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Georgia Michael

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University of Veterinary Medicine Budapest

Department of Surgery

Comprehensive evaluation of canine cranial cruciate ligament rupture: predisposing factors, treatment strategies, and postoperative physiotherapy techniques.

By:

Georgia Michael

Supervisors:

Dr. Tamás Ipolyi

Small animal clinical specialist.

Dr. Otilia Biksi

assistant supervisor

Certified canine rehabilitation practitioner.

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Abstract: English

Cranial cruciate ligament rupture (CrCLR) is one of the most prevalent orthopaedic conditions and the primary cause of hindlimb lameness in dogs. This study was designed to offer a comprehensive analysis of the entire rehabilitation process of CrCLR, focusing on three primary areas: predisposing factors, treatment approaches (surgical intervention versus conservative treatment), and post-operative physiotherapy treatment. For the methodology of this study an online questionnaire was developed and distributed to dog owners whose pets had experienced CrCLR. Of the respondents, 56 participants successfully completed the questionnaire in its entirety. What arises from the results is that degeneration was identified as the leading cause of rupture, accounting 60.7% of cases, while traumatic incidents contributed to 26.8%. Regarding predisposing factors, such as breed, gender, neuter status, age and overweight status, breeds were categorized according to size, with 62.2% being large breeds and 37.8% small breeds. The gender distribution was 39.3% males and 60.7% females, of which 59.1% were neutered and 61.8% spayed, respectively. The proportion of overweight participants was as follows: 28.6% of dogs classified as overweight, 50.0% were at a physiological weight and 21.4% of the owners were unable to recall the weight status of their dog at the time of the incident. The age distribution was: 5.4% adolescent (under 2 years), 28.6% adult (2-5 years), 39.3% senior (6-9 years) and 26.7% geriatric (10 years and older). With respect to the treatment approach, 89.3% of respondents selected surgery as treatment, while only 10.7% chose conservative treatment. The efficacy of each treatment is as follows: conservative treatment: 33.3% success and 66.7% failure, surgical treatment: 90.0% success and 10.0% failure. In relation to the proportion and individual success rate of surgical techniques the distribution is as stated below: TPLO was the most chosen procedure (70.0%), followed by extracapsular suture (20.0%) and intracapsular suture (2.0%). TPLO had a 97.1% success rate, extracapsular suture 70.0%, and intracapsular suture 0.0%. Lastly, physiotherapy was part of the rehabilitation for 84.6% of participants. Of these, 56.8% reported full recovery (1st degree of lameness), 34.1% indicated mild discomfort (2nd degree of lameness), and 9.1% reported moderate lameness (3rd degree of lameness). In conclusion, this study found an overall success rate of 55.4% reporting full recovery, 32.1% reporting mild discomfort and 12.5% moderate lameness following CrCLR rehabilitation. Valuable insights into the rehabilitation process are emerging form this study, with the potential to help veterinarians and owners make informed decisions. However, further research with a larger sample size is needed to improve accuracy, and veterinarian evaluations are essential to reduce owner bias and misinterpretation.

Abstract: Hungarian (Magyar Nyelvű Kivonat)

Az elülső kereszteződő szalag szakadás (EKSZ) az egyik leggyakoribb ortopédiai elváltozás, és vezető kórok hátsó láb sántaság esetén. Jelen tanulmány lehetőséget nyújt az EKSZ rehabilitációs folyamatának átfogó elemzésére, három fő témára fókuszálva: hajlamosító tényezők, kezelési lehetőségek – konzervatív, avagy műtéti -, és posztoperatív fizioterápiás kezelés.

A tanulmány módszerét illetően egy online kérdőívet alkalmaz, melyet olyan kutyatulajdonosoknak küldtünk ki, amelyek kutyái EKSZ érintettek voltak. A válaszadók közül 56-an töltötték ki sikeresen a kérdőívet. Az eredmények alapján az látható, hogy az esetek 60.7%-ban degeneratív folyamatok, míg 26,8%-ban trauma áll az elváltozás hátterében. A hajlamosító tényezőket tekintve a fajtákat méret szerint csoportosítva, 62,2% nagytestű, 37,8% kistestű kutyáról van szó. A nemek szerinti megoszlás 39,3% hím és 60,7% nőstény, ebből 59,1% volt ivartalanítva és 61,8% ivaros. A túlsúlyos résztvevők aránya a következőképpen alakult: a túlsúlyosnak minősített kutyák aránya 28,6%volt, 50,0%-a volt fiziológiás súlyú, míg a tulajdonosok 21,4%-a pedig nem tudta megítélni kutyája kondícióját. A kormegoszlás a következő volt: 5,4% serdülő (2 év alatti), 28,6% felnőtt (2-5 év), 39,3% idősödő (6-9 év) és 26,7% idősek (10 évesek és idősebbek). Ami a kezelési megközelítést illeti, a válaszadók 89,3%-a választotta a műtéti megoldást, míg csak 10,7% választotta a konzervatív kezelést. Az egyes kezelések hatékonysága a következő: konzervatív kezelés: 33,3% sikeres és 66,7% sikertelen, sebészi kezelés: 90,0% siker és 10,0% sikertelen. A sebészeti technikák arányát és egyéni sikerességi arányát tekintve a megoszlás az alábbiak szerint alakul: a TPLO volt a leggyakrabban választott eljárás (70,0%), ezt követi az extracapsuláris szalagpótlás (20,0%) majd az intrakapszuláris szalagpótlás (2,0%). A TPLO sikerességi aránya 97,1%, az extrakapszuláris szalagpótlás 70,0%, az intrakapszuláris szalagpótlás pedig 0,0%. Végül a fizioterápia a rehabilitáció részét képezte a résztvevők 84,6%-nál. Ezek közül 56,8% számolt be teljes gyógyulásról (1. fokú sántaság), 34,1% enyhe diszkomfortról (2. fokú sántaság), 9,1% mérsékelt sántaságról (3. sántaság) számolt be.

Összefoglalva, ez a tanulmány azt találta, hogy a CrCLR-rehabilitációt követően 55,4% teljes gyógyulásról, 32,1% enyhe diszkomfortról és 12,5% közepes sántaságról számolt be. A dolgozat értékes betekintést nyújt a rehabilitációs folyamatba, és segíthet az állatorvosoknak és a tulajdonosoknak döntéseinek megalapozásában. A pontosság javítása érdekében azonban további kutatásokra van szükség nagyobb mintaszámmal, és az állatorvosi értékelések elengedhetetlenek a tulajdonosok elfogultságának és félreértelmezésének csökkentése érdekében.

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List of abbreviations:

ACL – Anterior cruciate ligament

ATP – Adenosine triphosphate

CaCL – Caudal cruciate ligament

COX – Cyclooxygenase enzyme

CrCL – Cranial cruciate ligament

CrCLR – Cranial cruciate ligament rupture

ELSS - Extrascapular Lateral Suture Stabilization

IL-8 – Interleukin 8

ICS - Intracapsular 'over the top' Stabilization

LDE - lateral digital extensor

NSAIDs – Non-steroid anti-inflammatory drugs

OA – Osteoarthritis

ROM – Range of motion

SNP – Single nucleotide polymorphism

TPLO – Tibial Plateau Levelling Osteotomy

TPA – Tibial plateau angle

TTA – Tibial Tuberosity Advancement

TR – Tightrope technique

TENS – Transcutaneous electrical neutralizing stimulation

PROM – Passive range of motion

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Introduction:

Cranial cruciate ligament rupture (CrCLR) is one of the most prevalent orthopaedic conditions in dogs, similar to the anterior cruciate ligament (ACL) injury in humans. As the primary stabilizer of the stifle joint, the cranial crucial ligament plays a fundamental role in the function of the joint; thus, its rupture resulting in the leading cause of hindlimb lameness in dogs. The cause of rupture can be either a sudden tear due to a traumatic injury or a gradual tear due to degeneration, often associated with excessive mechanical stress placed on the ligament [1].

Over the years, the high prevalence of the condition has promoted extensive research into various aspects. The existing literature has predominantly focused on three main areas: (I) etiopathogenesis and predisposing factors, (II) treatment approaches and (III) post-operative management. Recent findings in etiopathogenesis suggest that this condition is multifactorial, involving both systemic and local mechanisms [2]. Several predisposing factors have been identified, including breed predisposition, sex, neutered status, age, obesity, and joint conformation [3]. Regarding treatment approaches, extensive research by veterinarians has led to the development of optimal treatment methods and the continuous advancement in surgical techniques [4]. Lastly, recent studies have highlighted the promising contribution of postoperative physiotherapy as a beneficial component of the rehabilitation process [5]. Despite the significant attention CrCLR has garnered, there remains a lack of extensive studies that provide a thorough analysis of the condition, encompassing all stages from onset to completion of rehabilitation process.

The following study was specifically designed to provide a comprehensive analysis of CrCLR. More precisely, the research was structured around the following three key aspects: (I) predisposing factors, (II) treatment approaches, including a comparison between surgical intervention, and conservative management, their success rates, and an evaluation of surgical techniques and their efficacy, and (III) the significance of postoperative physiotherapy. By examining these key aspects, the study pursues to generate valuable insights for the possible prevention of CrCLR and the development of appropriate treatment methodologies, supported by a detailed statistical analysis of various treatment outcomes. Ultimately, this research aims to equip veterinarians and dog owners with a thorough understanding of various treatment options available, enabling them to make informed decisions suitable to each individual patient's uniqueness. By doing so, enhanced clinical outcomes and improved quality of life for affected animals can eventually be achieved.

Literature review

1. Cranial cruciate ligament function:

The cranial cruciate ligament (CrCL) is one of the multiple ligaments in the knee joint that links the femur with the tibia. It begins from the inner surface of the femoral lateral condyle to central intercondylar area of the tibia [6]. The CrCL in dogs has numerous key functions that are essential for the stability and proper function of the knee joint. This stabilisation can only be achieved with coordination and synchronisation of the cranial and caudal cruciate ligaments, the medial and lateral collateral ligaments, the patellar ligament and quadriceps femoris, the gastrocnemius and biceps femoris muscles, the joint capsule, the synovial membrane, articular cartilage, and the medial and lateral meniscus [7].

The three most important biomechanical functions of the CrCL are: I. preventing the cranial displacement of the tibia in connection to the femur, also known as cranial drawer motion. II. prevention of the knee's hyperextension, and III. preventing an internal rotation of the tibia [1]. In addition, neuromuscular control of the limb can be achieved through the proprioceptive feedback provided by the CrCL [8].

By examining the functions of the CrCL in greater detail, it is clearly noticed that throughout the entire range of motion, the CrCL stabilises the tibia on the femur by preventing any forces that could cause a cranial translocation of the former in relation to the latter [1, 8]. Furthermore, to a lesser extent, it is able to prevent forces that cause a tibial rotation, during flexion of the stifle joint. Also, worth mentioning is the ability of CrCL to endure the multi-axial stresses during the normal function and range of motion. This results from the two anatomical components of both cruciate ligaments, and their ability to perform independently and differently from each other during loading [1, 8]. Moreover, an equally significant aspect of the cruciate ligament is that its tension helps in preventing hyperextension, with the CrCL serving as the main restraint. Both the craniomedial and caudolateral components of the ligament remain tight when the limb is fully extended, however, the primer contributor in the restriction of overextension is the caudolateral component of the CrCL [1, 8].

Finally, it is important to acknowledge that the caudal cruciate ligament (CaCL) contributes to some level in the function mentioned above. However, its significance in the stability of the joint is minor compared to that of CrCL [8].

2. Cranial cruciate ligament rupture (CrCLR):

A ligament rupture, such as a CrCLR in dogs, refers to the partial or complete tearing of the CrCL fibres, resulting in varying degrees of severity [1]. In the event of such a rupture, the stifle becomes painful and unstable, leading to chronic, progressive lameness. This condition increases the risk of meniscal tearing, as the meniscus can become injured during movement, and eventually contributes to the formation of osteoarthritis [9]. As the rupture leads to joint instability, it ultimately results in the clinically observed 'cranial tibial thrust', which refers to the forward movement of the tibia relative to the femur during weight-bearing, a motion normally restricted by the intact CrCL [10].

3. Etiopathogenesis:

The etiopathogenesis of CrCLR in dogs involves two primary pathways: acute traumatic injury and progressive degeneration of the ligament [1]. Over the years, numerous theories have emerged, with recent findings overturing the long-held belief that CrCLR is primarily caused by traumatic injury. While trauma can directly cause ligament rupture, research now concludes that the majority of cases are attributed to a progressive weakening and degeneration of the ligament, clinically referred to as 'spontaneous' cranial cruciate ligament rupture [1]. Progressive microtrauma gradually weakens the ligament over time, until the final strand will break, eventually leading to the rupture.

The etiopathogenesis of spontaneous CrCLR remains incomprehensible, despite extensive research efforts [1, 2]. Current evidence suggests that CrCLR is a multifactorial condition, involving a combination of mechanical stress, genetic predispositions, joint abnormalities, as well as chronic joint inflammation [1]. In a 2023 study conducted by Gert W. Niebauer et al. [2], the term 'cranial cruciate ligament disease' was suggested as a more accurate descriptor for CrCLR in dogs, as it better reflects its multidimensional nature.

In regard to joint inflammation, it has emerged as a significant focus of research due its suspected role in the progressive weakening of the ligament [1]. However, the precise mechanism and contribution of inflammation in CrCLR remain elusive. Many hypotheses have been inadequately supported or have produced inconclusive results, with each investigation raising further unresolved questions. For instance, in a 2008 study, M. Doom et al. [11] investigated the immunopathological mechanisms in dogs with CrCLR. Despite the presence of an anti-collagen type I antibody gradient and elevated cytokines such as interleukin 8 (IL-8) in predisposed joints, indicating an inflammatory process before the

rupture, the exact role of immune response and cytokines in the pathogenesis of CrCLR remained inconclusive.

4. Predisposing Factors:

Closely intertwined with etiopathogenesis are the predisposing factors such as mechanical stress, genetic predispositions and joint abnormalities, as they play a critical role in the underlying mechanisms that lead to ligament degeneration and eventual rupture. Various studies have established a correlation between CrCLR and the canine signalment, leading to the conclusion that breed, age, gender, body weight, neuter status, physical agility, and joint conformation could be identified as risk factors [3, 12, 13, 14].

4.1 Breed and genetic predisposition:

It is commonly assumed that large breeds are primarily predisposed to CrCLR due to increased load on the ligament and their high energy levels, which could result in either a traumatic or spontaneous rupture. A 2000 study from the University of Veterinary and Pharmaceutical Sciences in Brno [15], identified nine breeds with an elevated risk of CrCLR: the American Staffordshire Terrier, Rottweiler, Brazilian Fila, Labrador Retriever, American Cocker Spaniel, Chow-Chow, German Shorthaired Pointer, Saint Bernard and Bullmastiff.

This assumption was widely accepted in previous decades, and recently in 2023, C. Pegram et al. [12] supported these findings, while also providing additional insights. In their study, Rottweiler, Bichon Frise, West Highland White Terrier, Golder Retriever, Yorkshire Terrier, and Jack Russell Terrier were defined as the breeds with the highest risk, with small breeds also being included for the first time. This could lead one to assume the possibility that another predisposing factor, such as joint conformation could be in the background. In contrast, the breeds with the lowest risk mentioned in that study are Labrador Retriever, Cocker Spaniel, Border Collie, French Bulldog, German Shepherd, Shih-tzu, Chihuahua and Cockapoo [12].

In 2014, Dr Arabella B. et al. [16] hypothesized that marked breed-related predisposition to CrCLR in dogs likely has a molecular basis as well. In her study, she investigates this hypothesis by utilizing a single nucleotide polymorphism (SNP) genotyping approach. Through this method, she identified critical genes, that are mainly involved in ligament strength, stability and extracellular matrix formation, such as COL5A1, COL5A2, COL1A1, COL3A1, COL11A1, COL24A1, FBN1, LOX, and LTBP2. The study demonstrated a

profound association between variations in these genes and increased susceptibility to CrCLR, suggesting a molecular genetic link to the condition. However, to date, breed-specific associations for all these genes in dogs have not yet been fully documented or published in any recent studies.

4.2 Sex and neutered status:

Various studies have been caried out throughout the years verifying that females are more likely to experience a cruciate failure. According to P. Adams et al. (2011) [3], the likelihood of rupture in females is twice that of males. Despite the fact that only human researches were used to explain the origin of this phenomenon, it was demonstrated that while oestrogen can cause a functional improvement in bone and muscles, it can also cause an opposite effect on tendons and ligaments [17]. Specifically, oestrogen causes a decrease in stiffness, which consequently has an immediate impact on both performance and injury rates.

Over the course of time, more and more studies have revealed that there is a corelation between neutering status and CrCLR. More precisely, a 2007 study by Felix M Duerr et al. [13], revealed that an early gonadectomy, performed before six months of age, contributed profoundly to the development of excessive tibial plateau angle. This alternation in the joint conformation is directly linked to cruciate diseases in dogs. Into an agreement with the previous findings, a recent study in 2024 led by Daniel Low [18], supports that an early age gonadectomy, performed before one year of age, serves as a significant predisposing factor in certain breeds, specifically in female Golden Retriever, German Shepherd and Rottweiler. It is worth highlighting that the majority of studies in this area have focused on a limited selection of high-risk breeds [18]. This narrow scope restricts the ability to draw conclusions applicable to the broader population of canine breeds.

4.3 Age and body weight:

As spontaneous rupture is the result of progressive degeneration due to age and overload, it is anticipated that, older and overweight animals have significantly higher risk of CrCLR due to the increased mechanical stress exerted on the ligament. In fact, 2011 research by P Adams et al. [3] revealed that dogs equal to or younger than two years of age are substantially less prone to experience a rupture compared to dogs equal to or older than eight years of age. Nevertheless, it is important not to overlook, that a rupture due to traumatic cause can arise at any age, particularly in young ages, due to their higher activity levels.

Furthermore, obesity frequently contributes to maltreatment of the soft tissue and the development of osteoarthritis, especially in the knee joints, which can further predispose to a CrCLR. It is scarcely surprising that the previously mentioned study also demonstrated a fourfold increase in the risk of CrCLR in overweight dogs [3].

4.4 Physical agility:

It is broadly acknowledged that a proper physical agility both in humans and animals benefits the cardiovascular system and the body in general. However, the majority of traumatic CrCLR incidents originate from a sport accident. Debra C. Sellon et al. [14] in 2022 have evaluated and analysed the risk factors regarding the physical activity, not only in terms of level and frequency, but also in identifying which sports are actually beneficial for the CrCL and which ones could be harmful.

The results that emerged from that study were revolutionary. The findings showed that greater probability lies to canines that participate in fewer sport events, at a lower level, in events with lower jumping hights, and diminished emphasis on tight turns, compared to dogs that participate in events more frequently, more professionally, with more experience and in events with more technical challenges like tight turns. This can be justified due to the fact that, the latter dogs have a greater fitness level, properly developed over the years, as well as a proper core strength. Nevertheless, the same study identified one sport, called flyball, that it is scientifically proven to notably increase the risk of CrCLR, due to quick turns, speed and jumping [14].

4.5 Joint conformation:

Certain joint conformations and structural abnormalities, such as an excessive tibial plateau angle, predispose dogs to CrCLR by increasing the mechanical stress on the ligament [13]. Furthermore, improper joint alignment, osteoarthritis and cartilage degeneration, commonly associated with hip dysplasia and patellar luxation, may exacerbate joint instability and contribute to CrCLR [1]. Another contributing anatomical defect is a congenital predisposition toward hyperextension of the stifle joint [7]. This excessive and prolonged hyperextension forces the stifle joint to bend beyond its normal range of motion, further amplifying the strain on the CrCL and heightening the likelihood of rupture.

5. Treatment:

Over the years, in-depth research in veterinary medicine has focused on identifying the most effective treatment options for CrCLR, given its high prevalence in dogs. Treatment strategies are typically divided into two categories: surgical and conservative [4, 19]. Surgical interventions aim to permanently alter the joint conformation, allowing the stifle joint to function again properly without relying on the CrCL, essentially replacing the ligament [20, 21]. With a wide range of surgical techniques, these procedures are tailored to each individual, continuously advancing to achieve a more effective outcome.

In contrast, conservative treatment takes a less invasive approach, focusing on reducing inflammation, utilizing physiotherapy, and providing joint support, to help the dog regain knee function without surgical intervention [9]. Among veterinarians, surgical treatment is generally considered superior to the conservative treatment for CrCLR, particularly in terms of long-term functional outcomes and faster recovery [4].

5.1 Conservative treatment:

Conservative treatment focuses on managing symptoms and promoting healing without surgical intervention. Although it is not the preferred option for most veterinarians, in some cases, conservative management can be equally beneficial or the only viable option [9]. The extent of CrCL tear is a critical factor in determining the appropriate treatment approach. In case of a partial ligament rupture, where clinical signs and lameness could be relatively mild, conservative management may be considered as a first option before opting for more invasive interventions, such as operation.

In smaller dogs, weighing less than 10-15 kg, less invasive procedures may provide similarly positive outcomes compared to the surgical treatment. A recent study from Thailand in 2024 led by Irin Kwananocha et al. [19], explored the short-term outcomes of Tibial Plateau Levelling Osteotomy (TPLO) versus conservative treatment in small-breed dogs under 10kg. The study found no significant differences between the two groups, suggesting that conservative treatment could be just as effective in some cases.

Furthermore, some patients may not be suitable candidates for a surgical procedure, as they may be unable to fulfil the required criteria. Some of the surgical contraindications include age, weight, coexisting medical issues, compromised health, or sequential approaches for addressing bilateral CrCL insufficiency [9].

The conservative treatment plan consists typically of:

1. Rest and activity restriction: As the ligament requires time to heal and rest, high level of mobility and daily physical activity are contraindicated. Clinicians recommend crate rest, short leash walks, and avoiding any activities that can harm the knee [22].
2. Weight management: Since obesity is a predisposing factor, weight loss may be essential for overweight dogs, as well as sustaining an optimal weight. This will effectively reduce mechanical stress on the stifle joint [22].
3. Anti-inflammatory and pain management: Non-steroid anti-inflammatory drugs (NSAIDs) are the most commonly chosen option as they possess not only anti-inflammatory properties but also analgesic and anti-pyretic effects [22]. However, prolonged administration of NSAIDs, which is often required during conservative management of CrCLR, may eventually lead to unfavourable side effect, including gastrointestinal ulceration, renal damage, hepatotoxicity, and even platelet aggregation inhibition, thereby limiting the possible length of the treatment [23].
4. Physiotherapy: it is one of the most important parts of conservative treatment, as it facilitates the maintenance of muscle mass, enhance the stability of the joint and contribute to overall healing [22, 24]. The spectrum of physiotherapy interventions is vast, encompassing treatments such range of motion exercises, physical conditioning, hydrotherapy, cryotherapy, laser therapy, and transcutaneous electrical nerve stimulation (TENS), among others [9].
5. Orthotic devices: Stifle braces and other devices offer mechanical support by neutralizing the cranial tibial thrust [9].
6. Joint Supplements: These not only help to rebuild the cartilage but also enhance joint flexibility. Substances that can be used are Glucosamine, Chondroitin and omega-3 fatty acid [22].

One might reasonably conclude that conservative treatment is a promising option for small size dogs or patients, who are unable to undergo surgical procedures. While it offers significant benefits, the results it can achieve are limited and according to some, may only be temporarily [9]. The conservative treatment and postoperative physiotherapy are closely aligned, with many aspects being similar, if not identical. Further examination and analysis of these parallels can be found in greater depth in the subsequent chapter on postoperative physiotherapy.

5.2 Surgical intervention

Cranial cruciate ligament surgical intervention aims to restore normal joint movement, alleviate pain, and to regain full function. Given its status as the optimal treatment of CrCLR, especially in cases of severe lameness due to complete rupture, significant attention and resources have been directed toward the development of advanced surgical techniques aimed at achieving the best possible outcome [20, 25]. The principles for the surgical treatment of CrCLR in dogs have evolved over several decades, with major advancements occurring in 1990s.

Over the years some techniques have been outdated, such as Intracapsular 'over the top' Stabilization (ICS) and the Fibular Head Transposition procedure, while others have been improved, like the Extracapsular 'DeAngelis Suture' Technique, which has evolved into the modern Extrascapular Lateral Suture Stabilization (ELSS) and the Tightrope (TR) technique [25]. Moreover, newer techniques have been developed, such as Tibial Plateau Levelling Osteotomy (TPLO) in 1990s, and Tibial Tuberosity Advancement (TTA). These are now the primary and most promising techniques for achieving a faster recovery period and normal function after surgery with fewer post operative complications, despite being more invasive procedures, involving different bone incisions. To this day TPLO, TTA and Extracapsular techniques remain the cornerstones of modern CrCLR surgery [25].

5.2.1 Extracapsular Lateral Suture Stabilization (ELSS)

The fundamental principles of ELSS are to mimic the function of the CrCL and prevent a cranial tibial thrust by positioning a suture in a similar alignment to the original ligament. Following a healing period, the ultimate goal is to promote scar tissue development around the knee, surrounding the joint and offering support similar to that provided by the suture, as the suture will be inevitably undergo gradual elongation or break [20, 25].

The modern version of ELSS, commonly known as the Tightrope (TR) technique, has evolved over time, aiming a more precise implant placement and improved suture strength. This is achieved by placing a single suture loop external to the joint, routing it over the lateral femoral favella and through a bone tunnel formed within the tibial crest [25, 26].

Nowadays, ELSS is commonly used in small to medium-sized dogs, older patients or those with lower activity level. While it is considered a very promising and effective technique, it is less suitable for large, younger patients due to increased incidence of complications in

these animals. This is attributed to their higher activity levels and the corresponding elevated risk of suture failure [26]. ELSS is also a viable option for patients, who are not candidates for more invasive procedures like TPLO and TTA.

ELSS presents a high success rate, with approximately 85% of dogs regaining full or nearly full leg function, and recovery period between 8-16 weeks postoperatively [27]. Like any other surgical procedure, ELSS underlies complications, such as bacterial infection, risk of anaesthesia etc., along with premature suture failure, or surgical errors like inappropriate position of the tibial tunnel and excessive tightening of the suture implants [25].

5.2.2 Tibial Plateau Levelling Osteotomy (TPLO):

The TPLO procedure was invented by Dr Barlow A. Slocum in the early 1990s. This procedure revolutionized the treatment of CrCLR by focusing on altering the biomechanics of dog's stifle joint [21, 25]. Dr Slocum introduced the 'active model' of the stifle joint, which illustrates that the tibiofemoral shear force is influenced by the joint compressive force and the tibial plateau angle (TPA). In the normal stifle joint, the stifle joint flexor muscles, medial meniscus and CrCL are responsible for opposing the shear force [21]. The lowering of the TPA prevents cranial tibial translation relative to the distal femoral condyles by converting the tibiofemoral shear force into joint compressive force during stance. It also improves the flexor muscles' capacity to neutralize any remaining shear force. With a circular cut centred on the tibial intercondylar, the upper part of the tibia is rotated downwards and secured in that position with a metal plate to level the tibial plateau and reduce the TPA to 5°, which is considered critical for a thriving outcome [21].

TPLO shows one of the highest success rates, between 90-95%, but with slightly longer recovery period, that can last between 12-18 weeks [28]. Probable complications involve surgical site infection or implant infection, loosening of screws, delayed healing of the osteotomy, tibial tuberosity and fibular fracture, and meniscal tear [25, 29].

5.2.3 Tibial tuberosity advancement (TTA)

The concept of TTA as a surgical procedure for treating CrCLR in dogs was introduced in Europe by Dr Slobodan Tepic and Professor Pierre Montavon in the early 2000s [30]. TTA was developed as an alternative to TPLO but with the same goal to neutralize the tibiofemoral shear force during weight-bearing by altering the biomechanics of the stifle joint. [25].

According to Wikipedia on TTA, ‘a microsaggital saw is used to cut the tibial tuberosity off. Afterwards, a special titanium cage is used to advance the tibial tuberosity, and a titanium plate is used to hold the tibial tuberosity in position. An incision is made through the tibia parallel to the tibial crest and a cage implant is inserted between the tibial tuberosity and the bulk of the tibia to advance the tibial tuberosity’ [30]. Over time, bone integrates with the cage implant, eventually becoming part of the bone structure. By doing so, the shear force, created by the CrCLR, is successfully neutralized and finally joint becomes more stable.

TTA has a 90% success rate [31], however, it exhibits a greater incidence of complications in comparison to the other surgeries [32]. As previously mentioned, general surgical complications include a) oedema and extensive bruising, b) seroma and c) incisional infection. Other complications such as intraoperative, haemorrhages, iatrogenic lateral digital extensor (LDE) tendon injury, and iatrogenic patella tendon injury can also emerge [25, 31].

Upon reviewing various surgical techniques, it became evident that preferences for specific procedures vary among surgeons, clinics and even countries. Numerous studies present differing results regarding the efficacy of these surgical techniques. For instance, a 2010 study, led by James L. Cook et al. [33] found no significant difference between TPLO and TR procedures six months postoperatively in terms of radiographic evidence of OA progression and client-reported functional outcomes. In a subsequent study conducted in 2013 by James L. Cook et al. [32], it was concluded that, based on subjective evaluation by both clients and veterinarians, long-term results for TPLO and TR procedures were superior to TTA. While all three techniques had high rated of long-term success, the TR procedure demonstrated the best balance between safety and effectiveness. However, it is important to note that both studies relied on subjective assessments.

Consequently, determining a superior technique objectively may not be entirely feasible. A more appropriate approach would involve the selection of the most suitable technique based on several patient-specific factors, such as size, activity level, age, weight, joint conformation (e.g. shape of the tibia), severity of the lameness, clinical state of the patient, other concurrent pathologies (e.g. meniscus injury), and the anticipated recovery period [20]. After reviewing these parameters, one may conclude that TPLO is more appropriate for large, highly active dogs, compared to ELSS, which is preferable mostly for smaller sized dogs. On the other hand, if the objective is to achieve a faster recovery with minimal

invasion, TR is the optimal choice [33]. Lastly, TTA is appropriate for dogs of various sizes and activity levels, offering a shorter recovery period compared to TPLO. However, it is associated with a higher complication rate relative to other surgical techniques [32].

6. Postoperative physiotherapy:

Post-operative physiotherapy is a crucial part of the rehabilitation process, aimed at restoring motor function of the joint and ensuring optimal outcomes following surgery [7]. In recent years, the use of veterinary physiotherapy following orthopaedic surgeries has seen a significant rise. Veterinary surgeons are increasingly recognising that surgery, even when combined with conventional protocols, may not be sufficient on its own to fully restore normal function in animals.

In 2006, Michelle L Monk [34], a specialist in canine physiotherapy and rehabilitation, conducted a study evaluating the effects of early intensive postoperative physiotherapy on limb function after TPLO. The study found that dogs undergoing physiotherapy exhibited not only a significantly larger thigh circumference, but also a greater range of motion compared to those in the home-exercise group. This realisation has paved the way for the long overdue recognition of physiotherapy in the veterinary field.

A more recent study in 2015 by Laura S Romano et al. [5], further validated the benefits of postoperative physiotherapy. The study provided statistical evidence demonstrated that the rehabilitation group was 1.9 times more likely to achieve full functional recovery within eight weeks post-surgery. In contrast, the traditional treatment group was 2.9 times more likely to be classified as having unsatisfactory function during the same period of time.

As it encompasses a variety of approaches and techniques, including massage, passive range of motion exercises, active exercises, and hydrotherapy [24, 35], physiotherapy has been demonstrated to be an optimal option for pain management, enhancing muscle mass and mitigating post-operative muscle atrophy [34]. It also improves the range of motion of the stifle joint and prevents further development of osteoarthritis [7, 36]. Additionally, specialized techniques such as proprioceptive training can be employed to promote neuroadaptation, while also strengthening a specific muscle group [37]. Adherence to the rehabilitation protocol is essential for achieving optimal recovery and minimizing the risk of complications. This objective can only be attained by taking into account multiple parameters such as the patient's age, and health status, and physical activity as well as the

surgical technique performed. Furthermore, regular assessments and adjustments are necessary to accommodate the patient's progress and evolving needs [35].

Postoperative rehabilitation can be categorised into the following phases [38]:

- Acute phase – 0 to 72 hours
- Early rehabilitation phase – 72 hours to 4 weeks
- Advance rehabilitation phase – 5 to 8 weeks
- Return to activity phase – 9 to 12 weeks

6.1 Acute phase: 0 to 72 hours

This period represents one of the most critical phases in the patient's recovery. Having just been discharged from the hospital, the patient is particularly vulnerable to the effects of inflammation, including pain, effusion, loss of motion, and muscle atrophy. Additionally, without proper supervision, there is a significant risk of engaging in unintended activities that could result in the rupture of sutures. The desired outcome is to minimize the inflammation, pain and effusion as much as possible, while also reassessing full range of motion, and preventing muscle atrophy and joint contracture [38, 39]. Therefore, this phase can be categorized into two-parts, a. prevention of infection and adverse inflammatory effects and b. therapeutic exercises.

a. Prevention of infection and adverse inflammatory effects:

Antibiotics are commonly administered to prevent postoperative infections, as CrCLR surgeries involve significant tissue disruption, increasing the risk of bacterial contamination, especially at the surgical site or around the implant used to stabilize the knee. Typically, broad spectrum antibiotics such as cephalosporins are administered, and in some cases, amoxicillin and clavulanic acid are also used. Antibiotics are generally administrated for a short period of time, typically raging from five to fourteen days [40]. For osteotomy procedures such as TPLO, where bone implants are involved, the risk of implant related infections, such as biofilm formation on the implant, makes postoperative antibiotic treatment crucial. In cases of deep or persistent infections, local or longer courses of antibiotics may be necessary, and in rare situations, the implant might need to be removed after the proper healing of the bone [29].

Delving into the prevention of adverse inflammatory effects, one of the most prevalent options for contradicting inflammation is the use of non-steroid anti-inflammatory drugs

(NSAIDs). It is well established that the primary purpose of NSAIDs is to exert anti-inflammatory effects, along with providing analgesic and anti-pyretic benefits. These drugs operate by inhibiting the Cyclooxygenase (COX) enzyme, which in turn prevents the synthesis of Prostaglandin E, F, I and Thromboxane [23]. More specifically, second generation of NSAIDs, such as Meloxicam, offers more selective inhibition of COX-2. This selectivity helps to consequently reduce the typical adverse effects associated with NSAIDs [23]. Additional treatments, such as cryotherapy, laser therapy, and transcutaneous electrician nerve stimulation (TENS), can be employed to prevent further inflammation-related complications [9].

With its rising popularity in recent times, cryotherapy has become a reliable treatment option for numerous illnesses and ailments in dogs, particularly a potent treatment for musculoskeletal and skin diseases. The dog is subject to extreme cold through several methods such as briefly placing the dog in a cryotherapy chamber. Veterinarians often prefer cryotherapy on smaller areas, utilizing cold packs, ice bath or localized freezing techniques [35, 41]. In the initial 72 hours following surgery, cryotherapy plays a crucial role in the rehabilitation process. The application of extreme cold serves to constrict the blood vessels, thereby reducing blood flow to the injured area. Additionally, it decreases the velocity of nerve conduction, counteracting the adverse effects of inflammation, such as pain, swelling, heat and redness. Acknowledging that prolonged or improper application of ice can lead to skin irritation, redness or frostbite, each cryotherapy session should be limited to no more than 10 to 20 minutes or even shorter in case of discomfort. However, sessions can be repeated 3 to 4 times per day [39].

An even more revolutionary treatment technique of the modern era is laser therapy in dogs. The foundation of laser therapy is based on photobiomodulation, a therapeutic technique that uses light to promote healing, reduce inflammation and alleviate pain. A concise overview of its mechanism of action, is that the absorbed light energy stimulates cellular activities, including increased ATP (adenosine triphosphate) production, enhanced cellular metabolism and improved tissue repair and regeneration. In addition, it causes the reduction of inflammatory mediators and the promotion of anti-inflammatory factors. Lastly, it can affect pain pathways and reduce nerve sensitivity [42]. Recent studies have presented promising results regarding the benefits of laser therapy, however, further research is required to draw definitive conclusions [43].

Finally, Transcutaneous electrical nerve stimulation (TENS) is increasingly utilized in veterinary medicine, commonly for managing conditions such as post-surgical pain, OA and hip dysplasia. The treatment involves the application of low voltage electrical impulses, which stimulate the sensory nerves through electrodes placed on the skin near the area of pain [44]. By doing so, the perception of pain is being reduced or blocked, the pain signals sent to the brain are interrupted and it is also believed to stimulate the production of endorphins. TENS sessions usually last between 10 to 30 minutes, with dogs generally tolerating this procedure well and often experiencing pain relief shortly after [39, 44].

b. Therapeutic exercises:

Rest and controlled movement: Upon returning home after the surgery, the animal will require ample rest and continuous observation. Postoperative rest is vital for the patient, as the body needs time to heal. From the first day, it should be placed in a controlled and safe environment, with constant and rigorous observation. Any uncontrolled and unintended movement must be avoided, as it can result not only in suture rupture, but also, more severely, in damage at the surgical site. Therefore, unnecessary movement must be hindered, and assistance must be provided during ambulation [36]. Small dogs should be carried up and down the stairs and during the walks for bathroom breaks, which should be limited to a short time, no more than 5 to 10 minutes. For larger dogs, assistive devices such as hip harness can be used to provide support during weight bearing and guidance during movement. A more simplified and more affordable solution that provides a similar effect is using a towel as a sling [39]. It is crucial to point out that absolute withholding movement will unquestionably lead to harmful consequences, including, muscle, tendon and joint stiffness, arthrofibrosis and muscle atrophy [36, 39].

Massage: The healing benefits of massage have been known from many centuries, however the remarkable effects that can offer as a postoperative treatment are only being recognized in recent years [45]. Due to release of endorphins, pain management and reduction can be achieved. Furthermore, precise strokes enhance blood circulation and lymphatic flow, which not only eliminate possible swelling and oedema but also support the maintenance of muscle tone, reduce fibrosis and atrophy of both muscles and tendons, and alleviate stifle joint stiffness, a well-established result of knee surgery [39]. It is essential to bear in mind that the entire body has been affected from the CrCLR and during the pre-operative period, has been compensating to maintain the physiological movements and functions of the CrCL.

Therefore, the therapeutic massage must not be localised only on the operated limb but also on the rest of the body. Ideally, a qualified personnel should perform the massage, however after thorough and precise instructions, regarding the pressure, direction and hand movements that must be applied, the owner is capable of performing it as well [36, 39].

Passive range of motion (PROM): PROM exercise is a type of physical therapy where an external force, such as a therapist, moves a joint through its available range of motion without the patient's active involvement [46]. As highlighted above, proper rest and restricted movement is indicated at the beginning but prolong immobilization will result in reverse effects [36, 39]. In the absence of passive range of motion, joint contracture can develop, a condition in which a joint becomes, on most occasions, permanently shortened due to the tightening of the surrounding muscles, tendons, or other soft tissues, consequently resulting in movement range limitations [47]. For this reason, PROM is an essential component during the acute phase of rehabilitation.

Stretching: Similar to the indication of PROM exercises, stretching helps to counteract the side effects of postoperative immobilization, while focusing on the muscles. More specifically, it enhances proper blood support of the muscles and joints, increases flexibility of muscles, tendons, joints and surrounding tissue, as well as, maintaining muscle tone, reducing atrophy and gradually restoring muscle strength [36, 39]. A frequent issue of consideration following a CrCLR surgery is the rapid and substantial weakness of quadriceps femoris muscle. This can be prevented with early and successful stretching, which aids in achieving full knee extension, restoring normal patellar mobility and correcting abnormal gait patterns [36, 39].

6.2 Early rehabilitation phase: 72 hours to 4 weeks

Following the acute inflammatory phase and the necessary actions to counteract the inflammatory side effects, the focus in early rehabilitation phase shifts into regaining and improving normal movements such as weight-bearing, proprioception and gait. This phase begins after the first 72h post-surgical and it last until the first 2 to 4 weeks [38].

Heat Therapy: Heat therapy should only be initiated after the first 72 hours, as it produces effects contrary to those of cryotherapy. It is crucial to recognize that premature application of heat therapy may exacerbate oedema, swelling and potentially lead to seroma formation [39]. In spite of this, when applied at the appropriate time, heat therapy is extremely beneficial for the patient, as it can achieve analgesia, muscle spasms reduction, relaxation,

increase in local blood flow and enhance local tissue metabolism, all of which contribute to accelerated tissue healing [35, 39]. Taking all the above-mentioned benefits into consideration, therapists have concluded that heat therapy is an ideal complement to physical exercise preparation. Even more advantageous could be the moist heat therapy, compared to dry heat therapy, as the moisture enables the heat to penetrate more deeply into the tissue [39].

Short and slow controlled leash walks: One of the most essential stages of postoperative physiotherapy, as it reintroduces gradually the patient to the normal daily physical activities and reinitiates the operated leg in the movement [35]. The proper way to perform this exercise is by placing the patient very close to the owner during the walk. This allows the owner to have a complete control over the dog and intervene or assist when necessary. A slow walk will encourage the dog to use the affected limb and furthermore a short walk will gradually increase the strength of the leg, without excessive effort. This helps avoid adverse effects, such as overexercise, microtrauma of the muscles, tendons and ligaments, and possible recurrence of inflammation [39]. Moreover, walks can have a positive emotional effect on the patient, which can further lead to faster healing and improvement. At the beginning of these walks, hip harness can be used for better support and control. As the time passes and the improvement of the patient becomes observable, the harness can be removed, and the length of the walks can be extended as well [35, 36, 39].

Land treadmill and hydrotherapy: Both can be used as alternatives to the previous exercise or even as advancements of it. Equally land treadmill and hydrotherapy provide a safe and controlled environment for the patient, as the therapist can adjust the speed and inclination as well as provide appropriate assistance [35, 39]. These can result in the involvement of the affected limb, strengthening of the muscles, enhancing proprioception, re-establishing normal gait and improvement of the cardiovascular system and endurance. Hydrotherapy on the other hand, provides an extra advantage due to buoyancy, thereby decreasing the weight-bearing forces on the operated limb and allowing the patient to move more easily [35, 39].

Sit to stand exercise: This exercise is advantageous for two primary reasons. Firstly, the quadriceps, hamstrings, gastrocnemius and gluteal muscle groups will be strengthened. Secondly, the range of motion (ROM) of the hip, knee and hock joints will be improved, provided that proper sitting and standing position are executed [35]. As it is described in Topdog health TTA rehabilitation home guide [39], a proper sitting form should be ‘square’,

with both legs flexed and equally positioned under the dog's body. In addition, a proper standing position begins from the sitting position and should involve an equal push from both hindlegs.

6.3 Advance rehabilitation phase: 5 to 8 weeks

Advancement to this phase is permissible only if the patient has been fully reintroduced to the basic movements and the therapist has observed a proper execution of the aforementioned exercises. Additionally, the patient must demonstrate comfort during the performance of those exercises, without any signs of discomfort [35, 39]. Since the patient has achieved all of the above, the desirable outcome at this stage is further improvement of patient's strength, as well as re-establishing proper stability, proprioception and endurance. On the other hand, it is important to note that a premature transformation into the advance phase of rehabilitation can compromise the patient's recovery, making careful handling essential [38].

The exercises initiated during the early rehabilitation phase will be continue into the advance rehabilitation phase as well, with progressive increase in difficulty, length and duration [38]. Clearly, there are different variations, which could reflect the different time periods of rehabilitation and the physical strength of the patient. For instance, the duration and pace of leash walks will be gradually increased and as rehabilitation progresses, they may be replaced by slow, controlled hill walking. As a greater portion of the dog's weight is repositioned to the hind legs while walking uphill, it provides a remarkable exercise for strengthening the four primary muscle groups of the rear legs. Not only that, but it also enhances hip and knee extension and improves joints range of motion [35, 36, 39].

An increase in difficulty can be observed when the dog is walking downhill, as there is an increase in flexion and extension of the hip, knee and hock joints, making it a highly advantageous exercise for the dog. An alternative exercise while walking on the hill, is the perpendicular walking across the hill, positioning the operated leg on the side facing downhill. This will compel the dog to place a larger amount of body weight on the affected leg. Strengthening the entire body and restoring loss muscle mass are among the key benefits of controlled hill walking [35, 39].

Stairs: Moving into a more challenging exercise, stair climbing engages a remarkable combination of movements that strengthen the hindlimb muscles, increase muscle mass, and enhance joint range of motion, including flexion and extension [39]. Complete control of the

patient at the beginning, along with the use of a small number of stairs is required. As the dog develops greater control and confidence, the duration and the length of the exercise can be progressively increased. Nevertheless, even at an advanced level of rehabilitation, dogs must not be left unsupervised while practise the stair exercise, as the risk of falling and re-injuring themselves remains significantly high [35, 39].

Balance and proprioception exercises: Balance and proprioception are two essential abilities for movement in both humans and animals. These closely related principles play a crucial role in maintaining stability. Balance is defined by oxford languages as ‘an even distribution of weight enabling someone or something to remain upright and steady’ [48], while proprioception as ‘perception or awareness of the position and movement of the body’ [49]. Both functions can be disrupted, initially during the rupture of the cranial cruciate ligament as the body attempts to compensate, and later during the post-surgical period due to prolonged immobilization or absence of limb use [35].

As the body strengthens during rehabilitation and the muscle can perform more advanced exercises, it becomes appropriate to incorporate exercises that target the improvement of balance and proprioception [35]. Balance or wobble boards as well as therapy balls can be used to make the animal understand that the operated limb is no longer painful. In addition, they can be utilized for weight shifting exercises by placing the dog’s forelimbs on the board surface and the hindlimbs remain in a standing position on the floor. At a more advanced stage, all four limbs can be placed on a balance board, which requires a higher level of core strength and balance [35, 36, 39].

Figure 8 walking exercise: Another exercise in the same category is the figure 8 walking exercise. By walking the dog in a figure 8 pattern, the body is compelled to move in a multidirectional path, requiring coordinated movement between different parts of the body. This enhances proprioception and spatial awareness. Furthermore, it engages multiple muscle groups, increases joint range of motion, and stimulates joint stability, particularly in the hip, knee and hock joints. The exercise must be initially performed slowly, with the patient placed close to the owner to allow them an appropriate control and support [36, 39].

Cavalletti rails: Rails utilized as obstacles are placed above the ground and at certain distances so that the patients can walk over them. The use of cavalletti rails offers several advantages, such as enhancing stride length, improving ROM of the joints, boosting proprioception, increasing balance and encouraging limb use [35]. Another practical

advantage of this exercise is that the rails can be positioned at various height levels and distances. Additionally, the speed of the animal can be increased while performing this exercise to achieve the desirable outcome. In the beginning, the rails must be placed at an appropriate distance apart and set at the lowest possible height while the animal moves at a slow pace. As the distance between the rails decreases and the height increases, the level of difficulty is progressively enhanced, leading to an increase in flexion and extension of the limbs [35, 39].

6.4 Return to activities phase: 9 to 12 weeks

As this marks the final stage of physiotherapy and the rehabilitation process nears completion, the primary objective is to further strengthen the animal by introducing more challenging exercises, such as jogging and swimming, as well as the gradual return of the patient to normal activities [38]. Swimming is an excellent exercise during this stage, not only improves core strength, joint ROM and cardiovascular system, but it also provides a no impact environment, thereby reducing the risk of injuries [39]. It should be emphasized that the decision for moving to this stage of physiotherapy should be made by the surgeon, following confirmation of adequate healing. As anticipated, osteotomies may require 8 to 12 weeks for complete healing, during which additional caution should be applied with these patients [38].

It is important to restate that physiotherapy rehabilitation protocols must be tailored to the specific needs and goals of each individual patient. Proceeding cautiously through the various stages while closely monitoring the patient's level of pain, comfort and confidence is essential. Finally, performing exercises without professional supervision is inadvisable and may lead to adverse effects [35, 38].

In light of the above, postoperative physiotherapy plays a vital role in the rehabilitation process. Incorporating physiotherapy into postoperative care not only promotes faster recovery but also improves the long-term outcomes and quality of life for patients recovering from CrCLR.

Study

1. Aims

This study was designed to provide an in-depth analysis of CrCLR, following the condition from its onset through the completion of the rehabilitation process. The research focused on three main goals: the identification and analysis of predisposing factors associated with CrCLR in dogs, treatment preference among veterinarians and dog owners, assessing their efficacy, and examining the current surgical techniques used for the treatment of CrCLR in dogs alongside their success rate. Additionally, the study aims to evaluate the recognition of postoperative physiotherapy in the veterinarian field during the recent times and its effectiveness in enhancing the rehabilitation process.

As a result, this study has the potential to significantly enhance the understanding of risk factors contributing to the development of CrCLR in dogs, and therefore enabling more targeted strategies for prevention. Furthermore, the insight gained from this research will enable veterinarians and dog owners to make well-informed decisions regarding treatment approaches and postoperative rehabilitation, which will inevitably increase the success rate of CrCLR treatment, minimize unnecessary complications and treatment failures, and eventually improve the quality life of the affected animals.

2. Materials and Methods

An internet-based questionnaire was created and addressed to dog owners whose dogs suffered from a CrCLR. It was divided into five chapters, providing the necessary focus for each phase of the condition: prior to the treatment, treatment, and postoperative phase.

I. Dog's general information
   a. Signalment: breed, sex, age, weight, neutered status, dog's purpose-based classification (pet/sport/working animal) – at the time of the incident.
   b. CrCLR related information:
      i. Was it a partial or a complete rupture?
      ii. Was it a traumatic incident or due to degeneration?
      iii. Degree of lameness, instability, before any treatment was performed.
      iv. Type of treatment: surgery or conservative treatment.
      v. Why was this specific treatment chosen?

II. Conservative treatment:
    a. What kind of conservative treatment was performed?
    b. Why was this treatment chosen?
    c. How long was the duration of the conservative treatment?
    d. Degree of lameness, instability, after the conservative treatment.
    e. If the conservative treatment didn't work, was there a surgery performed?

III. Surgery:
    a. What type of surgery was performed?
    b. Why was this specific type of surgery chosen?
    c. Was this choice of treatment effective?

IV. Physiotherapy:
    a. Did the patient have any physiotherapy after the surgery?
    b. Did the surgeon suggest a follow up with a physiotherapist or did the surgeon provide a physiotherapy plan?
    c. If yes, how many days after the surgery did the physiotherapy start?
    d. During the 1st, 2nd, 3rd and 4th week of Physiotherapy, what kind of procedures/ exercises were performed?
    e. How long did the physiotherapy last?
    f. Degree of lameness, instability at the end of physiotherapy.

V. Without physiotherapy: degree of lameness and short description on the improvement of the dog's movement within the following months.

The spread of the questionnaire started on the 21st of July 2023 and ended on the 13th of September 2024. It was shared on multiple social media groups, e.g. Facebook, Instagram, mostly related to the veterinary field and veterinary physiotherapy. By the end of this period, a total of 58 responses were recorded, out of which 2 were rejected due to an unacceptable completion of the questionnaire due to various reasons, resulting in a total of 56 acceptable responses.

The questionnaire was shared across two different continents, Europe and America, with responses originating from nine different counties, Cyprus, Canada, Ireland, USA, Hungary etc. The majority of the respondents were from Cyprus (62.5%, n = 35), as it had the largest audience for the shares.

3. Results:

3.1 Breed:

The largest proportion of dogs represented in the results were mixed breed (33.9%, n = 19). Even though some owners were able to specify the primary breed of their mixed-breed dog (e.g. Pitbull mix, Jack Russel mix, Poodle mix etc.), the majority did not provide such details. Additionally, most of the remaining breeds in the dataset were represented by only one or two cases. Maltese and American Staffordshire Terrier were the only two breeds that had three cases, each reaching just 5.4%.

Therefore, after excluding the mixed breed participants, a further categorization of the dog breeds was made based on their size, 'large breeds' and 'small breeds'. The findings indicated that 62.2% (n = 23) of the participants were classified as large breeds, whereas 37.8% (n = 14) were classified as small breeds (Figure 1).

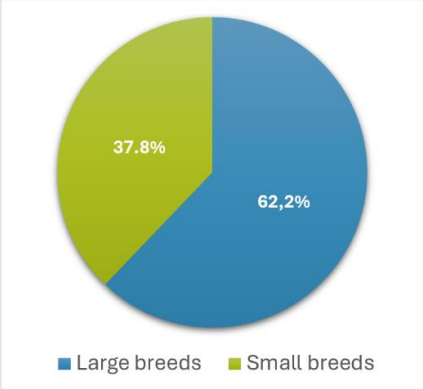

Figure 1: Distribution of the participant breeds size (%).

3.2 Gender, neutered status and overweight:

Among the questionnaire respondents, the gender distribution was 22 (39.3%) males and 34 (60.7%) females. Of these, 13 (59.1%) were neutered and 21 (61.8%) spayed, respectively. Furthermore, 28.6% (n = 16) of the participants were overweight at the time of the incident, 50.0% (n = 28) were of normal weight, and a minor proportion of 21.4% (n = 12) of the owners could not recall the weight status of the animal at the time of the incident.

3.3 Age and cause of rupture:

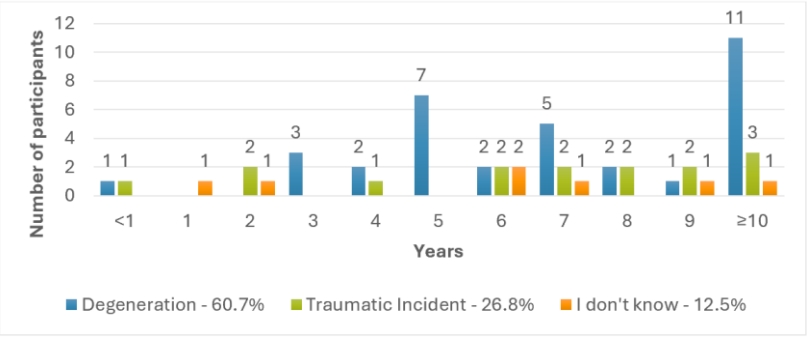

Figure 2: Correlation between age at the time of the incident and the cause of ligament rupture.

Figure 2 illustrates the age at the time of the incident, the cause of rupture, and the correlation between these two variables. As anticipated, the primary cause of rupture is degeneration, accounting for a significant 60.7% (n = 34) of cases. Traumatic incidents were responsible for 26.8 % (n = 15) of cases, while a small percentage of participants (12.5%, n = 7) were unable to

identify the cause of rupture. On one hand, the main age groups of dogs that experienced CrCLR due to degeneration were middle aged and elderly. On the other hand, the frequency of traumatic incidents across different age groups was relatively evenly distributed. Overall, the age groups were categorised as follows: adolescent (< 2 years of age) - 5.4% (n = 3), adult (between 2 and 5 years of age) – 28.6% (n = 16), Senior (between 6 and 9 years of age) – 39.3% (n = 22), and geriatric (≥ 10 years of age) – 26.7% (n = 15).

3.4 Dog's purpose-based classification and cause of rupture:

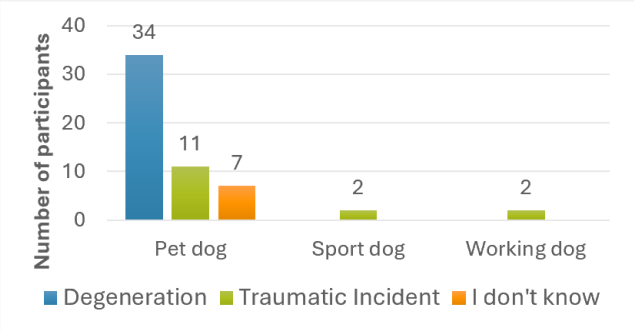

Figure 3: Purpose-based classification of dogs and associated causes of ligament rupture. Classification categories include: a) Pet dog, b) Sport dog, and c) Working dog.

In close relation to the previous figure, this one shows the correlation between the dog's purpose and the cause of rupture. Among the 56 participants, 52 were classified as pets (92.8%), 2 as sport dogs (3.6%), and 2 as working dogs (3.6%). Moreover, the results clearly demonstrate a strong correlation between the dog's purpose-based classification and the cause of rupture. Traumatic incident was the sole cause of rupture in both sport and working dogs. In contrast, degeneration accounted for nearly two-thirds (65.4%, n = 34) of the cause of rupture in pet dogs, followed by traumatic incident at 21.2% (n = 11) and unknown cause at 13.4% (n = 7) (Figure 3).

3.5 Treatment:

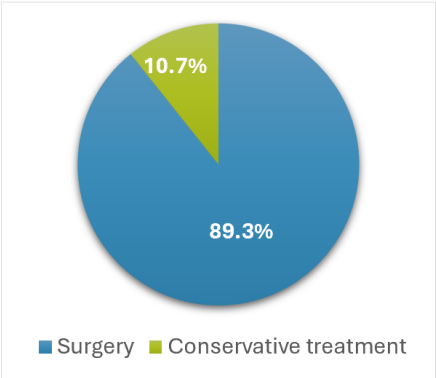

Figure 4: Types of treatment selected for CrCLR. Categories: a) Surgery and b) Conservative treatment.

An overwhelming of 89.3% (n = 50) of responders selected surgery as treatment, while only 10.7% (n = 6) chose conservative treatment, making surgery the most preferred choice among both veterinarians and owners (Figure 4). Participants were asked to explain the reasoning behind their choice, with the option to select multiple responses available. The majority of participants selected 'Veterinarian's preference' (89.7%) as the primary factor in the decision-making process, followed by 'owner's preference' (36.2%), activity level (25.9%) size (22.4%), age (24.1%), clinical state (17.2%) and weight (17.2%). At a percentage less than 10.0% of the responses cited 'economic reasons' and the 'stability of the joint'.

3.5.1 Conservative treatment:

Figure 5: Success rate of conservative treatment for CrCLR.

A small portion of the questionnaire focused on conservative treatment options. Of the 56 respondents, only 6 opted for this approach. The graph (Figure 5) on the left, presents the successful rate of conservative treatment, with the failure rate reaching 66.7% (n = 4) and the success rate at 33.3% (n = 2). Two out of the four failures eventually underwent surgery due to the ineffectiveness of conservative treatment. One respondent reported slight improvement, with the degree of lameness reducing from 4th to 3rd degree. However, further treatment, such as surgery was not feasible in this case due to the animal's advanced age.

In another case of failure, surgery was not plausible due to the lifestyle and responsibilities of the owner. The remaining two respondents reported successful outcomes, achieving full recovery with conservative treatment. Medication such as Meloxicam (administrated either intra-articularly or orally) Gabapentin, and Carprofen were used in 5 out of 6 cases. In one instance of full recovery, stem cell therapy was utilized as the primary treatment, along with physiotherapy. Lastly, it is important to note that in 5 out of 6 cases, the primary factor influencing the decision of the treatment was 'owner's preference'. Other factors, such as the clinical state, age, size and weight of the patient were mentioned sporadically across responses without establishing a discernible pattern.

3.5.2 Surgical intervention:

The success rate of surgery significantly surpasses that of conservative treatment, achieving an impressive 90.0% (n = 45) success rate with only 10.0% (n = 5) failure rate (Figure 6).

Figure 6: Success rate of surgical treatment for CrCLR.

The distribution of different surgical techniques chosen and their individual success rate can be illustrated effectively in the graphs bellow (Figure 7 and 8). Tibial Plateau Levelling Osteotomy (TPLO) is the most frequently selected procedure, accounting for 70.0% (n = 35) of cases. This is followed by Extracapsular suture at 20.0% (n = 10), and lastly, the Intracapsular

suture at 2.0% (n = 1). Additionally, 8.0% (n = 4) of participants were unsure of the type of surgery that was performed. Regarding the success rate of the surgical techniques, the results were presented as follows: TPLO showed a success ratio of 34:1, Extracapsular suture had a success ratio of 7:3, indicating a 97.1% (n = 34) and 70.0% (n = 7) success rate respectively. Finally, Intracapsular suture was performed only once and was unsuccessful.

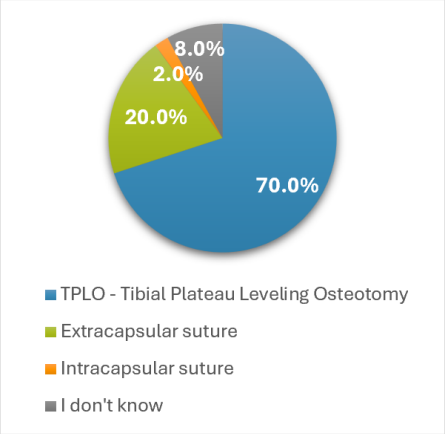

Figure 7: Percentage distribution of patients by surgical type, including: a) TPLO (Tibial Plateau Levelling Osteotomy), b) Extracapsular suture, c) Intracapsular suture, and d) 'I don't know' option.

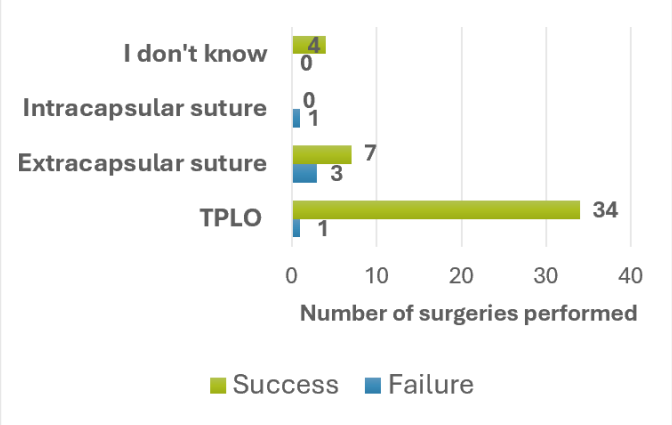

Figure 8: Success and failure rates of specific surgical types for CrCLR.

Participants were asked once more to clarify the criteria that both the veterinarian and they themselves took into consideration upon their decision on the specific surgical technique. Same as above, the option of selecting multiple responses was available. The majority selected 'Surgeon's preference' with 90.9%, followed by size 18.2%, clinical state 16.4% and weight 12.7% of the patient, further influenced the decision-making process. Factors such as the patient's age and weight, economic reasons and 'owners' preference' were each cited by less than 10.0% of participants.

3.6 Physiotherapy:

Physiotherapy was addressed in the final section of the questionnaire. Notably, 84.6% (n = 44) of the 52 participants who underwent surgery – including 50 participants who chose surgical intervention as the initial treatment and 2 who opted for surgery after the conservative treatment failed – reported receiving physiotherapy as part of their postoperative rehabilitation (Figure 9).

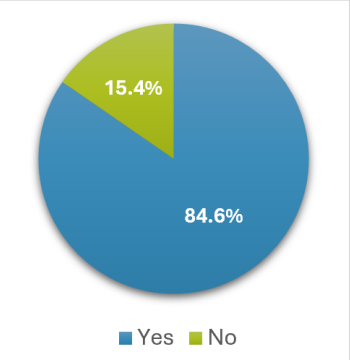

Figure 9: Percentage of patients who underwent physiotherapy following surgery.

As to the surgeon's approach regarding post-operative physiotherapy, participants were asked how they were informed about the physiotherapy plan and their available treatment options. Among the respondents, 75.0% (n = 33) indicated that a physiotherapy plan was provided by the surgeon, 6.8% (n = 3) reported that a referral to a physiotherapist was suggested, 11.4% (n = 5) mentioned receiving either of these options, and 6.8% (n = 3) stated that the surgeon made no suggestions.

As part of the evaluation process on the effectiveness of physiotherapy, participants were provided with a lameness scale and asked to select the most suitable option, that describes accordingly their dog condition (Figure 11).

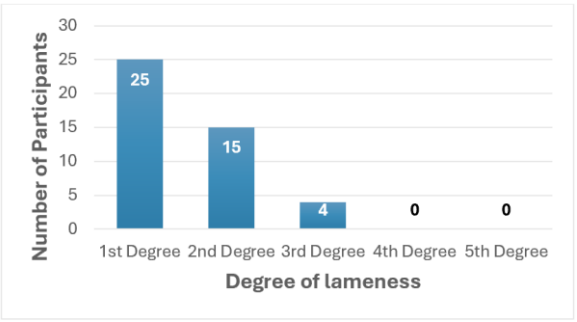

Figure 11: Degree of lameness by the end of physiotherapy.

Figure 10: Lameness scale in dogs - Degrees of lameness and pain. *[50]*.

Among the respondents who reported undergoing postoperative physiotherapy, 25 (56.8%) indicated that their dogs achieved full recovery, corresponding to the 1st degree of lameness. Additionally, 15 participants (34.1%) indicated a 2nd degree of lameness, signifying mild discomfort. Finally, 4 participants (9.1%) selected the 3rd degree of lameness, indicating that their dogs exhibited moderate lameness. Notably, no responses were recorded for the more severe degrees of lameness, 4th and 5th (Figure 10). The same lameness scale was provided to participants, who reported abstaining form postoperative physiotherapy. Of these 8 respondents, 4 (50.0%) selected 1st degree of lameness, 2 (25.0%) indicated the 2nd degree of lameness, and 2 (25.0%) reported 3rd degree of lameness. As in the previous group, no responses were recorded for the more severe degrees of lameness, 4th and 5th.

Lastly, participants were initially provided with a lameness scale and asked to evaluate their dog's condition before any treatment was administrated. The same question was posed after each treatment session and the results were collected accordingly. Prior to the treatment, the degree of lameness predominantly ranged from the 3rd to the 5th degree, with 28.6% (n = 16), 48.2% (n = 27), and 21.4% (n = 12) of the total 56 participants reporting these levels, respectively. In contrast, 0% (n = 0) and only 1.8% (n = 1) of participants reported 1st and

2nd degree lameness, respectively. Following any kind of treatment, the distribution shifted towards lower degrees of lameness, with 55.4% (n = 31) of participants reporting 1st degree, 32.1% (n = 18) reporting 2nd degree and 12.5% (n = 7) reporting 3rd degree of lameness (Figure 12 and 13).

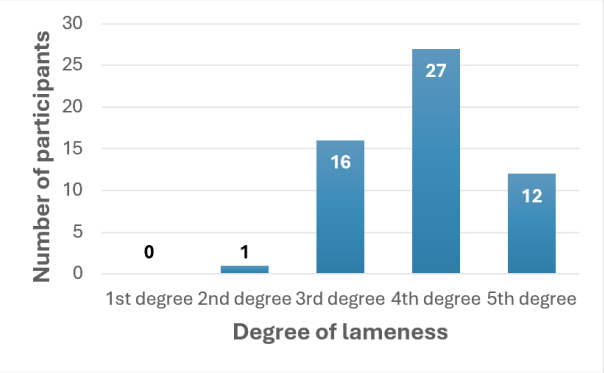

Figure 13: Degree of lameness prior to treatment initiation.

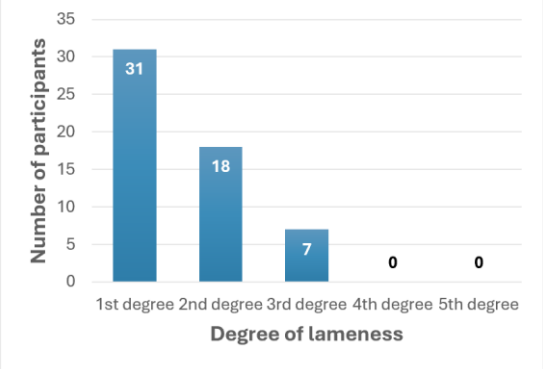

Figure 12: Degree of lameness following various treatment approaches.

Discussion:

Canine cranial cruciate ligament rupture (CrCLR) is among the most commonly encountered orthopaedic conditions in the veterinary medicine. This study aimed to address limitations in the existing literature by providing a complete overview of CrCLR.

Most of the research on breed predisposition of CrCLR has largely focused on validating the increased susceptibility of specific hypothesized breeds to the rupture. In contrast, in this study, no particular breed was targeted, resulting in the documentation of a wide variety of breeds in which CrCLR occurred. Notably, mixed-breed dogs constituted the largest group, representing 33.9% of the participants. Furthermore, the remaining breeds included in the study each accounted for 5.4% or less of the total sample, thereby limiting the ability to conduct a solid breed-specific analysis to a greater extend. Due to the lack of breed specificity in these cases, it was not possible to establish a definitive correlation between individual dog breeds and CrCLR susceptibility.

Nevertheless, some of the most well-documented predisposing breeds in the literature [12, 15], such as American Staffordshire Terrier, Rottweiler, Golder Retriever, and Bichon Frise were also represented in the results of this study. To identify potential patterns, an additional categorization was implemented, dividing the breeds into ‘large breeds’ and ‘small breeds’. This categorization revealed that nearly two-thirds (62.2%) of the breeds represented in this

study were large breeds, a finding consistent with the research conducted by the University of Veterinary and Pharmaceutical Sciences in Brno of Czech Republic [15].

Moreover, small breeds such as Yorkshire Terrier and Jack Russel Terrier were also included among the respondents, coming into an agreement with the recent study by C. Pegram et al. in 2023 [12], that first documented that small breeds are also susceptible to CrCLR. A potential hypothesis arising from these findings is that breed-specific predisposition may be less significant, with the primary predisposing factor being the size of the animal and the additional mechanical stress it places on the ligament. However, conformation of this hypothesis would require a much larger database.

Two closely related predisposing factors for CrCLR are gender and neutered status, both of which are influenced by the level of reproductive hormones such as oestrogen. The results of this study align with previous research [3, 17], which placed females at a higher risk than males, as well as dogs that have undergone a gonadectomy. Among the participants, 60.7% were females and 39.3% were males, with 60.7% of all respondents, regardless of gender, having been neutered.

Unexpectedly, this study revealed different results regarding obesity as a risk factor for CrCLR. Given that obesity is widely described as one of the main predisposing factors for CrCLR in numerous studies, a high prevalence of obesity among participants was anticipated. For instance, a 2011 study by P. Adams et al [3], revealed that overweight dogs are four times more likely to develop CrCLR due to the increased force and stress placed on the ligament, potentially leading to degeneration and eventually, rupture of the ligament. Contrary to these expectations, only 28.6% of the participants in this study were reported as overweight at the time of the incident, while 50.0% were categorised as being of normal weight. A potential explanation for these findings is that the owners may not have been fully aware of the appropriate weight, considering both breed and height. Alternatively, the weight may not have been accurately assessed based on the body condition system by a veterinarian.

Furthermore, the findings yielded clear results regarding age, purpose-based classification of the dog, and cause of rupture. It is well documented in the recent studies that the most frequent cause of rupture is due to degeneration, which ultimately leads to spontaneous rupture [1, 2]. In contrast, a smaller proportion of cases are attributed to traumatic injuries. This study produced similar findings, with degeneration at 60.7% and traumatic injury at 26.8% as cause of rupture.

Regarding the age, the majority of participants were categorised as seniors, between 6 to and 9 years of age, representing 39.3% of the sample. This finding correlates precisely with the P. Adams et al. study [3].

In addition, a correlation was established between the age and the cause of rupture. As expected, degenerative ruptures were predominantly observed in middle-aged and elderly dogs, consistent with the understanding that degeneration is a progressive condition, rather than an acute occurrence. Interestingly, traumatic ruptures did not predominantly occur in younger ages, as anticipated, but were instead distributed relatively evenly across all age groups. However, it remains unclear whether degeneration may have also contributed to the ruptures that occur in older dogs prior to the traumatic event.

Moreover, as expected, 100% of the ruptures in sport and working dogs were attributed to traumatic incidents. This observation is partially consistent with Debra C. Sellon et al. study [14], as the conditions in these environments inherently increase the probability of a traumatic injury. However, the questionnaire did not collect information on the type of sport, level of participation or the frequency of involvement.

Conclusive outcomes emerged from this research on treatment selection for CrCLR, with a striking 89.3% of cases selecting surgical intervention, while only 10.7% conventional management. As to the reasoning behind this choice, the option ‘veterinarian’s preference’ reached 89.7%, further reinforcing its position as the most favoured approach among veterinary professionals. In terms of treatment success, surgery demonstrated a strong efficacy, with a remarkable 90.0% success rate, compared to a significant lower success rate of 33.3% for conservative treatment. Another astonishing result that was revealed from this study was the 97.1% success rate of TPLO technique. This high success rate aligns with the results reported in the research led by James L. Cook et al. in 2010 [33], and in 2013 [32].

In contrast, for the justification of conservative treatment, ‘owner’s preference’ reached an 83.0%. From the owner’s perspective, favouring for a less invasive procedure is understandable, especially considering the well-known potential risks associated with surgery [25]. However, conservative treatment primarily addresses symptom management and is reasonably successful only when specific criteria are met, such as smaller size patient or in case of less severe clinical signs, as seen in partial ligament ruptures [20].

The findings related to post-operative physiotherapy participation were unexpectedly positive, with 84.6% of the respondents reporting undergoing physiotherapy treatment.

Regarding veterinarian's responsibility to inform owners about available physiotherapy treatment options, 75.0% of the participants indicated that the veterinarian provided a physiotherapy plan. However, 6.8% reported receiving no suggestion regarding physiotherapy. Notably, the latter mentioned participants independently initiated physiotherapy or sought out a physiotherapist on their own. These results suggest that while veterinarians are increasingly recognizing the importance of physiotherapy, there may still be a lack of acknowledgment regarding the importance of trained professionals. Without detailed information regarding the specific treatment plans provided, the adequacy of the instructions given, and the extent of the veterinarian's involvement throughout the physiotherapy process, it is not possible to conclusively determine the importance of physiotherapy from the veterinarian's perspective.

Regarding the success rate of postoperative physiotherapy, among participants who reported undergoing physiotherapy, 56.8% reported full recovery, a result that will further support the beneficial effect of postoperative physiotherapy [5]. However, there was a 9.1% of the respondents that reported moderate lameness, out of which, three quarters followed a physiotherapy plan provided by the veterinarian, and one fourth performed physiotherapy independently without a formal plan. This may explain the lower success rate as a professional practitioner was not present. A more detailed analysis of the responses indicated that participants that reported moderate lameness after the end of the physiotherapy treatment, did not consistently adhere to the recommended sequence of exercises or the recommended time periods for each. Another potential explanation for the suboptimal outcomes could be an inappropriate plan, a misunderstanding of the instructions or improper execution; however, it is not possible to confirm this theory based on the information provided by the questionnaire.

Proceeding to the section of the study where participants did not undergo post-operative physiotherapy, the reported success rate showed that 50.0% achieved full recovery, 25.0% experienced mild discomfort, and 25.0% reported moderate discomfort. It remains unclear whether the lack of physiotherapy was due to veterinarians suggesting the option and owners declining, or whether owners were unaware of its availability. While the results appear comparable to those who underwent physiotherapy, it is important to mention that there is a disparity in sample size, with 44 participants undergoing physiotherapy compared to 8 who did not. A larger sample size would provide a clearer and more accurate representation of these outcomes.

As a final point, the overall success of CrCLR rehabilitation can be inferred form this study, with 55.4% (n = 31) out of the 56 participants achieving complete recovery, 32.1% (n = 18) showing mild discomfort, and only 12.5% (n = 7) experiencing moderate lameness after treatment. These results indicate that the treatment protocol for CrCLR is largely effective and shows great promise, with potential for further improvement.

Conclusion:

This comprehensive study provides valuable insights into cranial cruciate ligament rupture (CrCLR) in dogs, addressing the condition's entire progression from onset to rehabilitation. Numerous correlations were established, and various comparisons of treatment efficacy were made, including the success rate of surgical intervention versus conservative management, the efficacy among different surgical techniques, and impact of participation in physiotherapy. All of the above are areas where existing literature is limited. One limitation observed during this study, is that the data were self-reported by owners, which introduces the potential for subjective bias, inaccuracies or even dishonest information. Additionally, without appropriate professional evaluation and confirmation by a veterinarian, the accuracy of assessment, such as the degree of lameness, may be compromised. Finally, as previously emphasized, this study was designed to provide a thorough understanding of the entire CrCLR rehabilitation process, aiding both the veterinarians and owners to reach informed decisions regarding the most appropriate treatment for each individual case. With favourable outcomes in the overall success rate of CrCLR rehabilitation, this study offers potential hope and reassurance to owners of dogs suffering from CrCLR, highlighting the effectiveness of appropriate rehabilitation strategies. In conclusion, while this study provides valuable new insights into CrCLR and rehabilitation process in dogs, further research involving larger sample sizes is necessary to obtain more accurate results. Moreover, evaluations conducted by the veterinarians are crucial to minimize the potential for owner bias and misinterpretation. These steps will enhance the reliability of findings and contributed to more effective treatment strategies for CrCLR.

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