literature references, the strain on the CrCL and the total shear component forces in the joint are increased. Therefore, those findings may add to the process of ligament failure, there is no

evidence of being the primary factors according to recent studies (Cook, 2010; Tanegashima *et al.,* 2019).

The clinical findings of early onset of CrCL disease are weight-bearing lameness, synovitis and joint effusion howsoever the stability of the joint is normally present and cranial drawer and tibial thrust tests may be negative at this point. In the contrary, when a complete injury of the CrCL is found the joint is unstable, non-weight-bearing is detected, pain on manipulation of the stifle, “medial buttress”, degenerative changes with osteoarthritis development as well as meniscal tear may be present (Tashman *et al.,* 2004; Kowaleski *et al.,* 2018).

2.3. BIOMECHANICS OF THE CRANIAL CRUCIATE LIGAMENT-DEFICIENT STIFLE

Slocum developed a biomechanical model which describes the correlation between the anatomical conformation of the proximal aspect of the tibia and the occurrence of CrCL disease (Slocum & Devine, 1983). As reported by this model, the femur is compressed against a tibial plateau that is orientated on a caudal direction and the ground reaction forces generated by this movement is transmitted along the tibial axis and the cranial tibial thrust (shear force). The resultant force (femorotibial) is orientated cranially and so the translation of the tibia occurs on the same direction. Static and active forces are identified in a stable stifle. The static force is primarily achieved by the CrCL and meniscus while the active force, by the hamstring muscle (Figure 7). The compressive force, which is generated by 70% of the bodyweight at trot, and the slope of the tibial plateau magnify the force generated by the gastrocnemius muscle (Figure 8) (Slocum & Devine, 1983; Slocum B, Slocum TD, 1993). Tashman and colleagues (2004), suggested the quadriceps contraction might lead to CTT along the stance phase. The CrCL acts first as a primary stabilizer, however on its absence the medial meniscus works on avoiding the rotation and translation of the femoral condyle, sustaining its common injury. The mobility of the lateral meniscus does not allow this function, which explains the reason it is not commonly teared (Pozzi *et al.,* 2006).

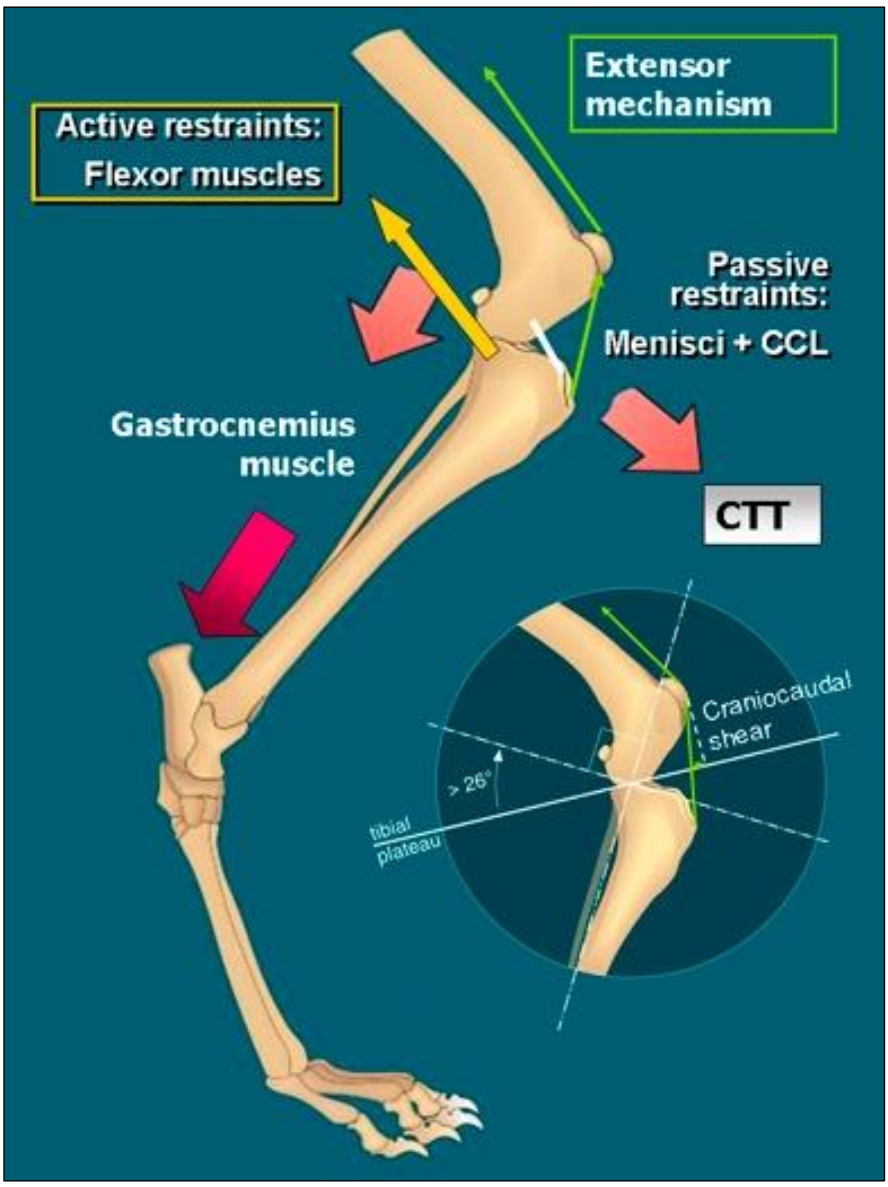


Figure 7 - Scheme of forces in the stifle joint.

The gastrocnemius muscle contracts and generates the CTT, which is neutralized by active (flexor muscles) and passive (menisci and CrCL) restraints. The position of the patella tendon with reference to the tibial plateau and the degree of stifle flexion influence the direction of the craniocaudal shear created by the contraction of the quadriceps muscle (Slocum & Devine, 1983).

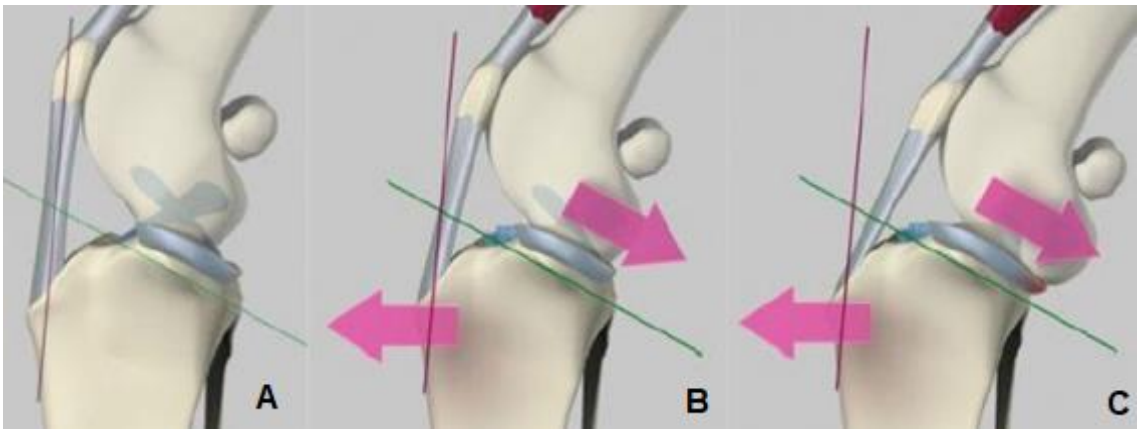


Figure 8- Mechanics of the CrCL rupture in dogs.

A: normal stifle joint with CrCL providing support. B: unstable joint, femur moves backward and tibia moves forward (cranial tibial translation, due to the caudally sloped tibial plateau), C: medial meniscus being injured (From: Fitzpatrick Referrals, 2011).

Osmond and colleagues (2006) demonstrated in an experimental model that an excessive tibial slope (>30°) is strongly associated with the proximal tibia being angulated cranially (Figure 9). Others previously studies had been associated proximal tibia deformity with CrCL disease (Selmi & Padilha, 2001; Macias *et. al,* 2002). Labrador Retrievers with CrCL deficiency had a greater inclination of the proximal tibia in relation to its distal axis (DTA/PTA) (Mostafa *et. al*, 2010). The contralateral limb of these breed was also measured and the same angulation was found and compared with normal controls, which brings up the conclusion of the proximal tibia deformity may predispose the CCLD (Osmond *et. al*, 2006; Mostafa *et. al*, 2010).

Figure 9 - Excessive tibial plateau angle secondary to proximal tibial deformity.

Radiograph of a Labrador with an excessive tibial slope of 36° and deviation of the axis of the proximal tibia (PTA) >9° relative to the distal axis of the tibia (DTA) (Osmond *et. al,* 2006)

A premature closure of the caudal portion of the tibial growth plate and an overgrowth of the cranial aspect of the tibial physis have been reported as the reason of the cranial angulation of the tibia and CrCL deficiency due its failure as a passive restraint. Microtrauma, imbalance between the quadriceps and gastrocnemius muscles, reduced blood flow to the caudal physis and increased vascularity to the cranial physis have all been discussed to explain the origin of the anatomical particularity on the proximal tibial growth plate, thus the real reason is still unknown (Selmi & Padilha, 2001; Macias *et. al*, 2002). Studies has shown that early neutering delays physeal closure and may increase the longitudinal bone growth

through prolonging the growth of the cranial proximal tibial physis. This fact may deal with higher odds of physis injury, having the premature closure of the caudal tibial physis as a consequence (Houlton & McGlennon, 1992).

Adaptative mechanisms are developed by patients with CrCL rupture as a result of joint instability and pain. The neuromuscular response results in variable degrees of lameness, flexion of the limb during the gait cycle, translation of the tibial thrust as well as escalation of the tangential shear forces. The progression of the OA is strongly correlated with all the instability presented on the deficient stifle (Ragetly *et al*., 2010; Pozzi & Kim, 2011).

2.4. MENISCAL TEARS

Meniscal injury is a common source of stifle pain and lameness in the canine patient (Johnson *et al*. 2004). Although there have been occasional reports of isolated meniscal injury in dogs (Langley-Hobbs, 2001, Williams, 2010), meniscal injury is usually a consequence of CrCL insufficiency and the resulting stifle instability (Flo 1993, Johnson *et al*., 2004). For those dogs with instability of the stifle because of cruciate ligament disruption, meniscal disease occurs in 20–77% of reported cases (Katz *et al.,* 2021). When meniscal injury is associated with acute or chronic cruciate disease, the medial meniscus is damaged in 96% to 100% of cases (Franklin *et al.,* 2010). This correlation is directly attributed to the anatomic difference between the two menisci.

The medial meniscus is more firmly attached to the tibia, joint capsule, and medial collateral ligament than the lateral meniscus, which is more mobile. Therefore, during weight bearing in the deficient stifle, the cranial displacement of the tibia squeezes the medial meniscus between the femoral condyle and the tibial plateau. Stifle flexion after CrCL rupture generates an excessive internal tibial rotation which also predispose to medial meniscal tear from the pressure caused by the medial femoral condyle as part of the “screw-home” mechanism, allowing the stifle to move in three different planes (Arnoczky, 1985). Persistent lameness is seen on medial meniscus injury and severely affects the long-term outcome and recovery of dogs with CrCL disease (Katz *et al.*, 2021).

The mobility reported on the lateral meniscus is because of its caudal attachment to the femoral attachment (Hulse & Shires, 1983). Nonetheless, a few studies have reported lateral meniscal injuries, including one that describes radial tears in the cranial horn of the lateral meniscus in 77% of dogs that underwent arthroscopy for CrCL rupture diagnosis (Ralphs & Whitney, 2002). In addition, Hulse and colleagues in 1986 had already described lameness associated with a lateral caudal pole tear, but the clinical significance of most lateral

meniscal tears is unknown. Studies have been done recently and reported lateral meniscal tears as isolated lesions not related with cruciate rupture (Krier *et al.,* 2018).

Injury to the medial meniscus may occur at the time of CrCL injury or as a consequence of chronic joint instability (Van der Vekens *et al.,* 2019). Tears into the medial meniscus can be classified based on anatomic orientation and the type of tear (Figure 10). Folded caudal horn, longitudinal tears, fibrillation of the surface, transverse tears, "bucket-handle" tears, and compression injuries are the lesions reported in the literature up to now. The bucket-handle tear (BHT) and folded caudal horn (pole) are the most commonly reported when the medial meniscal is damaged (Flo, 1983). A BHT is a medial to lateral tear in the caudal horn that allows cranial and caudal displacement of the axial border. Displacement of the torn portion during weight bearing and manual manipulation creates a palpable or audible meniscal click in some cases. Diagnose and treatment of meniscal injury are crucial to achieve satisfactory outcome in canine patients presented CrCL disease (Neal *et al.,* 2014; Van der Vekens *et al.,* 2019).

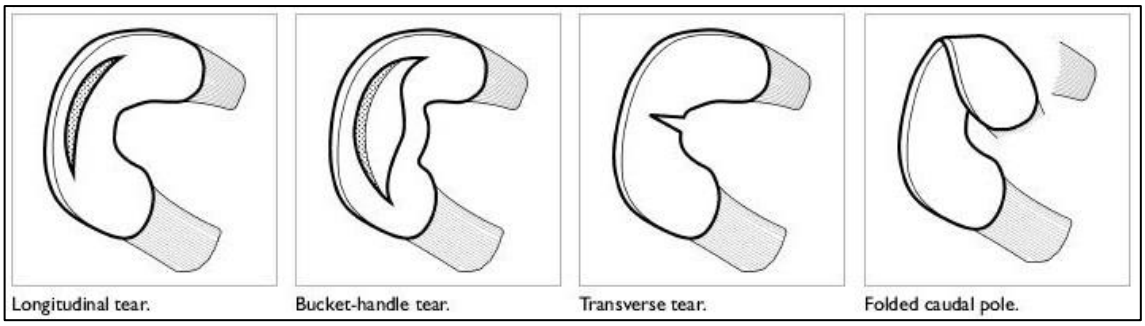


Figure 10 - Meniscal tears

(Flo, 1993)

Whilst arthroscopy and meniscal probing are reported to increase the likelihood of diagnosing medial meniscal tears, the reported prevalence of meniscal injury identified at the time of surgery for CrCL rupture varies between 20 and 77% (Ralphs & Whitney 2002, Pozzi *et al*., 2008). Postliminary torn menisci have been reported in up to 37% of cases. Late meniscal tears can be due to a failure of diagnosis at the time of stifle stabilisation or continued stifle instability depending on surgical technique performed (Katz *et al.*, 2021). Meniscal injuries can also be classified according to the time of occurrence relative to surgery. *Latent* meniscal tears are type of lesions missed at the time of the initial surgical intervention, whereas *subsequent* meniscal tears develop as a consequence of persistent instability after surgical stabilization of the stifle (Jeong *et al.,* 2021)

The reported risk factors for meniscal tears in dogs with CrCL disease include degree of stifle instability, duration of lameness, bodyweight and age (Hayes *et al*., 2013). Although several published studies have identified various risk factors, the evidence is conflicting and the real impact of these predisposed factors has not been analysed on a scientific basis yet.

Diagnosis and treatment are commonly reached by arthroscopy, preferably, or via arthrotomy (Pozzi *et al*., 2008). Arthroscopy and magnetic resonance imaging (MRI) are the best methods for diagnosis of meniscal tears in dogs. Gross inspection can also be performed by craniomedial or caudomedial arthrotomy with relatively good diagnostic accuracy, and is enhanced by meniscal probing. Computed tomographic arthrography (CTA) and ultrasonography have also been suggested for the diagnosis of meniscal tears. These tests are not invasive but may be cost prohibitive and may not be readily available (Neal *et al.,* 2014).

There is no conservative treatment for meniscal tears in dogs. The tear normally affects the avascular segment of the meniscal cartilage so healing does not occur. Consequently, surgical management is mandatory and failure on management of meniscal injuries is a very common reason for poor outcome after surgery (Case *et al*, 2008).

Meniscal tears are treated by resection of the affected area via partial, hemi- or complete meniscectomy (Thieman *et al*., 2009). The extension of meniscal resection in dogs is performed according to the location of the tear. If the lesion is located in the abaxial zone (red–red zone), an extensive resection is not need, differently from than a tear in the axial region with a poor blood supply (white–white zone) (Pozzi *et al.,* 2010; Jeong *et al.,* 2021). The meniscus resection has been under discussion between the scientists as it may progress the development of OA due to loss of meniscus stability and modification on the pressure distribution in the menisci surface (Kim *et al.,* 2012). Complete meniscectomy has been shown to worsening the OA, so partial meniscectomy has been better indicated. On the other hand, studies have been demonstrated that total meniscectomies may result in a reduced risk of iatrogenic tear of the cartilage in the joint or within the CaCL (Austin *et al*., 2007; Kaufman, 2017). There are biomechanical advantages on conservative meniscal resection when compared to segmental meniscectomy or extensive partial meniscectomy as described above, but the ideal solution for meniscal tears in dogs is far from its end (Pozzi *et al.,* 2010; Jeong *et al.,* 2021). It is very important to detect meniscal injuries on the initial assessment as failure to treat it can lead to persistent lameness and countless complication after surgery for stifle stabilisation (Case *et al.,* 2008; Jeong *et al.,* 2021).

Long-term degenerative joint changes are proportional to the amount of meniscus removed surgically. Partial meniscectomy increases the peak contact pressure in 58.3% while medial caudal pole hemimeniscectomy, 88.9%. The last one also seems to increase the contact pressure on the lateral side, which suggests that the biomechanical alterations caused

by the meniscus removal is not limited to the side it was performed (Figure 11). As the researches move forward on meniscal damage in dogs, orthopaedic surgeons have been limited the meniscus removal to its minimal and new alternatives to replace the deficient meniscus have been encouraged (Spina *et al,* 2014).

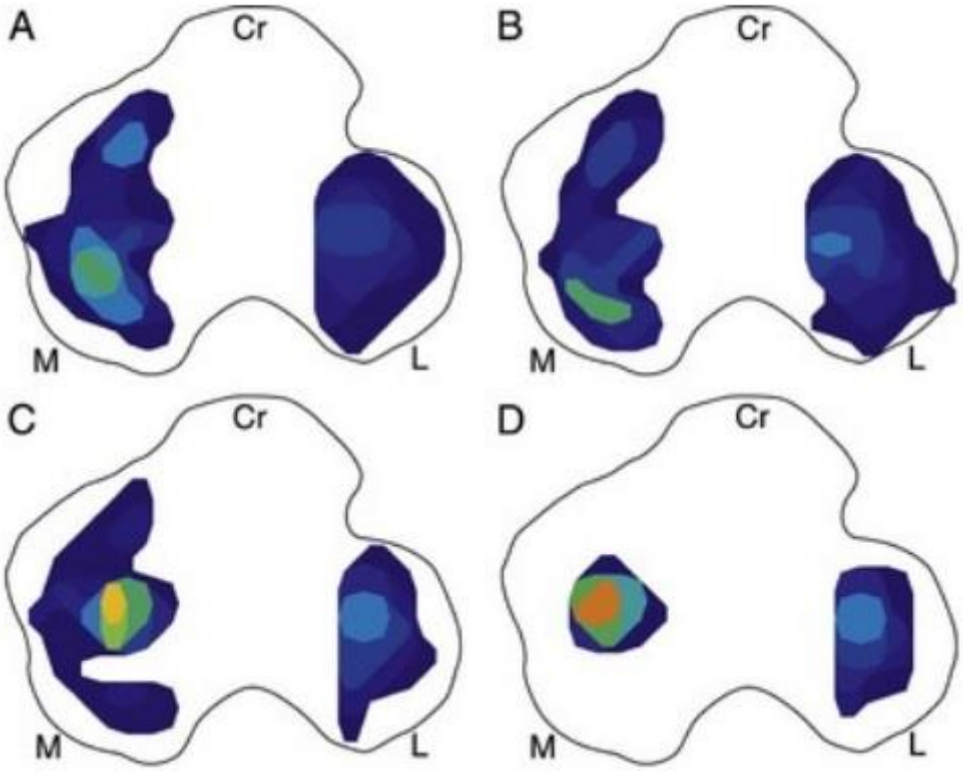


Figure 11 – Peak contact pressure according to meniscal removal technique.

A, Intact medial meniscus; **B,** 30% radial width medial meniscectomy; **C,** 75% radial width medial meniscectomy; and **D,** segmental medial meniscectomy. Pressure is illustrated by the colors and increases from dark blue to light blue to green to orange. (From Pozzi et al., 2010)

Meniscal release is based on the transection of the midbody of the meniscus or the meniscotibial ligament completely, with the aim of eliminating the wedge effect on its caudal horn when the medial femoral condyle moves backwards (Pozzi *et al,* 2017; Schmutterer *et al.,* 2021). Subsequent meniscal tears have been reported to occur in up to 50% of dogs treated surgically for CrCL disease, and meniscal release was previously associated with a significant reduction in incidence of subsequent tears without clinically apparent detriment to functional outcomes (Krier *et al.,* 2018). However, meniscal release does not avoid subsequent meniscal tears, and it is associated with progression of osteoarthritis, lameness, and meniscal pathology in healthy stifles (Jeong *et al.,* 2021). Pozzi and colleagues (2017) concluded that meniscal release should not be done as it has been shown to have a negative

impact on joint biomechanics and does not alleviate the pain neither preserves the meniscal function. The main goal is to achieve a better outcome after CrCL surgical repair, hence clinical trials on diagnosis and treatment for meniscal pathology is vital to improve patient care.

Because of the uncertain results achieved with meniscectomies, the ideal treatment for meniscal injury has been a topic of interest in veterinary orthopaedics. The new approaches include suture repair, creation of vascular channels, allograft implantation, synovial flaps, and tissue engineering (Spina *et al.,* 2014; Van der Verkens *et al.,* 2019).

Intra articular Platelet-Rich-Plasma (PRP) and Mesenchymal Stem Cells (MSCs) have been shown good results and excellent outcome on ligament deficient stifle and meniscal regeneration, especially on the white-white zone which is avascular and theoretically cannot heal (Wei *et al,* 2021). Platelet-Rich-Plasma (PRP) is a platelet concentration derived from autologous blood that secretes a large quantity of a preparation rich in growth factors (PRGFs) via the release of intracellular granules and has been used widely for bone regeneration and wound healing (Wei *et al*, 2021). The main achievement on using mesenchymal stem cells (MSCs) is its optimal potential of chondrogenic progenitor cell. It can be derived from adipose tissue, bone, muscle, periosteum and synovium, being the last one the best choice for hyaline chondrogenesis. The abundance of autologous synovial lining makes this source a good opportunity for meniscal tissue engineering in veterinary medicine (Spina *et al.,* 2014; Van der Verkens *et al.,* 2019).

Despite recent advances, more research is currently required to investigate meniscal regeneration, repair or replacement, due to the continuing evidence indicating the long-term deleterious effect of meniscectomy for treatment of meniscal injury.

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2.5. DIAGNOSIS

2.5.1 CLINICAL HISTORY

Cranial cruciate ligament rupture (CCLR) is a pathology with a high caseload in veterinary practices around the world, being a very common cause of hind limb lameness in the canine patient. CCLR happens secondary to degenerative changes within the stifle, but anatomic limb conformations seems to play an important role as well (Buote *et al*., 2009) Lameness is present in different degrees and can get worse after exercise or long periods of rest. It is frequently presented as a weight-bearing lameness, but the clinical presentation is always correlated with the extension of the ligament tear (Kowaleski *et al.,* 2018).

Dogs with complete CCLR normally develop a severe to non-weight-bearing lameness and stiffness after rest very noticeable on physical examination. Also, an audible clicking may

be present, being an indicative sign of meniscal injury. When partial ligament tear is present, lameness is more subtle and easily identified after exercise. Dogs with unilateral CCLR have 60% chances of developing the pathology on the contralateral limb in less than 12 months after the first diagnose and the disease does not have a good response to nonsteroidal anti-inflammatory drugs (NSAID; Muir, 2018; Kowaleski *et al.,* 2018)

Avulsion injuries of CrCL have been reported to occur mainly in young dogs, at the level of tibial insertion where the ligament is attached to the bone strongly than the immature bone. However, it is a rare finding in dogs and the cases reported in the literature are all in dogs of three years old or less, often with a history of trauma (Buote *et al.,* 2009).

2.5.2. CLINICAL SIGNS

The clinical presentation of CrCL disease can be acute or chronic. Dogs with acute CrCL rupture may be firstly presented with non-weight-bearing lameness and improve clinical signs significantly after medical management with NSAIDs, pain relief and rest. The improvement on weight-bearing may be seen after a week and has a better response in dogs under 10 kilograms. If meniscal tear is present, non-weight-bearing lameness is seen and surgery is strongly recommended. (Schulz *et al.,* 2019). Joint effusion is a common sign on acute ligament injuries and can be palpate on the majority of the time but it is also confirmed by radiograph where the patellar tendon lost its definition on the lateral and medial borders (Muir, 2018; Kowaleski *et al.,* 2018). Muscle wastage is not visible but may develop after a few weeks. Osteoarthritis may be already present in acute, non-traumatic CrCL ruptures or absent in acute traumatic injuries. Despite the typical weight-bearing presentation after medical management on acute CrCL disease, it will slowly get worse, becoming more and more persistent (Piermattei *et al.,* 2006; Schulz *et al*., 2019). Dogs with chronic CrCL rupture have a history of intermittent non-weight-bearing lameness and days when the weight-bearing lameness is present, but varying from moderate to severe (Kowaleski *et al.,* 2018). Stiffness after rest is frequent finding as the inability to sit straight and square, especially in unilateral injuries. The latter is called abnormal “sit test” and is an easily detectable clinical sign in dogs with cruciate disease, as the affected limb stays rotated externally and the calcaneus does not sit underneath the tuber ischia properly because the stifle cannot be flexed as it should be. When both cruciate is damaged, the dog has a tendency to lean forward with the aim of reducing the load in the hind limbs and on this case, neurological disease is a differential diagnosis (Muir, 2018). Muscle waste and osteoarthritis are normally seen in the affected limb. Medial periarticular fibrosis (“medial buttress”) is another important finding on physical examination and is very indicative of chronic CrCL injuries (Schulz *et al.,* 2019).

Generally, canine patients with partial CCLD do not have palpable joint instability so the expected clinical signs rely on lameness and joint effusion. As the ligament keeps tearing, the joint instability gets worse and so the osteoarthritis, the lameness becomes more visible and it is not solved with rest and pain relief. (Muir, 2018; Schulz *et al.,* 2019).

In any of the clinical presentations described above, the dog may demonstrate pain while testing the ROM of the stifle, meniscal "clicking" and crepitation. The ROM may be increased or decreased according to the severity of the OA in place (Johnson & Hulse, 2002; Vasseur, 2003).

There are two important tests to check veterinary patients in regard to stifle instability: the cranial drawer and the tibial compression tests. The dog must be positioned in lateral recumbency with the affected limb facing upwards. The cranial drawer test is performed with one of the thumbs on the lateral fabella and the index finger of the same hand on the patella, the thumb of the other hand goes on the caudal tibial plateau, and the index finger on the tibial tuberosity (TT). After positioning the fingers correctly, the tibia should be moved forward and the femur backwards (Figure 12) and the positive is determined when this movement of the tibia with respect to femur happens with an undefined end point. The periarticular fibrosis, meniscal damage or partial cruciate rupture may compromise the test result as the tibial translation can be reduce on these cases (Flo & DeYoung, 1978; Schulz *et al*, 2019). The cranial drawer test has to be done with the stifle in flexion and extension, especially in cases of partial rupture in which only one of the cruciate ligament bands (CMB/CLB) may be affected. In this situation, if only the CMB is damaged, the test is positive only with the stifle flexed as the CLB is taut in extension; on the other hand, if the CLB is injured, the cranial drawer test is negative as the CMB is kept taut in the full ROM of the stifle joint (Arnoczky & Marshall, 1977; Muir, 2018). Ideally, the clinical drawer test should be redone under sedation if it is not possible in a conscious dog as it is normally painful and very hard to elicited in large breed dogs. (Kowaleski *et al.,* 2018). The veterinary surgeon must be cautions when interpretating the cranial drawer test in immature dogs as the ligament still has a slightly laxity, making the result of the test a bit dubious. However, the main difference on this situation is that the end point is well defined, which characterizes the term "puppy drawer" (Muir, 2018; Kowaleski *et al.,* 2018). In general, puppies does not injure the CrCL before closing the growth plate, but radiographs should be taken when stifle instability is noted as salter harris fractures may happen on the distal femur as well as avulsion fractures on the tibial thrust (Schulz *et al*., 2019).

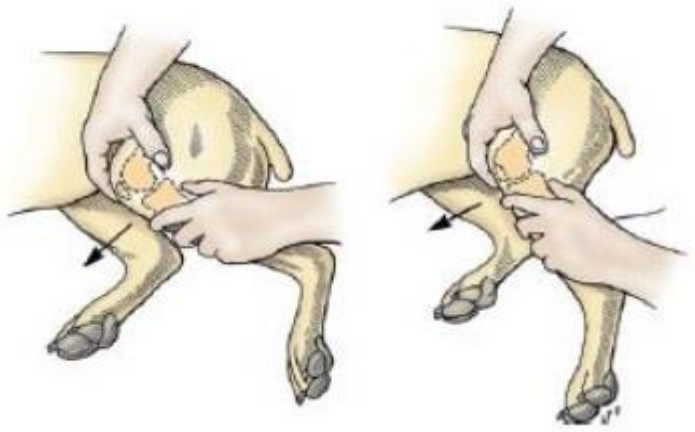


Figure 12 – Illustration of the cranial drawer test.

(From: Schulz *et al.*, 2019)

The tibial compression test is a very reliable method to confirm cruciate rupture, especially in large dogs with strong muscle coverage and bigger bones, facts that may become the cranial drawer test difficult to perform. The stifle is kept at a standing angle (120º), one of the thumbs is placed at the lateral fabella and the index finger on the TT, with the other hand the hock is flexed and the stifle is kept steady. This movement simulates the gastrocnemius muscle being contracted (Figure 13) (Schulz *et al.*, 2019; Kowaleski *et al.,* 2018). By flexing the hock, the tibia gets compressed and slopes cranially. If any motion is detected on the TT, it means the cruciate ligament may be rupture (Kowaleski *et al.*, 2018).

Figure 13 - Tibial compression test.

(From: Schulz *et al.,* 2019).

Dogs have a better acceptance when performing the tibial compressing test rather than the cranial drawer, which allows the manoeuvre to be done consciously. These two ambulatorial tests support the diagnose for CrCL rupture, therefore they have a greater specificity and sensibility when the patient is under sedation (Carobbi & Ness, 2009; Schulz *et al.*, 2019).

2.5.3. RADIOGRAPHY

Radiographic examination is the first imaging diagnostic performed when CCLD is suspect. Although the findings are not specific of cruciate disease, they confirm the stifle pathology and point the severity of the OA which is very important for prognosis in a long-term premises. Also, other differential diagnosis such as neoplasia and fractures may be rule out with radiographic examination. This diagnostic modality is done preferable with the patient under sedation, including both stifles for comparison and the stability at the joint is accessed at the same time through cranial drawer and tibial compression tests (Vasseur, 2003; Kowaleski *et al*., 2018).

There are two main views that should be performed: the mediolateral and the craniocaudal views. The joint effusion is better visualised on the mediolateral view and is characterised by the loss of patella tendon definition, where the infrapatellar fat opacity is replaced by a soft tissue opacity (Denny & Butterworth, 2000). This opacity transition starts at the cranial aspect of the tibial condyle and runs caudally, extending to the femoral condyle. The lack of definition in the caudal border of the patella tendon, cranially to the tibia condyle, is consistent with joint effusion or severe oedema of the infrapatellar fat pad (Kowaleski *et al.,* 2018). Osteophyte formation may be seen in the trochlear ridge surface, caudally in the tibial plateau, and in the distal pole of the patella. Subchondral sclerosis and thickening of the medial fibrous joint capsule are also important findings when stifle pathology is present (Figure 14) (Fossum, 2012).

Figure 14 - Mediolateral radiographic of the stifle

(Left) Normal stifle (Right) Stifle with chronic cruciate ligament rupture. The loss of fat pad definition is clearly seen and so the severe osteophyte formation along the trochlear ridge. Subchondral bone sclerosis is also visualised in the tibial plateau (From: Fossum, 2012).

Radiographs on a tibial compression position may also support the diagnose of CCLD (de Rooster *et al.,* 1998). Mediolateral radiographs are taken beforehand in a 90° of flexion and then the tarsocrural joint is flexed to its maximum to take the second radiograph. The two views of the radiographs are paired for comparison and if cranial translation of the tibia occurs on the stress view radiograph, the CrCL have a higher odd of being ruptured. The mechanism is exactly the same of the tibial compression test and is a reliable method to assist the diagnose of cruciate injury, especially when there are limitations on performing the cranial drawer test during the physical examination (Bree *et al.,* 2011).

2.5.4. ULTRASONOGRAPHY

Ultrasonography is not the first choice for diagnosing stifle pathologies as the sound waves will travel fastest through bone and slower in joint fluid, making this method more useful for soft tissue structures of the stifle. It may be helpful on assessing cartilage abnormalities, meniscal tears, muscle, tendon and ligament abnormalities. Cruciate ligament injury can be suggested when fluttering edges is seen around the torn ligament (Marino & Loughin, 2010). In chronic cases of CCLD, the ligament surface is thickened and incongruent and the rupture ends appears retracted. OA changes may also be seen as a hyperreflective image on the bone surface that is a sign of irregular borders (Cook, 2011). Due to anatomic restraints, it is difficult to have a good image of the entire meniscus that is normally homogeneous and congruent within the intra-articular margin. When it is injured and displaced, an hyperreflective area with irregular hyporreflective zones is visualised and a hyperechoic line is seen in the parenchyma (Van der Verkens *et al.,* 2019).

The ultrasonography has a better use on large breed dogs with a wide stifle that allows a reasonable imaging production. Ultrasound images generally have low resolution for stifle abnormalities which makes the vet to choose a more specific diagnostic method that would bring more reliable information (Van der Verkens *et al.,* 2019).

2.5.5. COMPUTED TOMOGRAPHY

Computed tomography (CT) is a sensitive imaging method and allows three-dimensional radiographic examination (Van der Verkens *et al*., 2019). From this, a 3D model can be constructed and displayed. Bone, muscle and cartilage can be represented in different colours, allowing multiples models to be constructed from several thresholds. The main clinical advantages are the high accuracy and the ability to perform 3D image reconstructions that support the veterinary surgeon on planning a complex surgery. Additionally, there is no superimposition of soft tissue or bone, resulting in a superior image quality (Marino & Loughin, 2010; Van der Verkens *et al*., 2019).

There is an additional CT modality called computed tomography arthrography (CTA) that had shown accuracy in diagnosing CrCL rupture and medial meniscal injuries (Han *et al.,* 2008; Tivers *et al*., 2008). It consists of iodine contrast injection into the stifle joint to promote a better visualisation of the inner structures, especially the ligaments and the meniscus. Studies had demonstrated the sensitivity and specificity on identifying intraarticular structures are better with CTA rather than CT in normal and cadaveric canine stifles and the findings seems to be more reliable on CrCL injuries than on torn meniscal fibrocartilage (Samii *et al.,*

2009). Han et al (2008) suggested CTA allows a better identification of partial cruciate rupture in canine patients when comparing to radiographs and ultrasonography, but has a risk of septic arthritis as contrast has to be injected into the joint.

Computed tomography also has a significant accuracy on diagnosing CrCL avulsion in immature dogs, especially on the identification of small bone fragments as tibial tuberosity fracture is often related (Gielen *et al.,*2011).

2.5.6. MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging (MRI) is a newer non-invasive imaging modality in veterinary medicine being used more commonly to assess musculoskeletal injury in dogs (Pownder *et al*., 2018). The images are converted into a computerized grey-scale image or tomogram through the emission of radiofrequency (RF) detected by the machine, using a magnetic field rather than ionizing radiation (Marino & Loughin, 2010). MRI has a superior imaging resolution, with an excellent soft tissue contrast and also allows the access of images in any plane. In addition, iodine contrast can be added into a joint if an even better resolution is required (MRI arthrograms) (Scrivani, 2011). Several studies have been shown that MRI can identify the early onset of OA in dogs and quantify its extension in the joint surface better than routine radiographs. Neither arthrotomy or arthroscopy are capable to promote a complete meniscal evaluation as its tibial surface and internal structure remains hidden from view. Those anatomical constraints does not affect the meniscal visualization on the MRI as three different section planes can be done till an ideal image is achieved, being this imaging modality already the first choice in human medicine when assessing for cruciate, meniscal, and articular pathology (Pownder *et al*., 2018). Regarding to MRI findings in the canine stifle, partial rupture is suggested when the CrCL is thicker and an abnormal sign of intensity is found; whereas a complete rupture is present, the disruption of CrCL continuity is seen and signs of moderate to severe OA is normally detected (Pownder *et al*., 2018). MRI has shown to have better results when comparing to other diagnostic imaging. However, due to high costs it is rarely used in veterinary practice.

2.5.7. ARTHROSCOPY

In veterinary medicine, the use of arthroscopy has been considered the gold standard over the last one to two decades when it comes to joint evaluation and treatment. Stifle arthroscopy is a very effective minimally invasive tool to evaluate the stifle joint not only to confirm the diagnosis of CrCL rupture, but also to evaluate and treat meniscal tears. Some of

the advantages of arthroscopy are that it allows a much more precise view of the stifle structures because the images are magnified; treatment of existing lesion, especially meniscal tears and minimal incisions within the joint capsule, which reduce the recovery time, surgical pain and risk of infection on the postoperative (Kowaleski *et al.,* 2018).

A large percentage of the surface of the cruciate ligament can be examined arthroscopically for gross tears, fibrillation, or discoloration associated with cruciate damage (Fossum, 2012). When partial CrCL tear is diagnosed via arthroscopy, the surgery to stabilize the joint can be done in an early stage, minimizing the risk of meniscal tears and reducing the development of OA changes (Kowaleski *et al.,* 2018). The loss of normal fibre pattern, with presence of tear within the ligament and oedema are the most common findings on early partial tears. Whereas in complete tears, when the chronic changes are in place, there are much more damaged fibres and the laxity of the ligament is potentially higher. Signs of OA (synovitis, cartilage fibrillation and osteophytosis) can also be found as the disease progresses (Kowaleski *et al.,* 2018).

Menisci evaluation is improved with arthroscopy as there are two portals that can be assessed for better visualization, cranial and caudal to the joint. This approach facilitates the diagnosis and allows the treatment of meniscal tears (Pozzi *et al.,* 2008; Beale & Hulse, 2011; Kowaleski *et al*. 2018). Clinical studies had demonstrated that the detection of concurrent meniscal tears is 2 times more accurate with arthroscopy than arthrotomy (Plesman *et al.*, 2013; Ritzo *et al.,* 2014). Nevertheless, caudomedially or craniomedially arthrotomy followed by probing the meniscus has been shown similar sensitivity to arthroscopy (Pozzi *et al.,* 2008).

Every minimally invasive surgical procedure has the risk of converting to an open procedure. In these cases, arthroscopy-assisted arthrotomy can be performed and has the advantage of shortening the arthroscopy learning curve as the same incision made for the arthrotomy can be used for the placement of the arthroscope portals, allowing a better view of the caudal aspect of the menisci as well as its internal structures. Treatment accuracy and quicker recovery time make the arthroscopy a preferable approach than the traditional arthrotomy (Beale & Hulse, 2011).

3. TREATMENT OF CRANIAL CRUCIATE LIGAMENT DISEASE

3.1. CONSERVATIVE MANAGEMENT

Surgical treatment is recommended over conservative management as the latter does not reduce the progression of OA. The damaged CrCL generates stifle instability and results in chronic, progressive lameness, predisposing to meniscal tearing, and formation of OA as a

consequence. However, surgery is not an option for some dogs when a life threating underlying disease is present, the dog is overweight or the owner has financial issues (Kowaleski *et al,* 2018).

Despite the OA gets potentially worse with the stifle unstable, the goals of the conservative treatment are to slow disease progression, minimize the pain, muscle waste, ROM restriction and lameness that come as a result of a long-term joint instability (Jaegger & Budsberg, 2011). Eventually, patients under 15 Kg seem to improve clinical signs after 6 weeks of conservative treatment (rest, anti-inflammatory drugs and pain relief) (Schulz *et al.,* 2019). According to Vasseur (2003), 83% of dogs weighting less than 15 kilograms have a good response with non-surgical treatment while only 13% of dogs over 15 kilograms show some improvement on clinical signs.

The conservative management relies on a multimodal therapy with the aim of minimizing the clinical signs that OA may cause, as well as reduce its progression and improve the limb function. Chondroprotective, nutraceuticals, NSAIDs, weight loss, physiotherapy and good analgesic plan with tramadol, amantadine or gabapentin represent the protocol that are mostly used for this purpose (Jaegger & Budsberg, 2011; Schulz *et al.,* 2019).

Nowadays, there is a wide variety of anti-inflammatory drugs available with similar efficacies, but every patient may show a different response to a certain nonsteroidal anti-inflammatory drug (NSAID), thus it may be necessary to evaluate each patient individually to achieve a good analgesia with less side effects (Jaegger & Budsberg, 2011). Meloxicam, piroxicam and carprofen are the most recommended NSAIDs to be safely used on clinical routine of CrCL rupture with an acceptable analgesia and minor adverse response.

Corticosteroids are not recommended as they might change tendon and ligament fibres structures causing laxity and rupture and also potentialize joint surface damage through the biosynthesis inhibition of chondrocytes production and proteoglycan (Schulz *et al.,* 2019).

Dogs that are overweight stress their joint due to constant and also, obesity overexpresses pro inflammatory cytokines which makes osteoarthritis worse, therefore, a weight control diet should be advised with the purpose of blocking the cytokines and decrease stifle overload. (Mlacnik *et al*., 2006; Marshall *et al.,* 2010).

Exercise and physiotherapy have an important role on multimodal conservative management. Daily walks on a lash , during a short period of time (10 minutes) for 8 weeks, associated with hydrotherapy and a good rehabilitation schedule to recovery the muscle wastage may help to return limb function in the majority of the cases (Arnoldy, 2011).

Many researches have been carried out with the aim of reducing the pain secondary to OA changes in the joint and promote cartilage and ligament regeneration. These studies include the use of monoclonal antibody, platelet-rich plasma and stem cells.

Bedinvetmab (Librela®) is a monoclonal antibody (mAb) designed for canine patients. It neutralizes Nerve Growth Factor (NGF), a key player involved in OA in dogs, by preventing from attaching to its receptors (targets) on nerve cells and blocks the transmission of pain signals. Since bedinvetmab is an antibody, it is eliminated by the body similar to endogenous proteins, with minimal involvement of the liver or kidneys. A recent study showed the results of improvement in pain score in 43.5% of dogs treated with Librela® compared with 16.9% in dogs given placebo. The examinations by veterinarians also showed significant improvements in the Librela®-treated group compared to the placebo group. It is a monthly subcutaneous injection and the recommended dose is 0.5-1mg/kg (Schmelz *et al*., 2019).

Platelet- Rich Plasma (PRP) is an autologous concentration of platelets in a small volume of plasma, where the platelet concentration is higher than the normal platelet concentration in a healthy dog´s blood. This therapy is a minimally invasive intervention which could be used to enhance tissue regeneration. PRP is injected into affected stifle joint and contains alpha granules, in which about 70% of their growth factors will be secreted in the first 10 minutes, and almost all the stored amount will be released in the first hour. These growth factors activate some of the cells which are responsible for tissue healing and bone and cartilage regeneration (Glynn *et al.,* 2018). In a recent study, it was shown multiple injections of PRP decreased pain and functional impairment in a canine model of CrCL and meniscal deficiency. In this study, patients received five intra-articular injections of PRP over the first eight weeks following CrCL transection and meniscal release. It was demonstrated these patients had beneficial effects for CrCL repair, including improved range of motion in the stifle, decreased pain, and improved limb function for up to six months (Canapp *et al*., 2016). As PRP is an autologous blood product, there is no risk of immunological reactions and disease transfer, however as with any other injection procedure, there will be some possibility of a local anaesthesia reaction, infection (septic arthritis) and bleeding (Glynn *et al*., 2018)

Several studies using regenerative medicine for ligament injury also demonstrate the success of intra-articular bone marrow aspirate concentrate (BMAC), a steam cell source, as an effective treatment for early partial CrCL rupture. Stem cells works via cell differentiation, modulation of signalling pathways via cytokines to decrease progression of disease and then contribute to the regeneration and replacement of injured and diseased tissue. Dogs with early partial CrCL tears, diagnosed via arthroscopy, that were submitted to IA BMAC have shown CrCL healing on the 90-day via arthroscopy, and improvement was analysed using objective gait analysis (Canapp *et al*., 2016).

Overall, there are options for conservative treatment for CCLD and regenerative medicine has been shown excellent results in regard to ligament and meniscal regeneration. Although, the veterinary surgeon has to be very clear when clarifying the cons and pros to the

owner as the progression of OA will keep going and the expected outcome may not be the same as the one achieved by surgical techniques (Canapp, S.O., 2018).

3.2. SURGICAL MANAGMENT

Different approaches have been described to stabilize the stifle through traditional surgeries. They are classified as intra and extra-articular procedures. The first one has the goal of replacing the CrCL to its anatomical position while the latter reduces the stifle instability through soft tissue transposition or placement of periarticular wires (Putame *et al.,* 2019). The traditional surgeries still have their place among orthopaedics veterinary surgeons, but due to its variable outcomes other techniques have been developed with the aim of improving stifle stability and reduce the OA progression. These surgical techniques are based on tibial osteotomies and promote dynamic stability to the CrCL-deficient stifle. Overall, the tangential articular force, which is responsible for the tibial translation during weight-bearing, is annulated and the consequence is the reduction of the tibial plateau slope (Knebel *et al*., 2020).

Several tibial plateau levelling methods have been proposed over the last ten years, with positive clinical results. However, there is no consensus about which method has the best outcome with regard to progression of the degenerative joint disease and improvement of limb function (Putame *et al.,* 2019).

Regardless of which surgical technique was chosen, arthrotomy or arthroscopy has to be performed in advanced to confirm CrCL rupture and to inspect the menisci for tears or other evidence of trauma. If any meniscal tears are identified, meniscectomy is indicated. Meniscal release can also be performed prophylactically to allow more mobility of the caudal horn, avoiding future injuries due to entrapment, but may increases the OA development. The joint has to be flushed with saline in either technique and the imbrication of the lateral joint capsule is indicated to prevent internal rotation of the tibial plateau, which helps on protecting the medial meniscus and diminishes the caudocranial instability of the patellar tendon. The lateral imbrication is an additional technique that provides extra stability and is applicable in most dogs with moderate to severe OA (Kowaleski *et al.,* 2018; Schulz *et al*. 2019).

If a bilateral CrCL rupture is present, the decision on which to operate first is based on the clinical signs, especially in regard to lameness score. The contralateral stifle should be submitted to surgery ideally when the dog is fully recovered from the first procedure, which is about 6 to 12 weeks after (Kowaleski *et al.,* 2018).

3.2.1. INTRA-ARTICULAR OR INTRACAPSULAR TECHINIQUES

Intra-articular techniques replace the function of the CrCL with an autograft, allograft, xenograft or synthetic prosthesis. Intra-articular techniques have been used for more than fifty years; although, due to their inferior results, the extra-articular sutures and tibial osteotomies took place and have been associated with better outcomes. Despite this, the majority of dogs still developed OA after treatment, most likely because not all these techniques functional replace the biomechanics of the CrCL (Pinna *et al.,* 2020). In humans, the most common method of anterior cruciate ligament reconstruction is the intra-articular placement of the graft (autograft or allograft) at the original attachment of the CrCL, with low rates of OA (Kowaleski *et al*.; 2018). In veterinary medicine, there are some limitations on graft implants as they lose resistance easily, have a longer healing time and the dog's activity is not simply controlled. Prosthetic ligaments can be employed in intra-articular reconstruction and are constituted by braided polyester, with good biomechanical features . The adverse effects of a synthetic material placed on a intra-articular space have to be considered and are listed as synovitis, delayed healing, immune rejection and cartilage degeneration (Pinna *et al.,* 2020). Howsoever, a recent study has supported intra-articular biocompatibility of non-braided absorbable suture tape with less side effects reported (Smith *et al.,* 2019).

Intra-articular techniques is not routinely used in veterinary medicine as the results achieved continue to be inferior to extra-articular techniques. However, there are many studies in progress with respect to prosthetic ligaments, graft selection and processing that if the correlation with the canine stifle biomechanics demonstrates good outcome, they may become more popular used in future (Biskup & Conzemius, 2017).

3.2.2. EXTRACAPSULAR TECHINIQUES

Extracapsular stabilization (ECS) is the most common technique for CCLD that does not have a high learning curve and it is routinely performed in small breed dogs with CCLD. A synthetic or biological material can be used to perform the technique with isometric fixation points at the femur and tibia (Figure 15), creating a passive restriction of the cranial drawer and blocking the internal rotation and hyperextension of the stifle. This procedure relies on fibrous tissue to form along the suture line to provide long-term stability. The two main concerns with this procedure are loosening of the suture and placement of the suture at non-isometric points. Previous studies have reported suture failure more commonly than anticipated (Manley, 2011; Hackett *et al.,* 2021). Nowadays, the osteotomies techniques have shown to have a better outcome on maintaining stifle stability and reducing progression of osteoarthritis (Hackett *et al.,* 2021).

The most common extracapsular techniques are lateral fabellar suture (LFS), fibular head transposition, TightRope® (Arthrex Vet Systems, Naples, Florida, USA) and the tibial corrective osteotomies – Closing Wedge Osteotomy (CWO), Tibial Plateau Levelling Osteotomy (TPLO), Tibial Tuberosity Advancement, Triple Tibial Osteotomy (TTO) and Cora Based Levelling Osteotomy (CBLO). This present study is going to discuss the most common techniques usually performed on recent orthopaedic surgical routine.

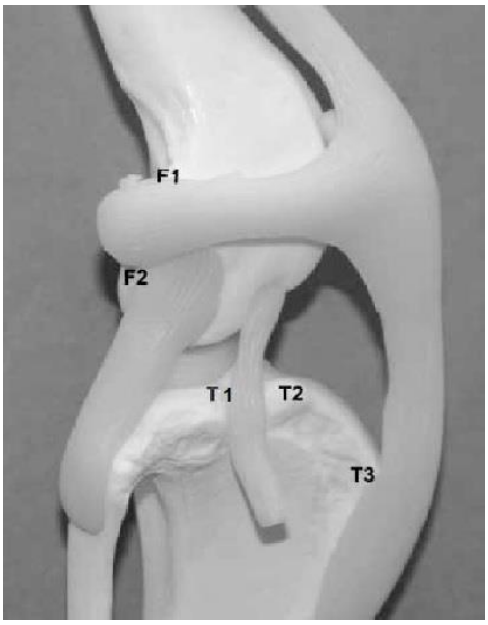


Figure 15 - Stifle Isometric Points.

F1 (proximal) and F2 (distal) poles of the fabella – femur isometric points; T1 and T2 – caudal and cranial to the long digital extensor tendon, respectively; T3 - adjacent to the patella tendon insertion -– tibia isometric points (Hulse *et al*, 2010)

3.2.2.1. LATERAL FABELLAR SUTURE (LFS)

Lateral fabellar suture is a simple procedure that do not require a wide range of technical equipment to be performed (Tonks *et al.,* 2011). It was firstly described by DeAngelis and Lau (1970) and is based on the placement of synthetic sutures around the fabella to the point of insertion of the patella tendon, on the lateral aspect of the stifle. A modification of this technique was done and renamed as lateral fabellotibial suture (Figure 16), being now the most frequent extracapsular technique in use (DeAngelis & Lau, 1970; Cook, 2011; Kowaleski *et al.,* 2018). It consists of passing a non-absorbable suture around the fabella on its proximal aspect and then through a tunnel drilled in the proximal tibial methaphysis (Kowaleski *et al.,* 2018). The two version of the LFS described above build periarticular fibrosis with the aim of

long-term stifle stability, so by the time the suture loses its strength, the fibrosis is formed and keeps the passive stability in the knee joint (Cook, 2011; Kowaleski *et al.,* 2018).

Different materials can be used for these procedures however nylon has shown better outcome when comparing to another suture material as it seems to have less site reaction (DeCamp *et al.,* 2016). The suture material diameter is chosen accordingly to the bodyweight of the dog (Schulz *et al.*, 2019). A crimp clamp system was developed to facilitate knot tightening of the thick nylon that is normally used, reducing the skin reaction previously described with bulky knotted loops (Moores *et al.,* 2006; *Schulz et al.*, 2019).

Nowadays, there are a few variations of the lateral suture procedure, but the most routinely performed involves the use of monofilament nylon placed from proximal to distal around the femoral-fabellar ligament, axial to the fabella, and adjacent to the femur. The tension of the suture around the fabella should be tested by pulling it up and checking if resistance is met by the movement of the fabella. After reassuring the suture is in the right place, it is passed from lateral to medial, deep to the patellar ligament and close to the tibial tuberosity. An isometric point is drilled on the proximal tibial methaphyisis and the suture is guided from medial to lateral, using a hypodermic needle and then tied or crimped on the lateral aspect of the stifle. The knot is tightened with the stifle in slight extension (around 100°) to reduce the tibial translation to its maximum, improving the passive stability given by the suture on the immediate postoperative period (Syrcle, 2021).

Two-hole extracapsular technique can also be carried out to stabilize the stifle. On this case, the proximal hole is drilled distally on the femur metaphysis and used to pass the suture from lateral to medial and then medial to lateral through the distal hole on the proximal tibial metaphysis. This method might result in less tension in the suture, avoiding the suture laxity to occur before the periarticular fibrosis is formed (Isaka *et al.,* 2014; Schulz *et al.*, 2019).

The stifle must be checked for instability before tightening the knot or crimp, through cranial drawer or tibial compression tests. If the stability has not been achieved or ROM is reduced, it means the isometric points were not preciously drilled and should be re-done for a better outcome. Excessively tightened knot or crimp might deal with technique failure, decreased ROM and high intra-articular pressure (Tonks *et al.,* 2011; Syrcle, 2021). After achieving ideal stability, the retinacular fascia has to be closed by imbrication technique, and subcutaneous and skin with routine suture pattern (Kowaleski *et al.,* 2018; Schulz *et al.,* 2019).

Postoperative restrictions for this technique include strict rest for the first 4 weeks, followed by short walks on a leash between 5 and 8 weeks, increasing the duration of the activity slowly. A recheck appointment is booked in between 6 to 8 weeks to assess lameness and joint stability. At 8 weeks the dog is allowed to have 20-minute walk, two to four times a

day. Normal limb function is achieved in between 9 to 16 weeks as the peri-articular fibrosis is strengthened (Kowaleski *et al*.,2018).

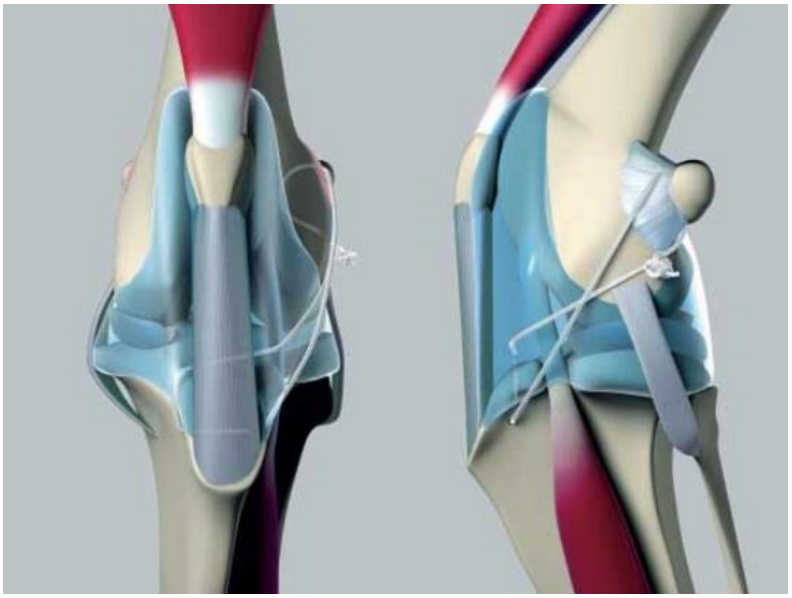


Figure 16 - Lateral fabellotibial suture technique in a craniocaudal and lateral illustration.

(From: Pozzi *et al.*, 2011)

3.2.2.2. TightRope® (TR)

The TightRope® (TR) (TightRope® CrCL, Arthrex Inc., Naples, FL, USA) were first used for the extra-articular treatment of CrCL rupture, through identification of the isometric points (Pinna et al., 2020). It is a modification of the lateral fabellotibial suture with the goal of being minimally invasive, using a synthetic braided tape (FiberTape®, Arthrex Inc., Naples, FL, USA) that goes through a tunnel drilled in the femur and tibia. Two toggle buttons hold the suture in a quasi-isometric position (Cook *et al,* 2010) (Figure 17).

The advantages of this technique are the possibility of anchoring the suture material in one or more isometric point, allowing better stifle stability and normal ROM. The disadvantage is the use of braided suture material that makes the risk of infection higher (DeCamp *et al*. 2016).

As being a extracapsular technique, the TightRope® implant is placed outside the joint capsule but deep to the fascia. A femoral tunnel is drilled just distal to the lateral fabella-femoral condyle junction and it is the starting point. It should traverse the distal femur and exit at the cranial-caudal midpoint of the distal diaphysis of the femur on the medial side immediately caudal to the vastus medialis muscle and at the level of the proximal patella. The groove of the long digital extensor tendon works as a guide for drilling the tibial tunnel, which has to be

angled to exit medially within the footprint of the caudal sartorius insertion. The isometric points have to be preciously drilled, so a guidewire and a cannulated drill bit are used. The TightRope® needle is inserted through the tibial tunnel in a medial to lateral direction and through the femoral tunnel in a lateral to medial direction. Once the toggle button has exited the femoral tunnel, the button is flipped by pulling the white suture in a slight upward direction and by pulling back on the FiberTape® suture strands laterally. The button over the FiberTape® suture strands is advanced and seated firmly and completely against the medial tibial bone. Drawer, internal rotation, and range of motion (ROM) of the stifle are checked and the knot is tightened with 5 throws (Trumpatori, 2020). Postoperative recommendations are exactly the same as described above for LFS.

This technique is a feasible and effective, especially in small breed dogs, giving the low rates of postoperative complications. It also assists strength and stiffness, revealing the TR to be secure in graft fixation and for maintaining stifle stability. Studies have been shown long-term comparable OA progression and limb function return between the TR and other popular techniques. Additional research is encouraged to prove feasibility in medium-large dogs as the positive outcomes has been mainly reported in dogs under 15 kilograms (Pinna *et al.,* 2020).

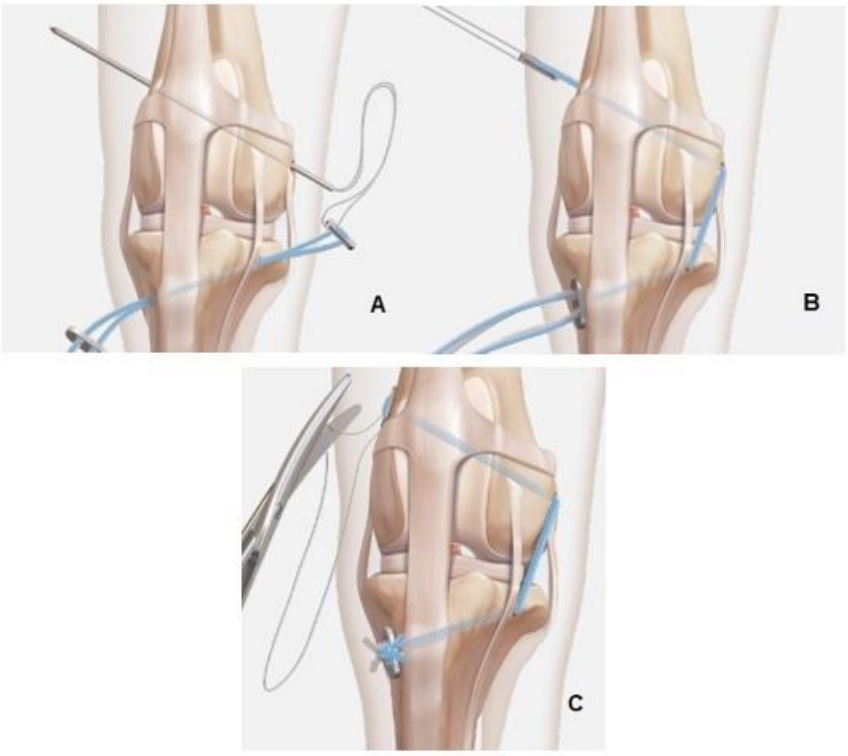


Figure 17 - Illustrations of TightRope® technique.

A. TightRope® needle is placed towards the femoral tunnel from lateral to medial; **B.** Suture is pulled in a slight upward direction and the FiberTape® suture strands are pulled back laterally; **C.** Craniocaudal view of the stifle after final assessment (From: Trumpatori, 2020)

3.2.2.3. TIBIAL CORRECTIVE OSTEOTOMIES

The introduction of tibial osteotomy procedures was aimed at improving stability and decreasing recovery time (Theyse, 2014). The aim is to reduce the tibial plateau slope, through the annulation of the tangential articular force generated during weight-bearing that allows the tibia to translate cranially. Variations of the tibial plateau osteotomies have been proposed in the last ten years, but none of them have been clearly recognized as the most effective surgical option (Putame *et al.,* 2019). The first change in managing the cranial tibial instability was the introduction of the cranial tibial wedge ostectomy (CWO) and the tibial plateau levelling osteotomy (TPLO) (Slocum *et al.,* 1984; Slocum *et al.,* 1993). Many more procedures based on the same biomechanics result was then developed and include tibial tuberosity advancement (TTA), Triple Tibial Osteotomy (TTO), Cora Based Levelling Osteotomy (CBLO) and so many more variations of these techniques have been studied to improve the outcome, especially regarding to OA development and meniscal tears.

3.2.2.3.1. CLOSING WEDGE OSTECTOMY (CWO)

Closing wedge ostectomy (CWO) of the proximal tibia was introduced in 1984 as a means of reducing the tibial plateau angle (TPA) and so the cranial translation of the tibia (Slocum *et al.,* 1984). This technique is performed through two osteotomies in the proximal third of the tibia in a wedge shape that is then removed. The bone gap is fixed with plate and screws, achieving a good apposition of the osteotomised site (Dejardin, 2003) (Figure 18). Beforehand, a preoperative plan is made to determine the angle of the ostectomy and it consists of the preoperative TPA minus 5° as the CWO postoperative TPA should be in between 4° and 6° to achieve a positive outcome (Dejardin, 2003).

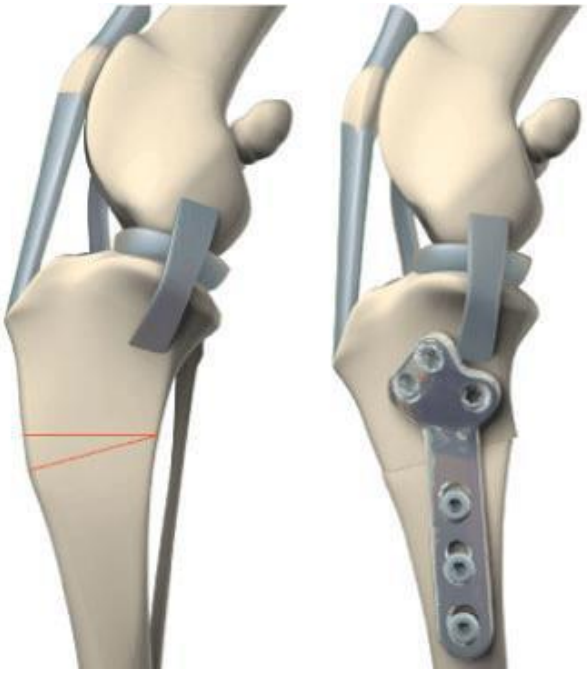


Figure 18 - Illustration of CWO surgical technique.

Preoperative plan with the ideal angle of the wedge to be removed (Left). Ostectomy is performed and fixed with plate and screws (Right) (From: Rata Veterinary Surgery, 2021)

Preoperative TPA is important for surgical plan in the majority of tibial osteotomies techniques. It is determined with a mediolateral tibial radiograph consisting of a 90° stifle and hock flexion, with the greater trochanter, lateral femoral condyle and lateral malleolus in direct contact with the table. The femoral condyles should exactly overlap each other (Christ *et al.,* 2018). The radiographs should ideally be measured using a computer-assisted planning software (Fox *et al.,* 2020). A line along the tibial mechanical axis has to be drawn from the intercondylar eminence of the tibia to the centre of the talus bone. A second line is drawn in a parallel direction to the tibial plateau, connecting the cranial and caudal aspect of the medial tibial plateau. The TPA is determined by a perpendicular bisect of the tibial axis and the formed angle between that line and the tibial plateau (Fox *et al.,* 2020) (Figure 19).

Figure 19 - Measurement of a TPA.

a. first line connects the cranial and caudal extents of the tibial plateau (tibial plateau slope);.**b.** second line goes from the centre of the intercondylar eminences to the centre of the talus; **c.** third line is perpendicular to the tibial long axis at intersection of line a and b. The TPA is the angle formed in between a and c (Kim *et al,* 2015).

Proposed limitations of CWO include distal displacement of the patella and resulting stifle hyperextension. Dogs treated with CWO display a hyperextended gait characterized by an increased velocity in stifle extension during the middle to end of the swing phase without changes during the stance phase. This hyperextension has been attributed to compensatory mechanisms seeking to restore contact patterns within the femoropatellar joint. Although the relationship between the length of the tibial cranial wedge and the degree of resulting stifle hyperextension has not been elucidated, smaller tibial cranial wedge has intuitively been proposed to limit compensatory stifle hyperextension (Christ *et al.,* 2018). Other complications reported include medial meniscal tears, tibial fractures, and implant failure, with surgical revision required in 12.3% (Campbell *et al.,* 2016).

The osteotomy generally takes about 6 to 8 weeks to heal (Dejardin, 2003; Christ *et al.,* 2018). Rest is strongly recommended during the first 4 weeks, with gradual increase in exercise in between 5 to 8 weeks. Rehabilitation, including physiotherapy and hydrotherapy, is advised as soon as the surgical wound is healed in order to strengthen the muscle coverage and improve weight-bearing. (Caldwell, 2015). An important characteristic to bear in mind when performing any tibial corrective osteotomy is the cranial drawer sign will remain positive

after surgery , but the tibial compression test keeps positive and may become negative around 90 days later when the osteotomy site is completely healed.(Slocum & Devine, 1984).

Studies have been shown this technique is better recommended for dogs under 15 kg, as they recover the limb function very quick with minor complications, rather than medium-to-large dogs that have higher risk of major complications and poor outcome (Campbell *et al.,* 2016; Christ *et al.,* 2018).

3.2.2.3.2. TIBIAL PLATEAU LEVELLING OSTEOTOMY

Slocum & Slocum (1993) firstly described the tibial plateau levelling osteotomy (TPLO) technique that consists on the reduction of the TPA, preventing the cranial tibial translation through the limitation of the shear force produced when the dog bears weight (Figure 20). This type of osteotomy also relies on dynamic stifle stability and it is very well recognised nowadays (Shimada *et al*., 2020).

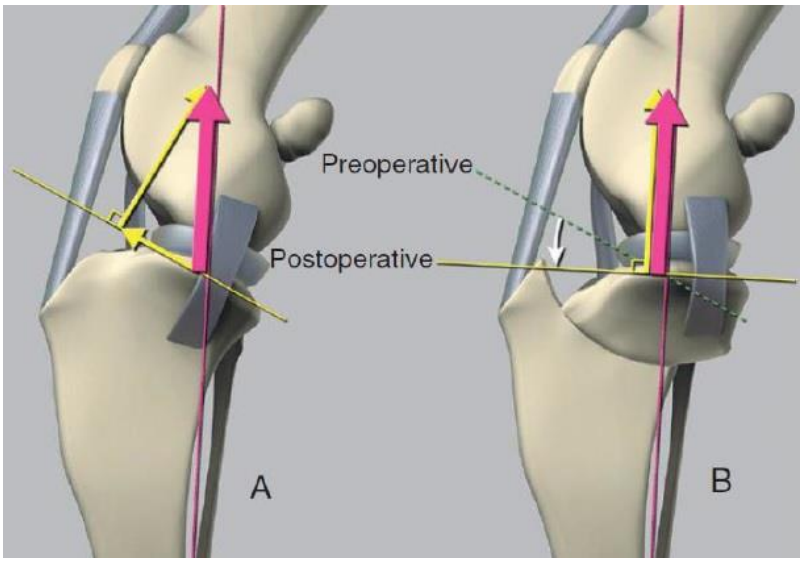


Figure 20 - TPLO Theory by Slocum.

A. CCLD – joint reaction force is parallel to tibia longitudinal axis (pink arrow) and it is resolved into a cranial shear force (cranial yellow arrow) and a compressive force (proximal yellow arrow, just perpendicular to the TP). **B.** TPLO – joint reaction force (pink arrow) is perpendicular to the TP (compressive force – yellow arrow) and so the cranial tibial thrust is eliminated (Kim *et al*., 2008.)

The goal of TPLO is to neutralize cranial tibial thrust and prevent cranial displacement of the tibia in the stance phase. A radial osteotomy is performed on the proximal aspect of the tibia and the bone fragment is rotated to achieve a TPA of 5°, a TPLO plate and screws is placed to fix the osteotomy (Figure 21) (Kowaleski *et al.,* 2018). Locking screws have been used in TPLO plates, showing better results than the conventional screws in facilitating the

bone fragment rotation and reduction as well as keeping its function during the healing phase (McGregor *et al.,* 2019).

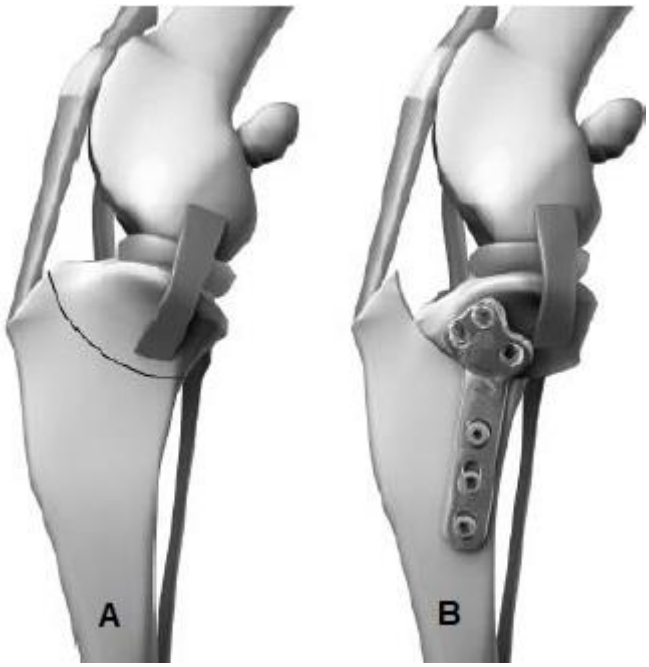


Figure 21 - Illustration of proximal tibia radial osteotomy (A). Postoperative result with TPLO plate and screws (B)

(Kim *et al.,* 2008)

The osteotomy rotation is based on the preoperative TPA and should be centred proximally in the tibia long axis, in between the intercondylar tubercles. According to studies that have been done in the last ten years, a positive clinical outcome has been reported with TPA ranging from 0° to 14°. However, in a day-to-day practice, the majority of the surgeons plan the osteotomy rotation to achieve a postoperative TPA of 5° as the rotation within several degree of this is considered critical to successful outcome. Over-rotation of the TPA may lead to caudal cruciate ligament injury as it is kept under biomechanical stress. Additionally, tibial tuberosity fracture may happen if the osteotomy is not properly centred with the tibia long axis (Nanda & Hans, 2019).

Currently, TPLO procedure has been improved with the development of computer software which allows a better surgical planning with less complications through measuring the ideal radial saw blade with a template and drawing the reference points to best centre the osteotomy on the tibial intercondylar eminence (Nanda & Hans, 2019)

Surgical site infections for patients undergoing TPLO have a reported rate of 2.5 to 25.9%. The factors previously reported to increase the risk of surgical site infections include arthrotomy versus arthroscopy, and prolonged anaesthetic, surgical and postoperative

hospitalization periods (Peress *et al.,* 2021). Micromotion at the osteotomy site, especially in large and giant breeds dogs with non-locking bone plates, has been strongly associated with risk of infection even without significant loss of reduction on the radiographs. Locking plates have biomechanical stability and best preserve the bone biology so they are highly recommended for reducing the rates of surgical site infection in this subpopulation of dogs (Nanda & Hans, 2019).

Tibial tuberosity fracture has been one of the most common major complications reported in the literature (Peress *et al.,* 2021) It is reported to occur between 0.4 – 4.8% of cases and numerous risk factors have been listed for increasing the risk of tibial tuberosity fracture. Anatomical particularities (thin, tall and narrow tibial tuberosity), insertion of more than one anti-rotational pins below the patella tendon insertion; bilateral TPLO, obesity and loss of TPA rotation on the follow up are on the top of this list (Simcock, 2019). One study revealed that 2.4% of dogs that underwent single TPLO suffered tibial tuberosity fractures compared with 40% of those that underwent bilateral TPLO (Peress *et al.,* 2021).

The risk of meniscal injuries can be high (0.7–13%) on the postoperative and it is influenced by a misdiagnosed at the time of the presentation (Knebel *et al.,* 2020). The persistent lameness on the postoperative can be due to the failure on diagnosing concurrent meniscal tears or even inadequate removal of the injured meniscal tissue. Despite the arthroscopy being the gold standard for intraarticular assessment, there are a few limitations as described previously on this study, especially in regard to anatomical constraints for meniscal inspection. For this reason, MRI has been shown superiority on specificity (96%) and sensitivity (90%) to asses medial meniscal injuries (Knebel *et al.,* 2020), but it is still a limited approach in veterinary medicine due to cost.

An excessive internal rotation of the tibia during the gait phase, known as "*Pivot Shift"* can happen after TPLO and could be related with tibial torsion, angular deformities and excessive internal rotation of the tibia. A complete CrCL rupture and meniscal injury were identified as a risk factor for its occurrence (Gatineau *et al.,* 2011).

The progression of OA does not stop regardless the technique was chosen and it significantly affects the long-term outcome as chronic stifle pain is present (Nanda & Hans, 2019). A recent study compared the long term (>3 years) progression of OA following both TPLO and TTA, through the correlation of OA radiographs signs and clinical presentation, and TTA showed more significant progression than TPLO. Dogs that were submitted to TPLO surgery had less stifle pain and better mobility by owners' assessment (Moore *et al.,* 2020).

Early hydrotherapy and intensive physiotherapy is recommended as soon as the wound is healed as they improve stifle ROM and prevent muscle wastage by building mass and strength (Monk *et al.,* 2006; Griffon, 2016).

TPLO is a technically challenging procedure that requires a large learning curve and the effectiveness relies on following the guidelines correctly and being aware of possible complication and associated risk factors. The majority of complications that result in implant failure or fracture are related to the surgeon experience (Simcock, 2019). The clinical evidences have evolved the TPLO as a standard of care for CCLD, leading to accommodate any size of patient with this procedure with quick return to limb function. That said, patient individualities, surgeon experience and cost have to be considered before deciding for this type of surgery (Nanda & Hans, 2019).

3.2.2.3.3. TIBIAL TUBEROSITY ADVANCEMENT

Tibial tuberosity advancement (TTA) was first described by Maquet (1976) and his theory said an increase on the quadriceps efficiency would decrease the retropatellar pressure, reducing the femoropatellar joint pain in humans. Several biomechanics studies in humans demonstrated the variations of tibial plateau slope, knee flexion angle and axial loading increase the translation knee joint instability (Boudrieau, 2017). The TTA surgical technique was developed by Tepic and Montavon (2002) by suggesting an alternative stifle model where the dynamical tibiofemoral shear forces depends on the patellar tendon angle (PTA) (Figure 22). The PTA is the angle formed in between the tibial plateau and the patellar tendon and TTA surgery aims to achieve a PTA at 90° where there is neither cranial nor caudal tibiofemoral shear force present (“crossover point”). By modifying the geometry of the proximal tibia, the PTA is maintained under 90° while weight-bearing and the cranial tibiofemoral shear force is neutralised (Muir, 2018).

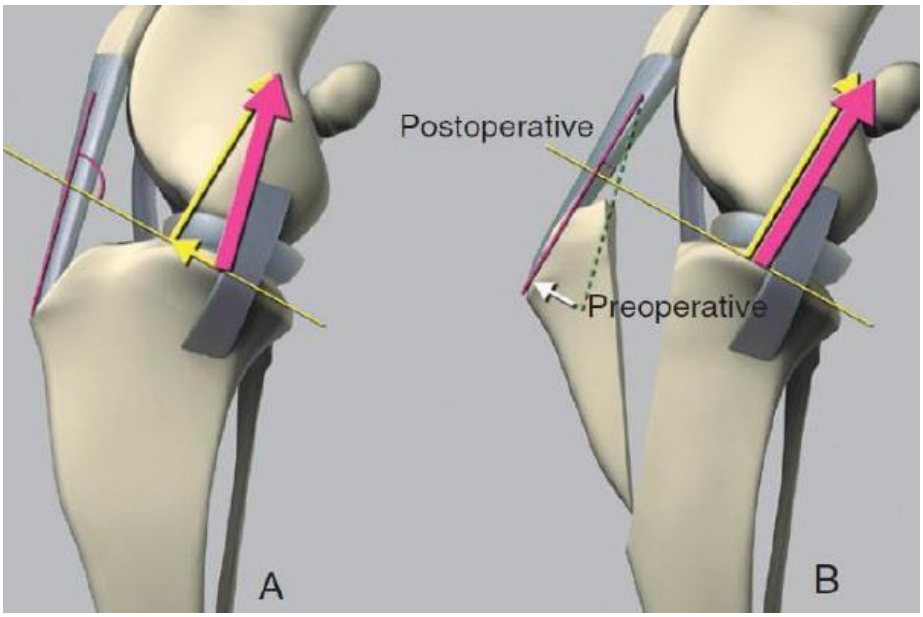


Figure 22 – Illustration of Tepic and Montavan model.

A. CrCL rupture stifle – the joint reaction force (pink arrow) is divided in two components (yellow arrows): one is cranially, parallel to the tibial plateau and the other is perpendicular to the tibial plateau. **B.** TTA principle – the joint reaction force (pink arrow) is located in a perpendicular direction to the tibial plateau and, as a consequence, the elimination of the cranial tibial thrust occurs (From: Kim *et al.,* 2008.)

The goal of TTA is neutralizing the cranial tibiofemoral shear force by realigning the PTA to 90°, achieving dynamic stabilization of the stifle by advancing the tibial thrust (TT) (Jin *et al*., 2018). To achieve this PTA, the tibial tuberosity is osteotomized and advanced cranially by a measured amount based upon the preoperative planning. The surgical planning is based on preoperative radiographs. The stifle is kept in extension of 135° while the tarsocrural joint is kept in 145° and the femoral condyles must be superimposed on one another (Brown *et al.,* 2015). There are several preoperative methods described to measure the TT translation distance to achieve a PTA of 90° and they are done at the level of the patellar tendon insertion point. A cage size is matched with the distance found and it is inserted into the osteotomy, altering the PTA through the desired advancement (Meeson *et al.,* 2018).

Surgical planning for TTA is of great importance and is based on the preoperative measurements to find an ideal cage size, avoiding over or under advancement of the TT. The ideal measurements depends on the sagittal patellar ligament angle formed in between the tibial plateau slope and the patellar ligament and it is technique-dependent. There are two techniques that are commonly used nowadays, the tibial plateau slope and the common tangent technique. The first one is simplest and relies on the re-orientation of the patellar ligament perpendicularly to the tibial plateau slope, drawing a line between the cranial and caudal aspect of the medial tibial plateau (Brown *et al.,* 2015). The second, takes into consideration the anatomic structures between the tibial plateau and femoral condyles. A circle is drawn on the medial femoral condyle and the medial tibial plateau articulation, a line joins both centre of the circumferences and the common tangent is the line that is perpendicular to them and then perpendicular to the patellar ligament as well to achieve the desirable PTA of 90° (Figure 23). None of these two techniques has been shown superiority, however, the stifle biomechanics understanding is warranted using both planning techniques preoperatively (Mayo, 2018).

Figure 23 - Common tangent technique.

Two circles is draw around the articulating surface of the distal femur and proximal tibia. Next, a line is drawn connecting the centre of both circles. Another line must be drawn perpendicular to the previous one and tangential to the circles (common tangent). To determine the advancement cage size, a line must be drawn from the distal pole of the patella in a distal perpendicularly direction to the common tangent line. Finally, the advancement distance is measured between the TT and this last drawn line (red line) (Mayo, 2018).

Tibial tuberosity advancement was initially developed by using a tension band plate with angle stable forks to secure the osteotomized tibial crest and a titanium cage (Kyon, Zurich, Switzerland) was placed on the most proximal aspect of the tibia, fixating the TT osteotomy to the tibial diaphysis (Figure 24) (Lafaver *et al*., 2007). Alternative forkless plates have since become available with two or three cortical screws in the TT and have demonstrated similar complications rates when comparing to fork-based design (Edwards *et al,* 2016). Forkless plates allow contouring to the tibial tuberosity, require fewer drill holes in the TT, the screws can be angled and individually chosen for better fit, and require a reduced selection of implants and orthopaedic equipment (Figure 25) (Edwards *et al*, 2016; Matchwick *et al,* 2021).

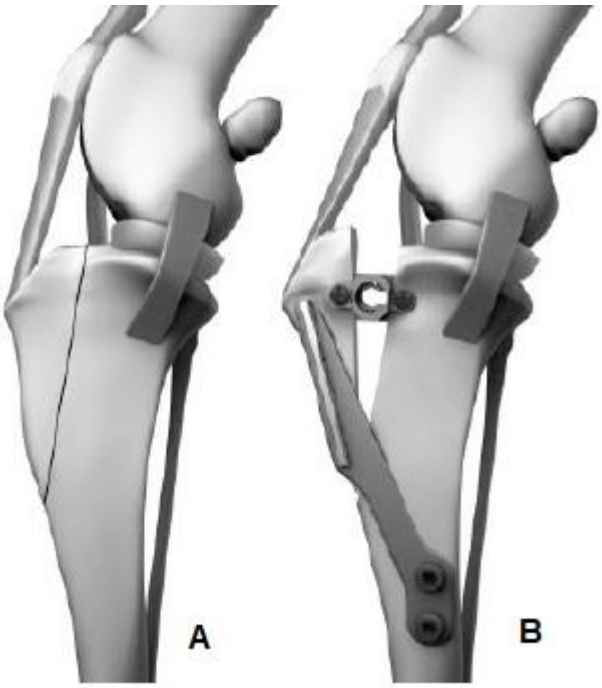


Figure 24 – Illustration of TTA surgical technique with fork-based plate

(Adapted from: Kim *et al.*, 2008)

Figure 25 - Illustration of TTA fixed with forkless plate

(From: SecureSurgical®, 2021)

The traditional TTA technique and its “forkless” plate design still has several potential disadvantages, such as displacement of the tibial tuberosity fragment and fracture, medial or lateral translation of the tibial crest predisposing to patellar luxation and imperfect plate contouring. This technique is slightly more technically challenging than the modified Maquet technique (MMT) and does not eliminate standard complications such as postoperative swelling and bruising, meniscal injuries, surgical site infections, implant failure, tibial fracture, and persistent stifle instability (Retallack & Daye, 2018).

A MMT was firstly described in humans and adapted for using in veterinary medicine. A drill hole, termed the Maquet hole (Maquet, 1976), is preplaced on the distal aspect of the tibial tuberosity where the osteotomy is supposed to end. The osteotomy is done in the frontal plane and left incomplete, keeping the distal attachment of the TT on the tibial diaphysis. A bone cage and screws are placed to advance and hold the tibial crest in a cranial position. A bone bridge can be secured through a figure-of-eight wire placed in the distal portion of the TT to the tibial diaphysis (Figure 26). The Maquet hole has the purpose of preventing fissure and extension of the osteotomy after this predetermined point. MMT was developed to reduce the number of implants, and preserve soft tissues and associated vascularity to encourage biologic repair of the osteotomy. The MMT has become less frequently used as alternative techniques have been developed with less complication rates and predictable outcomes. Potential concerns with this technique is relate osteotomy stabilization without bone plate, and risk of fracture of the distal tibial crest, or tibia diaphysis if osteotomy propagation occurs. (Retallack & Daye, 2018)

Figure 26 - Postoperative radiograph of a MMT

(Etchepareborde *et al., 2011*)

Currently, other variations of TTA have been described and used. A TTA Rapid technique-based on the Maquet technique was developed in 2014 and have been another option for CCLD in dogs. On this technique, the distal cortex of the tibial tuberosity remains intact, avoiding the distractive pull force of the quadriceps muscle (Figure 27) (Samoy *et al.,* 2015). The main goal of the TTA-rapid is to maintain the dynamic stabilization of the stifle as provided by the traditional TTA technique, but with no necessity of bone plate placement. Furthermore, since the proximodistal height of the cage is larger than that of a classical TTA cage, there is more room for the application of bone screws, resulting in a firm fixation of the implant. The direction of the bone screws is proximomedial-distolateral, which is the same direction as the fork in a classical TTA (Samoy *et al.,* 2015). The combination of the intact distal cortex, the presence of multiple proximomedial-distolateral directed screws, and a higher cage make the use of a plate redundant. There is also no need for a tension band or pin as long as there is no full avulsion of the tibial crest, which simplifies the surgical technique. The TTA-rapid is another alternative treatment for CrCL rupture with good outcomes reported and apparently low rate of complication. Therefore, the Maquet hole causes a slightly weakness on the tibial shaft which may predispose to tibial fractures, being the main technique disadvantage demonstrated by *in vitro* and *in vivo* biomechanics studies (Butterworth & Kydd, 2017; Dyall & Schmökel, 2017).

Figure 27 - Illustration of TTA-rapid technique.

Note the cage and plate with an open mesh construction. This combination enables high stability and faster bone growth. (From: Advanced Veterinary Care Group, 2021).

Meniscal tear is one of the most common complications of TTA surgery and has a significant incidence report of 27% (Christopher *et al.,* 2013); followed by TT fractures (4.5%); patella luxation, incisional trauma and infection (3.2%); implant failure (2%) and less commonly, tibial diaphysis fracture (<0.5%)(Hirshenson *et al.,* 2012; Wolf *et al.,* 2012; Calvo *et al.,* 2014, Griffon, 2016). Predisposing factors to complications include breed, poor implant position, and narrow distal osteotomy width. The impact of body weight remains controversial as conflicting results have been published. Simultaneous bilateral TTA procedures and concurrent correction of patellar luxation via tibial tuberosity transposition advancement (TTTA) are other factors that could be expected to increase the risk of postoperative complication (Costa *et al.,* 2017)

The outcomes regarding TTA procedures relies on a proper advancement of the TT. Over advancement may lead to patella luxation, stress overload on the caudal cruciate ligament as well as increasing on the joint forces in the caudal aspect of the stifle. Under advancement leads to poor reduction of the TT and the stifle instability persists as the final PTA is greater than 90°. This fact induces the tibia to continue dislocating cranially during weight-bearing which increases the shear force on the medial meniscal caudal horn, potentially

causing it to tear. An erroneous cage size has the potential to lead with chronic and misdiagnosed subsequent meniscal tears (Mayo, 2018; Matchwick *et al.,* 2021).

Overall, TTA has shown to have a good outcome in regard of return to normal function and stifle stability. When performed by an experienced surgeon, complications are rare and very occasionally surgeon revision is necessary. Despite of that, the risk of meniscal tears on the postoperative and development of OA is still a subject of further studies.

II. OBJECTIVES

The objective of this study was to assess the meniscal tears prevalence regarding breed, body weight, gender, age, preoperative and postoperative PTA, type of tears and outcome with reference to lameness of those dogs submitted to tibial tuberosity advancement as a surgical technique. All surgical procedures were performed by one vet at Village Vets, Ireland.

III. MATERIAL AND METHODS

1. DATA COLLECTION AND INCLUSION CRITERIA

Medical records of 72 dogs that went through a standard TTA as a surgical option for CrCL rupture at Village Vets, performed by Dr. Jackie Layng, between September 2019 and February 2021 with more or a at least 4 weeks follow-up were analysed. A dog was included in the study when previously diagnosed with CrCL by the responsible clinician, through a complete orthopaedic examination and radiographs under sedation or general anaesthesia. The medical record must have included details of signalment, surgical procedure, intra and postoperative complications and detailed follow-up findings. The exclusion criteria were incomplete medical records or a history of previous stifle surgery.

2. SIGNALMENT

For each individual TTA, data collection included body weight, gender, age, breed, preoperative and post operative PTA, procedure date and cranial cruciate ligament status (complete, partial, stretched or gone) found via arthrotomy. The meniscus status was determined from the surgical reports relating to meniscal pathology (none or present), location (medial or lateral), area affected (caudal horn, mid-body or cranial horn) and type of tear (folded caudal horn, longitudinal tears, transverse tears and "bucket-handle" tears).

3. CLINICAL ASSESSEMENT AND DIAGNOSIS

All the patients included on this study that underwent to TTA surgery were previously assessed by the clinician. Grade of lameness (0-4), signs of stifle effusion, periarticular fibrosis (medial buttress), ROM on flexion and extension of the stifle, pain score (CMPS – SF), cranial drawer and tibial thrust compression test were firstly checked before sedation for radiographs. The sedation protocol was butorphanol 0.3mg/kg and medetomidine 5-15ug/kg on the majority of the dogs, except from those ones who present with a higher pain score, then buprenorphine 0.02mg/kg was the choice rather than butorphanol. The dogs were rechecked again under sedation, especially in regard to stifle instability. All the radiographs taken under sedation were sent to the orthopaedic surgeon before surgery (Figure 28). The radiographs findings, like joint effusion and osteophytosis, were extremely important as being the main source of diagnostic imaging and the results shown on that, together with the clinical examination findings, were crucial on rather recommending surgery or not.

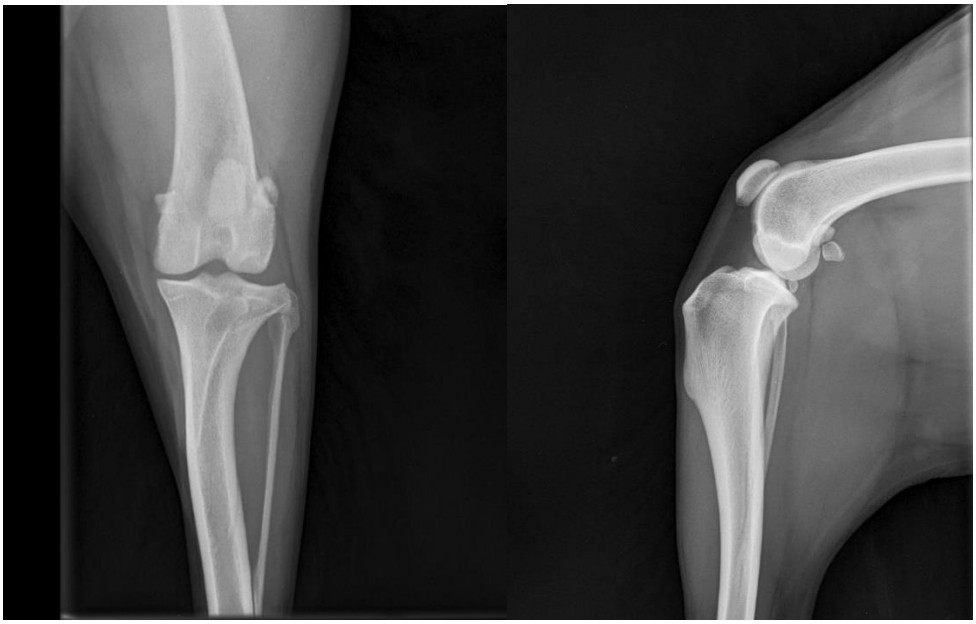


Figure 28 - Preoperative radiographs taken under sedation.

Left – Cranio-caudal view of a 9 years old Border Collie stifle. *Right* – Medial-lateral view, showing mild stifle effusion and no evident signs of OA, which might suggests partial CrCL rupture.

4. RADIOGRAPHIC ASSESMENT

On the day of the surgery the radiographs were re-taken on mediolateral and caudocranial views to assure ideal positioning and the stifle were positioned in a standing angle (135° of

flexion) for TTA planning. The femur condyles should be overlapped on the mediolateral view, as well as the tarsus included on the radiograph for measurement of the preoperative PTA. Both stifles were always included for comparison. Radiographs findings were recorded, including OA signs and stifle effusion. The TPA was not measured as the surgeon in charge did not perform TPLO or any other corrective osteotomy that might be better to medium-large breed dogs with high TPAs, so all dogs over 15kg underwent to TTA surgery on this study.

Postoperative radiographs were also assessed on mediolateral and craniocaudal views to check postoperative PTA, positioning of the surgical implants (plate, screws and cage) and osteotomy reduction on the distal aspect of the tibial thrust.

After a minimum of 4 weeks postoperative, the clinician rechecked the dog, especially for grade of lameness, pain score, presence of stifle effusion, ROM and crepitus on flexion and extension of the stifle that could signalize subsequent meniscal tears and progression of OA. Radiographs were taken at this stage to asses osteotomy healing, progression of OA and possible complications in case lameness was still present (Figure 29). The medical progression and radiographs were sent to the orthopaedic surgeon for analysis and advice.

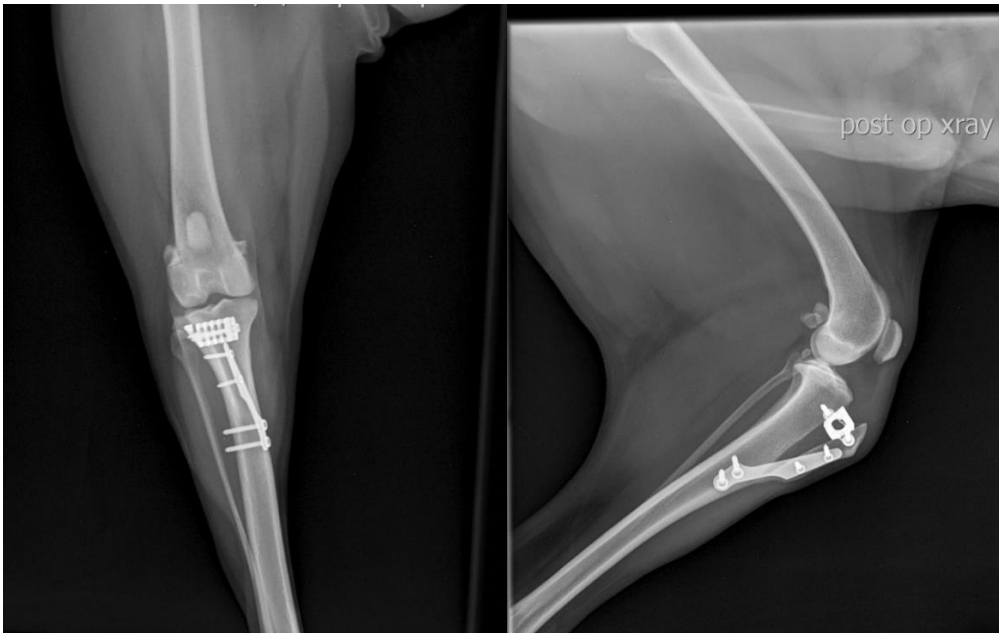


Figure 29 - Four-weeks postoperative radiographs

Left – Cranio-caudal view. *Right* – Lateral-medial view. All the implants were in place, there were no signs of implant failure, tibial thrust fracture or osteomyelitis. Bone healing was progressing but as it was 4 weeks postoperative radiographies, bone callus formation was not visualised yet.

5. SURGICAL MANAGEMENT

5.1. PREOPERATIVE ASSESMENT AND ANAESTHESIC PROTOCOLS

Prior to surgery, all patients were assessed individually to adequate the best anaesthetic protocol. In the majority of the cases, the premedication was performed with acepromazine (0.025mg/kg) and methadone (0.5mg/kg) or medetomidine (5-15µg/kg) and methadone (0.5mg/kg), by IV or IM injection. Meloxicam (0,2mg/Kg/SC) or Robenacoxib (2mg/kg/SC) were administered at premedication. Induction was performed with Propofol (1-4mg/kg/IV) and maintained with Isoflurane. Cefuroxime (30mg/kg/IV) was administered just before the surgery starts and every 90 minutes during surgery. The dogs were kept on fluid therapy (Hartmann's solution) in a maintenance rate (5ml/kg/h) during surgery and on the immediate postoperative. Paracetamol (10mg/kg/IV) was given intraoperative over 15 minutes for a multimodal analgesia.

5.2. SURGICAL PROCEDURE

All the patients that underwent to TTA surgery were previously prepared with the affected limb suspended and a wide limb trichotomy were performed from hip to tarsus, procedure gloves and elastic cohesive bandage were applied on the distal aspect of the limb. The surgical area was scrubbed with Hibiscrub® and final preparation spray (Hydrex®) was applied.

Arthrotomy was first performed with dog positioned on dorsal recumbency. A craniomedial incision was performed and a blunt dissection was used to separate the edges of the medial retinaculum from the underlying exposed joint capsule. The joint capsule was incised and stifle retractors were carefully inserted into the joint proximo-distally and gelpi retractors were placed medio-laterally to aid exposure. CrCL was checked for integrity and torn and damaged parts were resected. Lateral and medial meniscus were probed to check integrity and damage. All menisci noted as torn were preferable treated with hemimeniscectomy or partial meniscectomy accordingly to the extension of the lesion. Meniscal release was performed when it was already loose or frayed in the joint. The joint was flushed with Hartmann´s fluid and closed with 3/0 Polydioxanone (PDO), simple continuous suture pattern.

For the TTA surgery, the dog was positioned on a lateral recumbency with the operated limb placed flat on the surgical table. The cranial tibial muscle was separated of its attachments from the tibial crest and the appropriated plate size was checked by placing the plate over the tibial crest and ensuring the first hole is 5mm caudal to the tip of tibial tuberosity. The plate was gentle bended to fit best the shape of the tibia. The plate holes were drilled using a drill guide. An osteotomy was performed monocortical proximally and bicortical distally. After placing the proximal screws, the osteotomy was completed by making the cut bicortical

proximally. The osteotomy was advanced and the ideal cage size was fitted accordingly to the preoperative radiographs planning. The caudal ear hole of the cage was drilled and the screw was placed. A bone forceps was used to hold the end of the tibial tuberosity to the tibial shaft. The most distal screw was placed first, followed by the proximal one. The second cage screw was then placed on the cranial ear of the cage (Figure 30). The surgical site was flushed with Hartmann´s. The superficial fascia and the subcutaneous were sutured with 3/0 PDO, continuous suture and intradermal sutures were performed with 4/0 polyglycolic acid (PGP).

Figure 30 - Trans operative image of a TTA surgery after placing a standard “forkless” titanium plate and cage.

6. POSTOPERATIVE

Radiographs were taken on the immediate postoperative to reassure the PTA of 90° was achieved and to check if the surgical implants were satisfactorily in place. The dogs were kept

for at least 12 hours in the clinic. Methadone (0.3mg/kg/IV) was given every 6 hours, and a last dose of 0.5mg/kg/SC was given before going home.

Oral medication was prescribed to go home and included NSAID – Meloxicam 0.05-0.1mg/kg or Robenacoxib 2mg/kg, once daily for 15 to 21 days; tramadol (2-5mg/kg), twice to three times daily, for 7 days and paracetamol (10mg/kg), twice to three times daily, for 7 days. Gabapentin (15mg/kg, once to twice a day) was also prescribed, as part of a multimodal analgesia protocol, for patients which were already presented with moderate to severe OA. The discharge was given on the following morning, after the dog being assessed by the vet regarding to pain score, and the nurse in charge went through all the post operative care at home that included wound care, use of Elizabethan collar and restrictive exercise. On the first seven days after surgery, strict rest or even cage rest was strongly recommended, followed by five to ten minutes of lead exercise, twice daily, for the next two weeks and then the exercise should be increased to ten to fifteen minutes, twice daily, but the dog should still be kept on a lead. Hydrotherapy and physiotherapy were always indicated as soon as the surgical wound was healed, but dependent on owner's discretion.

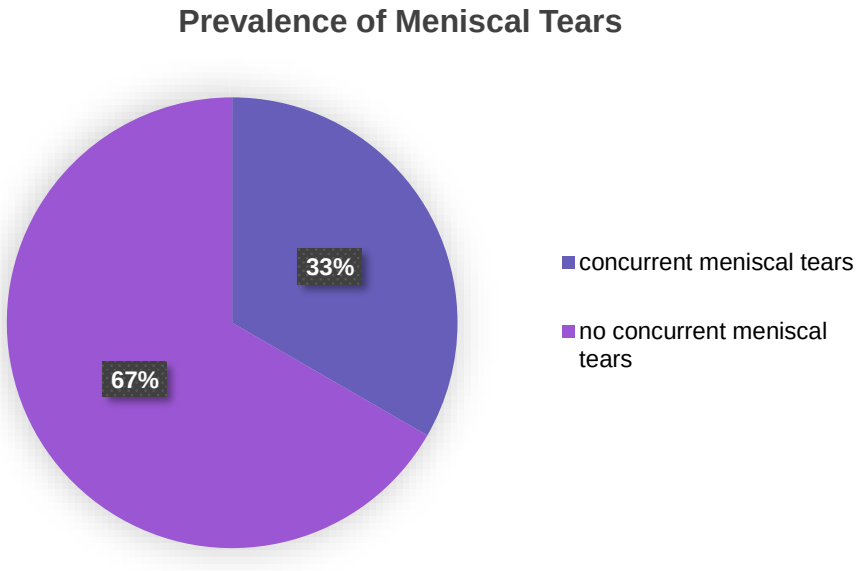
All dogs were checked by the clinician on the third and on the tenth day after surgery with respect to wound healing. Radiographic examination was booked four weeks following surgery to evaluate the bone healing process at the osteotomy site and the OA progression. The radiographies taken immediately after surgery were used for comparison. In accordance with bone healing status, progression of OA and implants integrity, the exercise activity was readapted and the veterinary surgeon explained to the owners if further radiographs were necessary or not. If the radiographs had shown no concerns, a gradual increase on exercise was suggested during the following 4 weeks with the goal of returning to normal limb function by that time.

7. STATISTIC ANALYSIS

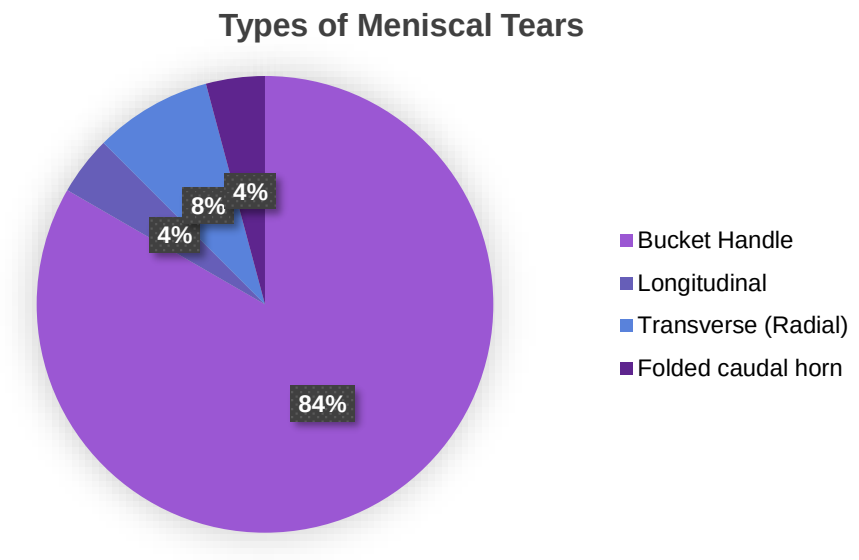
This is a retrospective study based on 72 dogs with CrCL rupture that underwent to TTA surgery. Meniscal tears on the trans operative were recorded to evaluate outcome after surgery. The statistical analyses of this study were done using Microsoft Office Excel 2010 and submitted to descriptive statistics regarding meniscal pathology (none or present), type of tear (folded caudal horn, longitudinal tears, transverse/radial tears and "bucket-handle" tears) and its prevalence with respect to breed, gender, age, body weight, preoperative and postoperative PTA. The outcome was analysed by the presence of lameness in patients with concurrent or no concurrent meniscal tears.

III. RESULTS

In the studied population (N=72) that underwent to TTA surgery performed by Dr. Jackie Layng, between September 2019 and February 2021, 33% of the dogs were diagnosed with meniscal tears (N=24, Graphic 6). From those, 84% was “bucket handle” tears, 8% transverse tears, 4% longitudinal tears and the other 4% remaining was folded caudal horn tears (Graphic 7). One-third of the dogs in this study had previously meniscal injury diagnosed by arthrotomy just before performing the TTA.

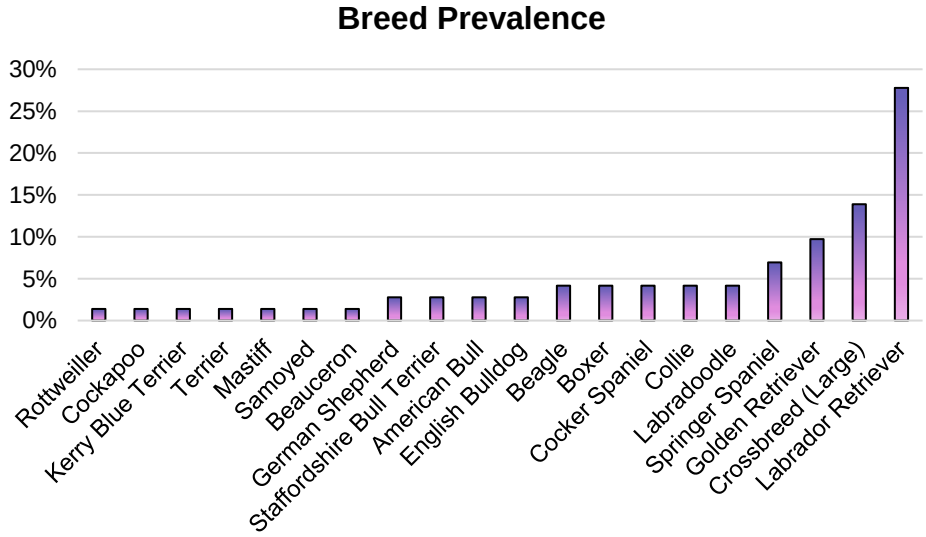


Graphic 6 - Prevalence of meniscal tears in 72 dogs represented on this study.

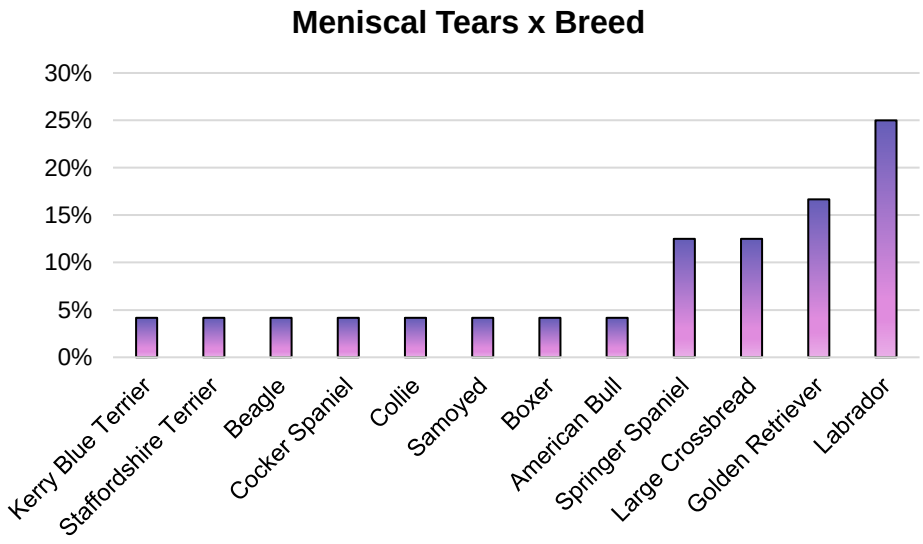


Graphic 7 - Types of meniscal tears identified on this study.

The most prevalent breed was Labrador Retriever (28%), followed by Large Crossbreed (14%), Golden Retriever (10%) and Springer Spaniel (7%) (Graphic 8). Overall, breed was a statistical variable with high prevalence for meniscal tears. Particularly, Labrador Retriever (25%), followed by Golden Retriever (17%), Springer Spaniel and Large Crossbreed at same proportion (13%) (Graphic 9).

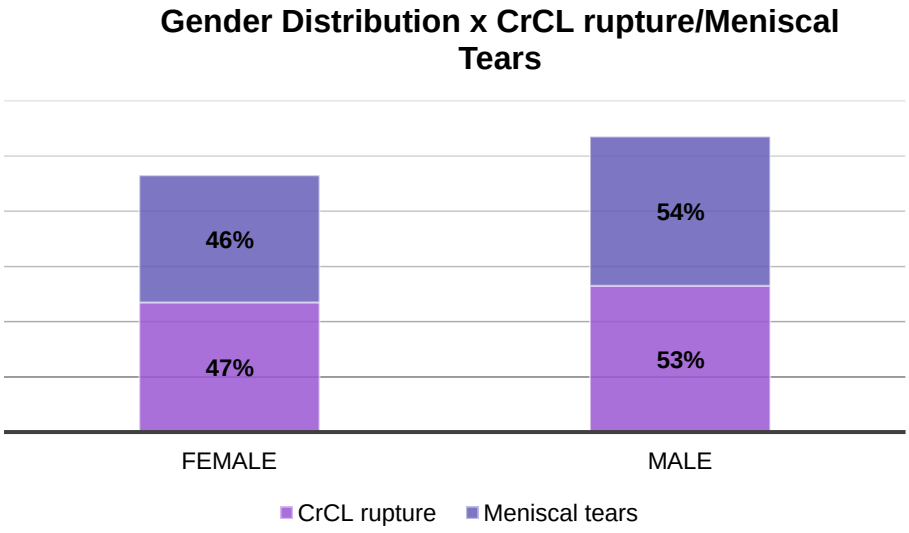


Graphic 8 - Dog breed prevalence for CrCL rupture that underwent to TTA surgery.



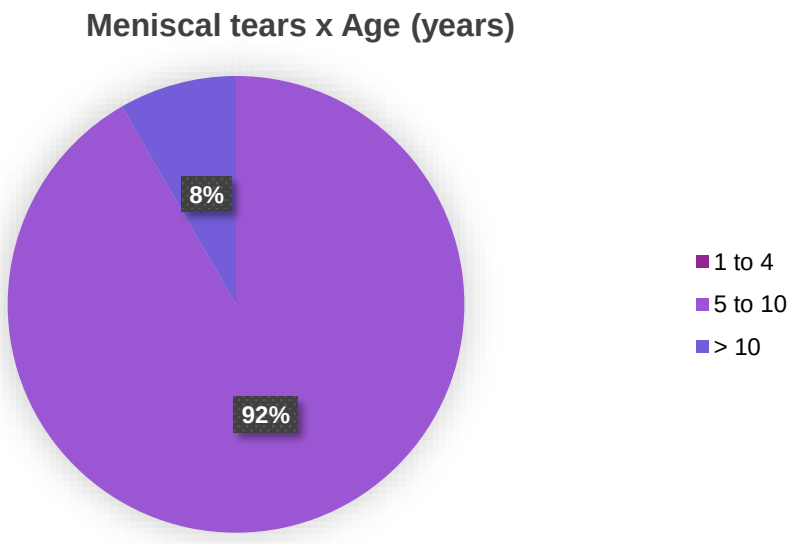
Graphic 9 - Dog breed prevalence for Meniscal Tears.

The gender was not statistically associated with CCLD in this study. Male dogs demonstrated a slightly higher occurrence of CrCL rupture (53%) and meniscal tears (54%) in comparison to female (47% and 46%, respectively) (Graphic 10).



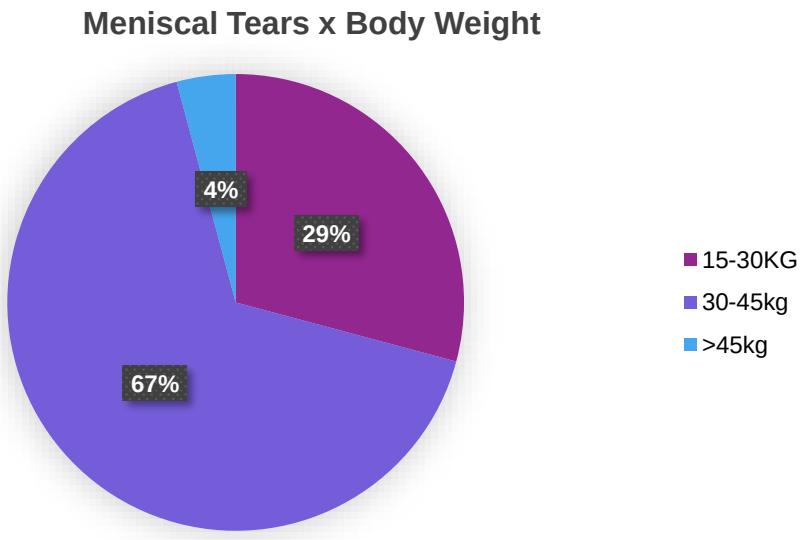
Graphic 10 - Gender distribution according to CrCL rupture and Meniscal Tears.

Middle-aged dogs represented a higher caseload for CrCL disease (57%) when comparing to young (31%) and old dogs (12%). Also, the prevalence of meniscal tears was higher on middle-aged patients (92%, Graphic 11).



Graphic 11 - Meniscal tears prevalence according to age.

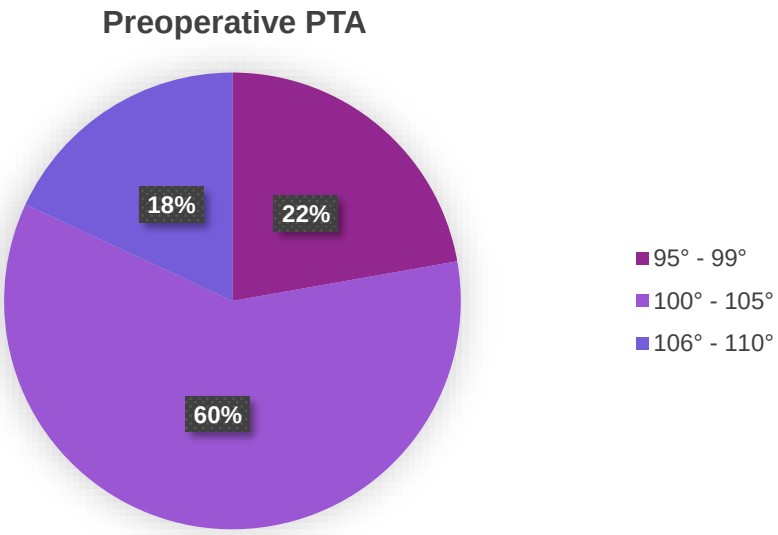
The average weight of the dogs on the study was 37.5 kilograms and the prevalence of meniscal tears were higher in dogs between 30 to 45 kilograms (67%), followed by 29% on the interval of 15 to 30 kilograms and 4% in dogs over 45 kilograms (Graphic 12).



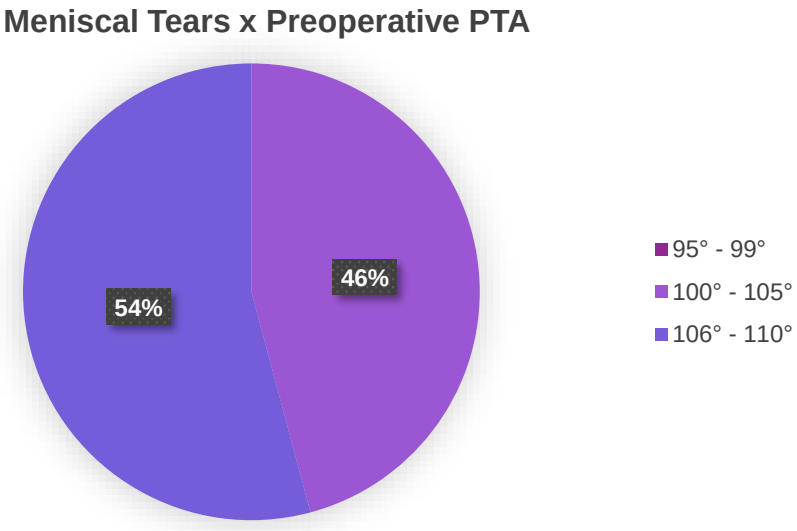
Graphic 12 - Meniscal tears prevalence in relation to body weight.

The median preoperative PTA from 72 dogs in this study was 102.6° (95.8° - 109.4°) (Graphic 13). The meniscal tears prevalence (N=24) was higher in dogs with PTA between 106° to 110° (54%) and PTA of 100° to 105° was also statistically associated with meniscal

tears (46%). Although lower PTA (95° to 99°) was not associated with meniscal tears on the present study (Graphic 14).



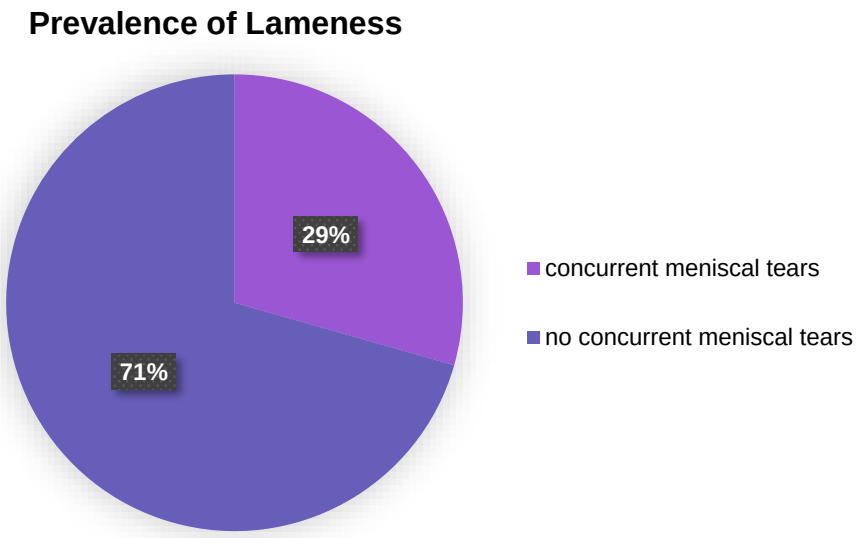
Graphic 13 - Preoperative PTA of the study population (N=72)



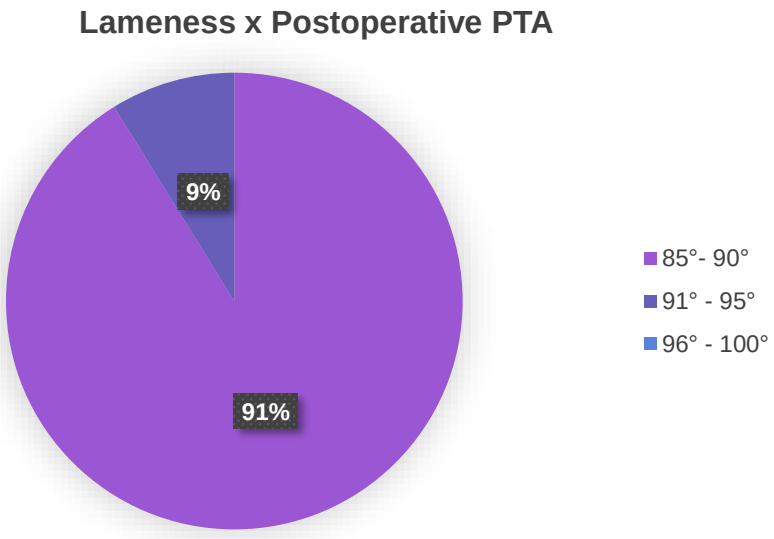
Graphic 14 - Comparison between preoperative PTA and prevalence of meniscal tears.

The final analysis was the outcome with respect to lameness in between dogs with no concurrent meniscal tears and concurrent meniscal tears. Thirty-four (N=34) dogs were presented with some degree of lameness on the 4-week follow-up. The prevalence of lameness was higher in dogs with no concurrent meniscal tear (71%) than in dogs with

meniscal tears diagnosed by arthrotomy just before performing the TTA (29%) (Graphic 15). From those dogs that were presented with lameness on the postoperative follow-ups, 91% had postoperative PTA from 85° to 90° and 9%, from 91° to 95° (Graphic 16). The median value of postoperative PTA was 90.1° (88.2° -92.1°). All the population in this study with concurrent meniscal tears and lameness (N=10) had a postoperative PTA range from 85° to 90° (100%).



Graphic 15 - Prevalence of lameness on the 4-week post operative follow-up.



Graphic 16 - Comparison between lameness and postoperative PTA.

IV. DISCUSSION

This study aimed to establish the prevalence and outcome of meniscal tears identified via arthrotomy during treatment for CrCL disease through TTA surgery. A minimum of 4 weeks follow-ups was done as at this time the radiographs were taken to check the implants and bone healing progression. After this period of time, different outcomes may be seen as a long-term follow-up, but they are outside the reach of this study. The signalment of this study population was consistent with other studies on cranial cruciate ligament disease and medial meniscal tears.

Similar to previous studies, not every case in this study resulted had a PTA of exactly 90 degrees or under (Pozzi *et al,* 2017). Despite this, gross over or under advancement of the tibial crest did not lead to any relevant postoperative complications, neither had been associate with a poor outcome. Gross over or under advancement of the tibial crest may occur due to lack of precision on cage sizes as well as radiographic measuring variability or poor radiographic positioning due to varus and torsion deformity (Hackett *et al.,* 2021).

Antimicrobial administration is recommended, even in clean orthopaedic surgeries that last more than 60 minutes, to avoid further contamination of the surgical site and osteomyelitis. The prophylactic protocol is based on a first-generation cephalosporin given no more than 60 minutes before the surgery starts. The antibiotic administration has to be continued for every 90 minutes till the end of the surgery. Reported surgical site infections ranges from 0.6% to 7.1% in neurosurgeries and non-contaminated canine orthopaedic surgery. Therefore, higher surgical site infection rates of 25.9% have been reported in tibial correctives osteotomies (Välkki *et al.,* 2020). Cefuroxime (30mg/kg/IV) was administered in all patients just before the surgical incision and every 90 minutes. In a population of 72 dogs, none of them were prescribed antibiotics on the postoperative period and no surgical site infection was reported. This reflects good compliance with prophylactic antimicrobial protocols, which brings the conclusion that no postoperative antimicrobials are needed if the orthopaedic surgery is considered a clean procedure. It is important to emphasize the surgical site preparation was performed thoroughly which may result in an excellent outcome described on this retrospective study.

Tibial tuberosity advancement (TTA) is one of the most common surgery options to treat CCLD and, similarly to TPLO, involves a considerable soft tissue and bone manipulation which initiate an inflammatory response straight forward. Due to the invasiveness of the tibial correctives osteotomies, the patients develop a high pain score on the postoperative and so

an appropriate analgesia during the intraoperative and on the postoperative is mandatory (Pownall *et al.,* 2021). The opioid of choice on this study was methadone as it promotes a better analgesia than buprenorphine and has been demonstrated excellent analgesia on postoperative pain in dogs. Methadone is a full μ-agonist and has an excellent action for moderate to severe pain through a full saturation of the receptor binding sites. It is a dose-dependent drug, facilitating its use for the best effect. On the other hand, buprenorphine is considered to be a partial μ-receptor agonist but recent papers have said buprenorphine shows full analgesic effect in animal models, dependent on the stimuli produced. The analgesic effect of methadone and buprenorphine still requires more studies to clarify their effect with regard to pain score in animals (Shah *et al.,* 2018). Hunt *et al.,* 2013 compared buprenorphine and methadone as a premedication with acepromazine for orthopaedic surgeries and concluded methadone had a significant better analgesia than buprenorphine. Consequently, as methadone is well consolidated as an excellent analgesia for orthopaedic surgeries, it was the main choice on this study and in most of the veterinary practices globally. Acepromazine and medetomidine were the sedative drugs of choice and were chosen accordingly to patient underlying disease, breed and behaviour, with a good sedative effect in the majority of the cases.

The gold standard of postoperative analgesia relies on a multimodal approach with NSAID and opioids. Methadone was given to the dogs every 6 hours, for the first 24 to 12 hours that they were kept in the clinic. Meloxicam was the first choice of NSAID, unless the dog had a previous reaction to this drug that may contraindicate its use. If so, Robenacoxib was chosen due its selectivity for cyclooxygenase-2 (COX-2), with minimal side effects on gastric, renal, and platelet functions. Once-daily administration of Robenacoxib has been found as efficacious as Meloxicam to manage pain and inflammation after orthopaedic surgery when associate with opioids for a multimodal analgesia (Bendineli *et al.,* 2019).

The standard TTA technique was performed in this study using a titanium forkless plate, which can be contoured on the tibial tuberosity and requires fewer drill holes on the tibial crest, minimalizing the risk of tibial crest fracture when comparing to forked plates used previously. There is no report of complications related to the implants used on this study, which confirms the benefits of using forkless plate instead of forked plates. The traditional TTA technique and its forkless plate design still has disadvantages, but has been shown better outcomes than forked plates, especially regarding to reduced selection of implants and orthopaedic equipment and also less risk of implant failure and tibial fracture (Matchwick *et al*, 2021).

This study showed that breed, age, body weight and preoperative PTA were consistent with CrCL rupture and consequent meniscal tears. Gender was not associated despite the

literature demonstrates female and neutered dogs are more susceptible to CrCL disease secondary to hormone changes (Jeong *et al.,* 2021).

Of the 19 breeds studied, Labrador Retriever showed a higher prevalence in the identification of meniscal tears. Labradors were identified as an at-risk breed by Kaufman and colleagues, 2017. The study also noted that medium-breed dogs, as Cocker Spaniel, Beagle and Samoyed, were less likely to have meniscal tears.

Middle-aged to older dogs are mostly affected with CCLD with a range of 4.3-7.0 years old at presentation (Engdahl *et al,* 2021). The present study confirms this fact as 57% of the dogs were middle-aged. The higher prevalence of meniscal tear was also in middle-aged dogs, however there are insufficient studies in respect of meniscal tears and age relation. Laube & Kerstetter, 2021 demonstrated that age was reported as a risk factor, with 30% higher chances of meniscal tears for each years' increase in age. In human medicine, the meniscus in aging patients shows increased deposition of degenerative products, becomes stiffer, loses elasticity and cellular elements. Moreover, dogs with a grossly normal menisci in a cranial cruciate ligament-deficient stifle aged ≥ 3 years showed significantly less surface cellularity than dogs that were <3 years old.

The average weight of the dogs with meniscal tears on this study was 37.5 kilograms and the most common affected breed was Labrador Retriever. The normal weight range for a Labrador Retriever is from 25 to 32 kilograms, therefore the majority of dogs on this population was overweight. Obesity has been reported to be associated with a four-times increased prevalence of cranial cruciate ligament rupture and overexpresses pro inflammatory cytokines which makes osteoarthritis worse being a high-risk factor for CrCL disease and meniscal tears. Also, obesity leads to constant stress into the joint surface, which compromise the normal stifle biomechanics predisposing to trauma and further injuries (Marshall *et al.,* 2010; Katz *et al.,* 2021).

Recent literature has shown a wide range of meniscal tears in CrCL rupture stifles that varies from 20-77% (Jeong *et al.,* 2021; Katz *et al.,* 2021). The meniscal tears prevalence on the present study was 33%, which endorses the researches findings up to now. It might be even lower if the diagnose was made before OA develops. On the other hand, it is well known there is a risk of post operative meniscal tears after TTA surgeries or any other type of corrective osteotomies for CrCL repair (Kowaleski *et al,* 2018; Katz *et al.,* 2021).

Several published studies have been strongly correlated meniscal injuries with the duration of lameness, bodyweight, age but mainly with the degree of stifle instability (Jeong *et al.,* 2021; Katz *et al.,* 2021). This work identified that breed is another important factor for meniscal tears, as 25% of the cases were Labrador followed by 17% of Golden Retriever, which brings up those Retrievers breeds seems to be more vulnerable to this condition. In this

study, arthrotomy was the choice for meniscal inspection, however a clear view of the caudal aspects of the meniscus was not possible in most of the cases, particularly in chronically affected joints. Therefore, incomplete lesions affecting the ventral (tibial) side of the meniscus could be easily missed. Pozzi *et al.* (2017) reported that probing enhanced the sensitivity, specificity, and correct classification rate of all diagnostic methods for meniscal tears, so all the meniscus were probed in this study. However, this does not address tears contained within the meniscus, which cannot be observed on the exterior of the meniscus and may be a factor in latent tears. MRI is arguably the best way to diagnose meniscus abnormalities as discussed previously on the literature review. Unfortunately, advanced imaging was not available in this study due to cost restrictions. The prevalence of subsequent meniscal tears may be falsely reduced because variables that are not under the veterinary surgeon control but owners control. Those variables are in respect of financial concerns (especially regarding to advanced imaging), compliance and outcome expectations that the owners may have. However, the prevalence of meniscal tear may also be due to misdiagnose on the first assessment during the arthrotomy – *latent* tears (Katz *et al.,* 2021). Medial meniscal tears accurate diagnosis is very challenging, especially without advanced imaging available. Also, altered stifle biomechanics after surgery may predispose the occurrence of late onset of meniscal tears. Stifle instability after TTA surgery has been signalised as a possible biomechanical factor for subsequent meniscal tears (Kowaleski *et al,* 2018).

The “bucket handle” tear was the highest percentage of meniscal tears founded on this study (83%). In fact, several studies demonstrated the “bucket handle” tear, followed by folded caudal horn as being the most common type of meniscal injuries in dogs stifles (Van der Vekens *et al.,* 2019). On the majority of the cases, hemimeniscectomy was performed through a conservative meniscal resection approach, as it has been shown to have a much better advantage with regard to biomechanics of the menisci pressure zones when comparing with a segmental meniscectomy or extensive partial meniscectomy (Jeong *et al.,* 2021). Despite the meniscal release being a controversial manoeuvre nowadays, the surgeon in charge still does in cases the menisci was loose on the joint or frayed, with apparently good outcomes as the dogs submitted to caudal meniscal release did not show clinical symptoms of subsequent meniscal tears during the study period. However, meniscal release does not exclude subsequent meniscal tears, and there is a correlation with progression of osteoarthritis, lameness, and meniscal pathology in healthy stifles (Jeong *et al.,* 2021). This study was based in an average of 4 weeks follow-ups, therefore long-term outcomes was not recorded and requires new data collection for a better interpretation.

Dogs with higher TPAs and PTAs may have an increased risk of meniscal tears following CrCL rupture (Jeong *et al*, 2021).This fact was proved on this study as 54% of the

population had a PTA range of 106° to 110°. Pozzi and colleagues (2017) suggested that TPLO might be better than TTA when higher TPA and PTA are found on the preoperative measurements by neutralizing tibial thrust through levelling the tibial slope, reducing the TPA (≤ 6.5°) and consequently the PTA to approximately 90°. Boudrieau (2017) suggested that in both TPLO and TTA, the tibial plateau and the patellar ligament stay oriented at about 90 degrees to each other, so the biomechanical result of these two techniques are very similar. However, TPLO procedure may be protective of the medial meniscus with respect to load transmission that may cause meniscal tears to occur. Nevertheless, the veterinary surgeon who performed the surgeries on this study did not perform TPLO, so TTA was always the choice of surgical treatment in dogs over 15kg regardless of the preoperative TPA and PTA.

The median preoperative PTA in this study was 102.6° and based on biomechanical model of forces acting into the joint, cranial tibial translation is dependent on PTA. To eliminate the cranial tibial translation and stabilize a CrCL deficient stifle, a TTA is performed to achieve a PTA of 90° with the stifle positioned at a standing angle of 135° (Mayo, 2018, Meeson et al, 2018). This study had an excellent outcome in regard the achievement of an ideal PTA of 90° as the postoperative average was 90.1°. Despite the excellent postoperative PTA in the majority of the cases, the prevalence of lameness was higher on the PTA interval of 85° to 90°. The lower postoperative PTA on this study was 88.1° which is still on the acceptable range suggest by the literature (90° ± 5°) (Santhya et al., 2014, Meeson et al, 2018). Over-advancement of tibial thrust may lead to patellar luxation and increase joint forces in the caudal aspect of the joint which causes caudal cruciate ligament injury and pain. Under-advancement results in poor reduction of the TT and the joint instability persists (Mayo, 2018). However, in this study none of the dogs that underwent to surgery had a postoperative PTA lower than 85° or higher than 95° which suggests that the lameness observed on the postoperative follow-ups was not direct associated with over or under-advancement of the tibial tuberosity.

A cage size chosen wrongly has the potential to cause chronic meniscal problems (Mayo, 2018). Etchepareborde and colleagues (2011) demonstrated that the use of radiographs templates for preoperative planning does not provide an accurate cage size selection as *in vivo* the cage is orientated in a different direction. As a result, an under-advancement is achieved and the stifle remains unstable, dealing with OA and late meniscal tears. PTA measurements were taken on the postoperative radiographs on this study and the limb position was always reassured at 135° to achieve accurate measurements, but it is well known by recent studies that a slightly angle alteration on the radiographs positioning may misdiagnosed an under or over-advancement, compromising the outcome with respect to chronic lameness secondary to osteoarthritis progression and late meniscal tears (Katz *et al*, 2021).

Surprisingly, the prevalence of lameness was higher in dogs with no concurrent meniscal tears than dogs with concurrent meniscal tears. The lameness was graded from 0 to 4 scale with 0 being absence of lameness, 1 subtle lameness, 2 weight-bearing lameness, 3 toe touching lameness and 4 non-weight-bearing lameness. The dogs in this study potentially had varying levels of osteoarthritis, effusion, chronicity, instability, and other factors that would likely contribute to lameness at varying degrees. None of the dogs that took part of this study had an implant reaction, fracture or considerable major complication that could affect the lameness assessment. Thus, the lameness presented on follow-ups was most likely due to OA development and subsequent or misdiagnosed meniscal tears. The development of meniscal tear postoperatively may vary from 17% to 28% in dogs depending on meniscal assessment method, surgical treatments, diagnostic methodology, and time frame for determining outcome (Kowaleski *et al.,* 2018). Also, studies have demonstrated that subsequent meniscal tears are most likely to occur after a year of the surgery and any meniscal tears diagnosed earlier than that is probably related to misdiagnose at the time of the arthrotomy or arthroscopy (Ritzo *et al.*, 2014; Laube *&* Kerstetter, 2021). The duration of lameness is a risk factor that has been reported in other studies (Krier *et al*, 2018), but this information was not readily available in this study as the dog came back to the primary veterinarian after the 4 weeks follow-up and further information have not been assessed.

The limitations of this study are the fact of being a retrospective one, lack of data in regard to postoperative outcome and the performance of only open arthrotomies to identify meniscal tears. Although this method provided unintentional consistency to this study, other options of stifle exploration could be pursued as arthroscopy and MRI. Arthroscopy, similar to arthrotomy, has anatomical restraints as the tibial surface of the menisci is difficult to assess and is kept hidden from view and meniscal injuries could still be misdiagnosed. MRI is the recommended diagnostic imaging method but due to high cost it does not have a good acceptance for pet owners. Further studies with MRI findings should be performed to validate all the results that have been demonstrated on recent literature about CrCL disease and prevalence of meniscal tears.

V. CONCLUSION

Meniscal disease is strongly related to CrCL rupture. The prevalence of meniscal tears on the present study was associated to breed, age, weight and preoperative PTA. Veterinary patients are mostly diagnosed with “bucket-handle” tear and represents the majority of the tears found during the arthrotomy. The outcome was worse on dogs with no concurrent

meniscal tears than dogs with meniscal tears found during arthrotomy just before performing the TTA.

Hemimeniscectomy was the surgery option to treat the meniscal injury on this study. The ideal treatment for meniscal disease has been under discussion nowadays as meniscectomy, hemimeniscectomy or even meniscal release may worse the OA and lameness on a long-term outcome analysis. This fact has made many surgeons to carefully remove the damaged portion of the menisci and support studies on meniscal regeneration or replacement instead. The regenerative medicine has been growing in veterinary with PRP and MSCs showing excellent outcomes and minor complications reported (Wei et al, 2021).

The progression of lameness on the postoperative follow-up was not associated with concurrent meniscal tears on this study. In contrast, the dogs with no concurrent meniscal tears were presented with a higher percentage of lameness (71%). This result may be related to latent or subsequent meniscal tears as well as progression of OA. In fairness, further studies should be developed using preferably MRI as a preoperative imaging diagnostic as it is already scientifically proven that dogs presented with meniscal tears have more chances of OA development because of increasing in stifle contact pressure and alteration of biomechanical forces (Pozzi et al, 2010, Spina et al, 2014). Preoperative accurate diagnosis is important to give the owner a clearly prognosis and expected outcome after surgery.

This study has some limitations, especially with respect to long-term outcome and diagnostic imaging, but hopefully the data presented will help some orthopaedic veterinary surgeons and stimulate further researches on CrCL disease and development of innovative techniques for the best approach to meniscal tears.

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