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Patellar luxation and concomitant cranial cruciate ligament rupture in dogs – A review

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Abstract: A patellar luxation and concomitant cranial cruciate ligament rupture is a common pathology in dogs. Diagnosis is based on clinical evidence of a patellar luxation and stifle joint instability. However, diagnostic imaging is required to assess the number of skeletal deformities and signs of instability. Surgical options include both soft tissue and osseous techniques, although, in most cases, a combination of multiple procedures is necessary to correct the patellar luxation and restore the stifle joint stability. Complication rates are generally low, but can include reluxation and implant-associated complications. This article describes the patellar luxation and cranial cruciate ligament rupture signs in dogs, including the clinical presentation and diagnosis, and discusses current treatment options.

Keywords: canine lameness; knee surgery; stifle pathology

Introduction

Patellar luxation (PL) and cranial cruciate ligament ruptures (CCLRs) are common orthopaedic issues in dogs, which have been well described over the years (Jerram and Walker 2003; Di Dona et al. 2018). The combination of both pathologies differs significantly between small and large breed dogs. In contrast to both PL and CCLR individually, limited literature is available on the combination of both orthopaedic problems. Therefore, the purpose of this article was to review the most current veterinary literature and take a close look at the pathogenesis, diagnosis and surgical techniques available to treat the combination of these common orthopaedic pathologies.

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Pathogenesis, prevalence, affected breeds and risk factors

PATHOGENESIS

Currently, two hypotheses regarding the pathological connection of PL and CCLR are under debate, although both are yet to be proven.

Theory I: Patellar luxation as a primary cause for CCLR

The quadriceps muscle group, trochlear groove, patellar ligament and the tibial tuberosity form the extensor mechanism of the stifle. A decreased angle of inclination of the femoral neck has been named as a cause of laxity of the extensor mechanism (Kowaleski et al. 2018).

Malalignment of the extensor mechanism during the growth period can lead to patellar instability as well as secondary bone changes and the absence of physiological pressure on the trochlear groove during growth, leading to a lack of width and depth commonly named trochlear hypoplasia (Petazzoni 2014). Anatomical changes observed in these patients include: distal femoral varus or valgus, external or internal torsion of the distal femur, proximal tibial varus or valgus and internal or external tibial torsion and a shallow trochlear sulcus (Wandgee et al. 2013; Yasukawa et al. 2016; Kowaleski et al. 2018).

It has been postulated that malalignment of the quadriceps mechanism, which leads to instability of the stifle joint, skeletal changes and abnormal stress on the stifle joint and the cranial cruciate ligament (CCL) can cause CCLR (DeAngelis and Lau 1970; Hayes et al. 1994; Marsolais et al. 2002). In addition to this, the progression of osteoarthrosis, joint effusion and degenerative joint disease could also contribute to CCLR in older dogs (Campbell et al. 2010).

Theory II: Cranial cruciate ligament rupture as a primary source of instability in the stifle joint

Preventing excessive internal rotation between the femur and tibia is an important function of the CCL (Arnoczky et al. 1977; Robins 1990). When the ligament ruptures, the lack of internal rotation constraints could lead to a patellar luxation or increase the grade of a pre-existing patellar luxation. This theory is supported by studies which have demonstrated that CCLR influences the Q-angle, the angle between the vector force of the quadriceps muscle, patella and patellar ligament (Kaiser et al. 2001). However, further studies are warranted to investigate the effect of a ligament rupture on the development of patellar instability.

PREVALENCE OF PL AND CONCOMITANT CCLR

While patellar luxation can be medial, lateral or bidirectional, most cases report a medial luxation and are diagnosed in small breed dogs. Lateral patellar luxation is less frequent and more commonly diagnosed in larger breeds (Roush 1993; Hayes et al. 1994; LaFond et al. 2002; L'Eplattenier and Montavon 2002; Harasen 2006; Di Dona et al. 2016; Bosio et al. 2017). Medial patellar luxation in small breed dogs is 12 times more frequent than in larger breeds (Priester 1972) and female predispositions have been identified (Priester 1972; Hayes et al. 1994; Alam et al. 2007; O'Neil et al. 2016; Bosio et al. 2017). Moreover, a connection to the neuter status has been described (O'Neil et al. 2016). Bilateral patellar luxation has been described with varying frequency (Hayes et al. 1994; Arthur and Langley-Hobbs 2006). Patellar luxation is generally graded from I to IV (Singleton 1969) (Table 1).

Prevalence reports on the combination of both pathologies differ significantly. One study found that 15–20% of stifles in middle-aged and older dogs with PL had concomitant CCLR (Piermattei and Flo 1997).

Other studies in small breed dogs with PL found a 22–41% incidence of concomitant CCLR (Campbell et al. 2010; Candela Andrade et al. 2020) and only 13% in large breed dogs (Gibbons et al. 2006). Moreover, CCLR has been found in 41% of large breed dogs with a medial patellar luxation (MPL) (Brower et al. 2017).

AFFECTED BREEDS

Breeds most commonly affected by PL include the: Yorkshire Terrier, Chihuahua, Pomeranian, Poodle, French Bulldog, Lhasa Apso, Cavalier King Charles, Bichon Frise, Pug, Spaniel, Bulldog, West Highland White Terrier, Jack Russel Terrier and

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Table 1. Singleton classification for patellar luxation (Singleton 1969)

Patellar luxation	Description	Rotation of the proximal tibia in relation to distal femur
Grade I	patella can be manually luxated, but returns to normal position when released	no rotation
Grade II	patella luxates with stifle flexion or on manual manipulation and remains luxated until stifle extension or manual replacement occurs	tibial rotation up to 30° is achieved
Grade III	patella continuously luxates and can be manually replaced, but will reluxate spontaneously when manual pressure is removed	between 30° and 60°
Grade IV	patella is permanently luxated and cannot be replaced manually	between 60° and 90°

Shih-Tzu (Arthurs and Langley-Hobbs 2006; Alam et al. 2007; Bound et al. 2009; O'Neil et al. 2016).

Studies suggest that up to 38% of dogs diagnosed with an MPL are medium to large breed dogs (Priester 1972; Hayes et al. 1994; Gibbons et al. 2006) and commonly affected breeds include the: Chow Chow, Dutch Flat Coated Retriever, Great Pyrenees, Bulldog, Labrador, French Bulldog, English Bulldog and Staffordshire Bull Terrier (Hayes et al. 1994; LaFond et al. 2002; Gibbons et al. 2006; O'Neil et al. 2016).

In studies including dogs with PL and concomitant CCLR, Yorkshire Terriers, Chihuahuas, Labrador Retrievers, Golden Retrievers, Staffordshire Bull Terriers and American Staffordshire Terriers have been named as the most common breeds (Campbell et al. 2010; Langenbach and Marcellin-Little 2010; Yeadon et al. 2011; Leonard et al. 2016). Moreover, a breed predisposition for Maltese dogs was found (Candela Andrade et al. 2020).

RISK FACTORS

The aetiopathogenesis is believed to be multifactorial. Risk factors include malalignment of the quadriceps mechanism, which leads to instability of the stifle joint (DeAngelis and Lau 1970; Marsolais et al. 2002), anatomical changes like proximal tibial deformities of the frontal plane (varus or valgus angulations) or an excessive tibial plateau angle (Talaat et al. 2006; Duerr et al. 2007).

Additionally, high grades of patellar luxation and degeneration of the ligament have been described as risk factors (Vasseur et al. 1985; Campbell et al. 2010). Patients with PL and CCLR are generally older (7–8 years) than those with PL only (3–5.2 years) (Campbell et al. 2010; Candela Andrade et al. 2020). Maltese dogs have been found to be a predisposed breed and being overweight has been shown to be a predisposing factor for the development of a concomitant CCLR (Candela Andrade et al. 2020).

Diagnosis and clinical presentation of patellar luxation and concomitant cranial cruciate ligament rupture

DIAGNOSING PL

Clinical signs for patellar luxation can vary between patients. They usually include stiffness of the stifle joint, permanent flexion or incapability of complete stretching (Matis 2005). Depending on the degree and duration of the luxation, PL patients may also show intermittent or consistent hind limb lameness (Roush 1993). The PL grading can be performed according to Singleton's (1969) classification (Table 1).

Radiographic views of the stifle help to confirm permanent luxation and assess degenerative changes or skeletal abnormalities like valgus or varus deformities. Lateral projections help to assess the correct positioning of the patella in the trochlear groove. Accurate positioning is essential to assess deformities and avoid false interpretations (Marino and Loughin 2010; Kowaleski et al. 2018). Anatomic and mechanical joint angles can be assessed and calculated in preparation for surgical corrections on both radiological and computed tomography (CT) studies (Kaiser et al. 2001;

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Sarierler 2004; Dudley et al. 2006; Dismukes et al. 2007). However, 3D reconstruction CT scans are an essential diagnostic tool, as they enable the precise assessment of the anatomical changes in the patient.

DIAGNOSING CCLR

Cranial cruciate ligament rupture signs include refusing to sit on the affected limb (Matis 2005), avoiding flexion or extension as well as acute inflammation and hemarthrosis of the stifle joint. These symptoms result in acute lameness, which, depending on the degree of the injury, may result in intermittent or persistent and weight or non-weight bearing lameness (Sandman and Harari 2001). Other signs to be assessed include thigh muscle atrophy, asymmetry in the hind legs, joint effusion, periarticular swelling, pain during flexion or extension and cranial displacement of the tibial crest (Paatsama 1952; Johnson and Johnson 1993). A positive cranial drawer test and a positive tibial compression test are pathognomonic for CCLR (Brunnberg 1989). To confirm and eliminate the differential diagnoses, mediolateral and craniocaudal radiographs of the stifle should be taken (Jerram and Walker 2003). Radiological findings may include effacement loss in the infrapatellar pad shadow through soft tissue opacity, caudal displacement of the fat density located caudal to the joint capsule and osteophyte formation (Kowaleski et al. 2018).

Arthroscopy has proven useful due to its diagnostic sensitivity, particularly in cases of partial ruptures of the ligament and the added benefit of combining diagnostic and treatment procedures, such as a partial meniscectomy (Pozzi et al. 2008; Ertelt and Fehr 2009; Kowaleski et al. 2018). In dogs with chronic patellar luxation and acute lameness, a concomitant CCLR should be considered as a differential diagnosis.

While non-invasive imagining techniques of the stifle such as magnetic resonance imaging (MRI) or an ultrasound can assist the diagnosis, they require special equipment, practice and technical skills, which makes their reliability operator-dependent. Therefore, arthroscopic visualisation and palpation are the most reliable diagnostic methods for the vast majority of suspected CCLR or meniscal pathology cases (Kowaleski et al. 2018).

Treatment for PL and CCLR

CONSERVATIVE THERAPY FOR PL AND CONCOMITANT CCLR

Medical management consists of the restriction of activities, weight reduction and anti-inflammatory drugs (NSAIDs) in combination or without additional analgesics (Jerram and Walker et al. 2003). Weight control and physical rehabilitation, to improve the quadriceps extensor mechanism, are additional measures included in the conservative treatment of these pathologies (Mlacnik et al. 2006; Ramirez et al. 2015). However, the vast majority of authors reject conservative treatment.

SURGICAL TREATMENT

Surgical treatment for PL

For didactic reasons, we present a brief overview of the methods used to treat PL and CCLR. The majority of these techniques can be combined with each other, but evidence of suitability or superiority only exist for a few combinations of techniques and these will be explained below.

Surgical treatment options for patellar luxation include soft tissue techniques, deepening of the trochlear groove, tibial tuberosity transposition and corrective osteotomies for cases of distal femur or proximal tibial malalignment. The combination is chosen according to the severity of the patellar luxation and the anatomical changes.

Soft tissue techniques include medial desmotomy, lateral imbrication, antirotational sutures and release of the medial musculature. Their common goal is to release tight tissues and tighten loose tissues, in order to position the patella in the trochlear groove. These techniques are generally combined with other osseous procedures, as they are generally not able to correct the patellar luxation itself (Roush 1993; Hulse 1995; Di Dona et al. 2018).

Sulcoplasty techniques are used to change the shape and deepen the trochlear groove to optimise the fitting of the patella on it (Di Dona et al. 2018). The common goal of these techniques is to embed 50% of the patella above the trochlear ridges (DeCamp et al. 2015). Trochlear wedge and block recession osteotomies are performed to deepen the trochlear groove. An osteochondral autograft, either

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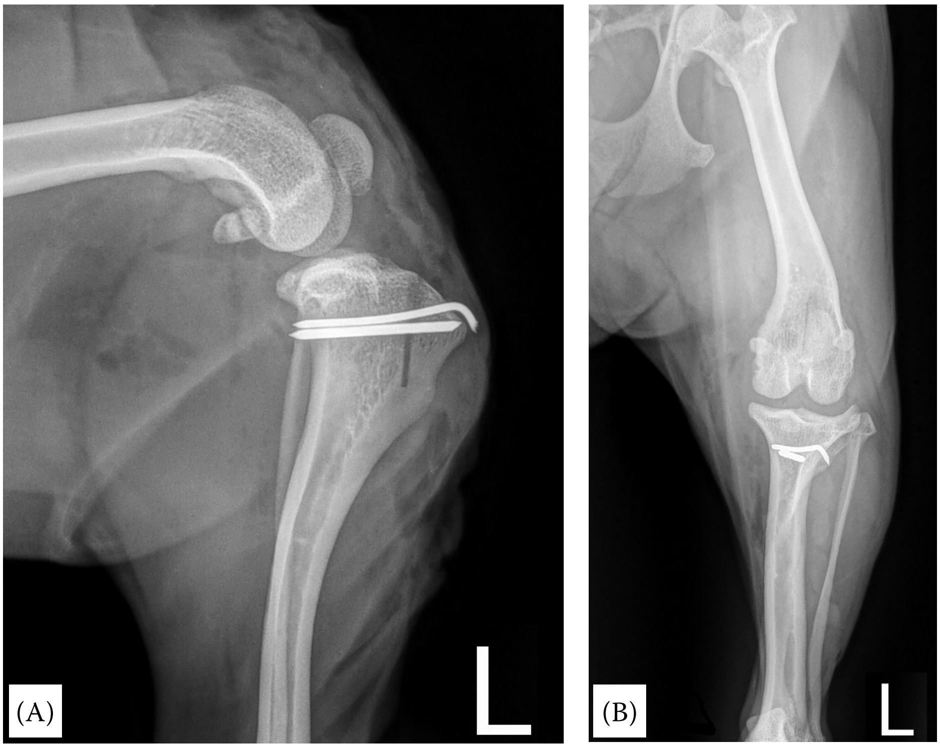

Figure 1. Postoperative radiological views of the stifle joint
(A and B) Mediolateral and caudocranial postoperative radiological views of the left stifle joint of a 4-year-old spayed female Pekinese (5.5 kg) with a medial patellar luxation grade III. The pathology was surgically corrected using a wedge recession osteotomy in combination with a tibial tuberosity transposition, medial desmotomy and lateral fascial and capsular imbrication

triangular (wedge) or rectangular in cross-section, is taken from the femur. Next, the femoral defect site is deepened and finally, the autograft is put back into place (Figure 1A, B). No fixation is needed, as patellar pressure and congruence between the surfaces create sufficient stability (Boone et al. 1983; Slocum and Devine 1985; Johnson et al. 2001) (Figure 1A, B). Variations of these methods have been described in recent years. The "K-shield-shaped wedge recession" is a trochlear wedge shape, which uses half a wedge distally and half a block proximally (Katayama et al. 2016).

The "extended proximal trochleoplasty" is another alternative that has been proposed for the treatment of bidirectional patellar luxation in dogs (Wangdee et al. 2015).

It offers the advantage of maintaining a periosteal attachment of the wedge, which leads to a diminished periosteal formation post-surgery. Furthermore, the "ridge stop technique" (www.orthomed.co.uk/eu/category/ridgestop/), which uses a polyethylene rim on the trochlear ridge to prevent patellar luxation, can also be used.

The goal of a tibial tuberosity transposition is to correct the malalignment of the patella and its insertion through the patellar ligament in the tibial tuberosity of the tibia. The tibial crest, where the patellar ligament is attached, is cut and fixed to a more correct position, either laterally or medially, depending on the direction of the luxation, in order to relocate the patella within the trochlear groove (Singleton 1969) (Figure 1A, B). The "rapid luxation" technique (leibinger.vet/patella-luxation/patella-luxation-in-dogs-and-cats/) is a modern variation of this technique, which consists of the use of an implant (tibial tappet) to transpose and fix the tibial tuberosity into a new position for the patellar ligament realignment.

Corrective osteotomies are needed to correct bone deformities in case of malformations of the distal femur or proximal tibia, as well as to realign the quadriceps muscle group and re-establish its functionality. Techniques like a closing lateral wedge osteotomy or a medial opening osteotomy can be used to treat valgus or varus malformations. Derotational osteotomies are performed in case

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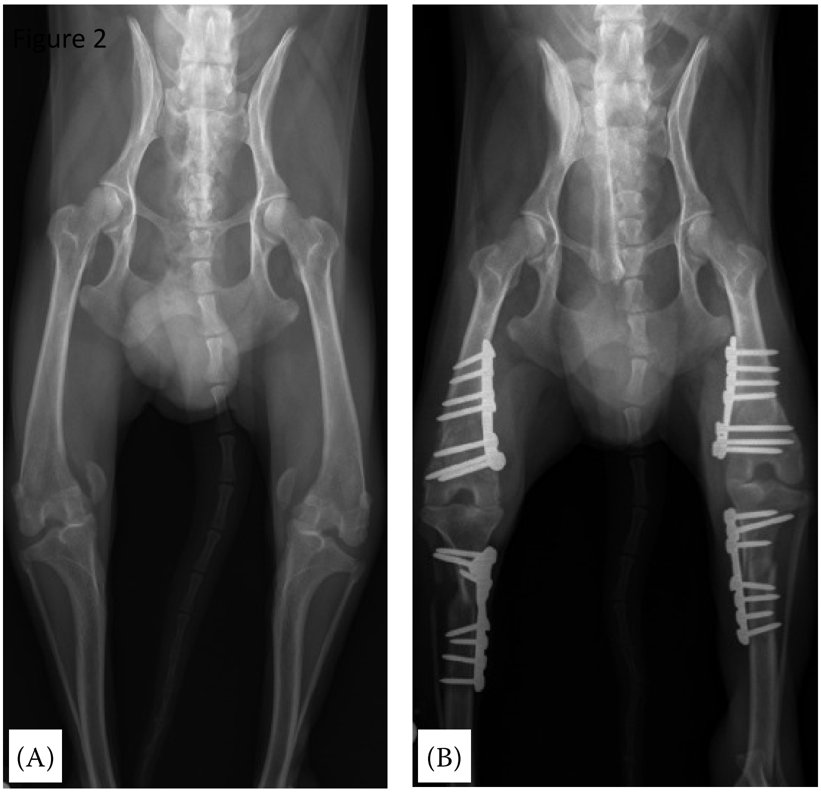

Figure 2. X-ray of the hip and hind limbs
(A) Ventrodorsal X-ray of the hip and hind limbs of a 7-year-old intact mixed-breed dog with medial bilateral patellar luxation grade IV. (B) Ventrodorsal X-ray of the hip and hind limbs of the same patient after a bilateral trochlear wedge recession osteotomy, a bilateral medial femoral opening osteotomy to correct a valgus angulation of the distal femur and a bilateral derotational osteotomy of the proximal tibial for realignment

of torsional deformities of long bones like the proximal tibia (Petazzoni 2014; Brower et al. 2017; Kowaleski et al. 2018) (Figure 2). For all these procedures, pre-operative CT scans are recommended to calculate the grade of the deviation and plan its correction (Dudley et al. 2006).

Outcomes after surgical correction for PL depend heavily on the patellar luxation grade. While all cases of PL grade II had an excellent outcome, reluxation after surgery occurred in 11% of PL cases with a grade III luxation. The success rates for cases with PL grade IV vary between 64–93% and have a higher risk for complications and additional surgery, such as corrective osteotomies (Wandgee et al. 2013; Dunlap et al. 2016).

Surgical treatment for CCLR

Numerous techniques have been described over the years. The surgical treatment options for CCLR can be divided into three technical categories (Jerram and Walker et al. 2003).

Intra-articular techniques

Intra-articular techniques replace the CCL through an autograft, allograft or synthetic material to substitute the torn CCL and mimic its function (Figure 3A).

Autografts can either be obtained from the patient's patellar ligament or fascia lata and are applied during the "fascia over the top" technique and its modifications (Arnoczky et al. 1979; Brunnberg et al. 1992). If the patient is not a suitable donor, allografts of the patellar ligament or fascia lata can be taken from another dog.

However, due to the difficulties of finding a suitable donor, this option is rarely used to treat CCLR in dogs. Synthetic grafts from Dacron, silk or ligament augmentation devices can be implanted to simulate the ligaments functional properties. A recent bioengineering approach has investigated a new graft, based on a matrix scaffold cultivated with progenitor ligament cells (Kowaleski et al. 2018).

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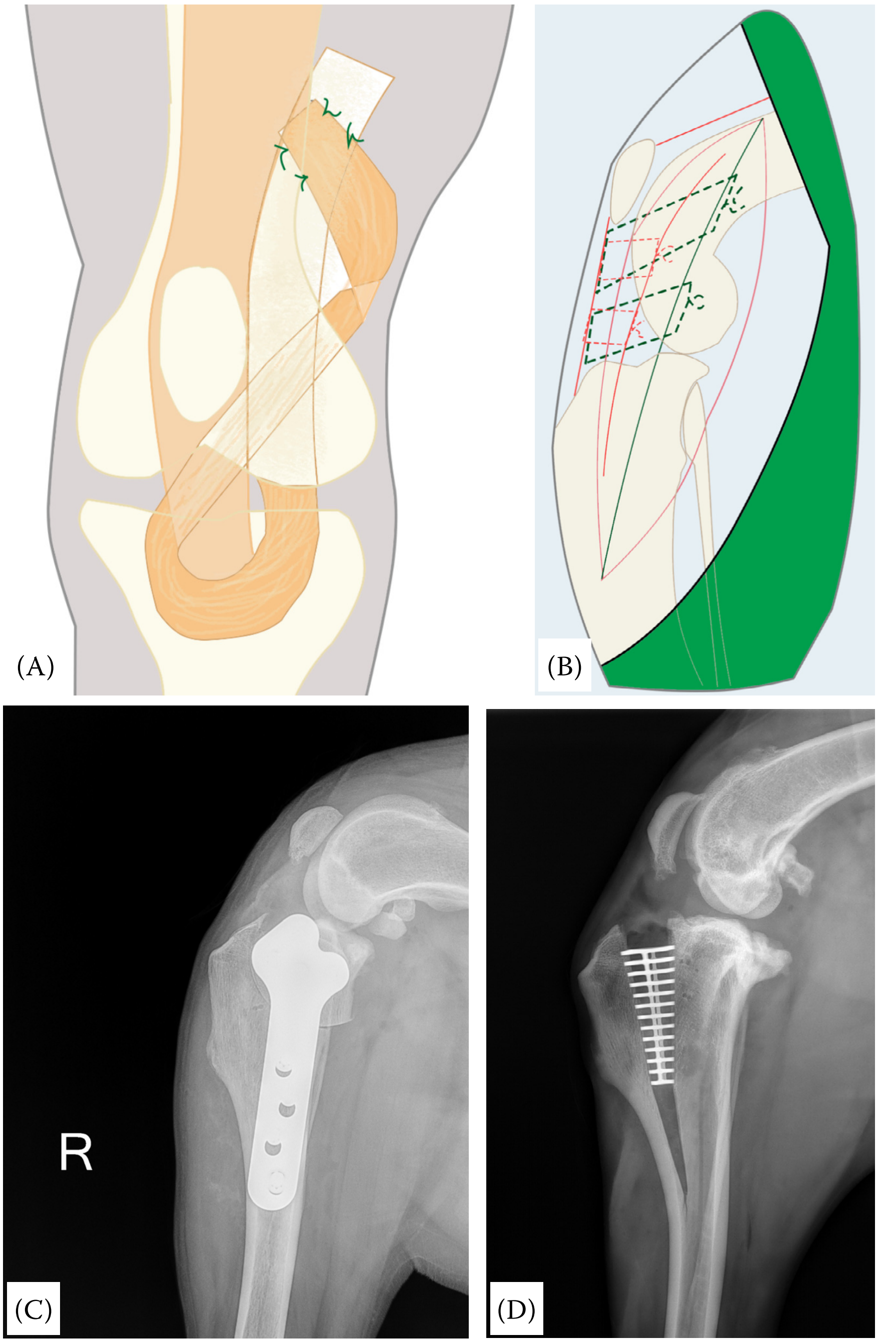

Figure 3. Illustration of different techniques to treat CCLR

(A) Intra-articular method: "Modified fascia over the top" technique (Brunnberg et al. 1992). (B) Extra-articular method: "Capsular fascial imbrication" technique (Allgoewer et al. 2000). (C and D) Remodelling osteotomies. (C) Mediolateral views of a "tibial plateau levelling osteotomy" (Slocum and Slocum 1993) in an 8-year-old intact male Entlebucher mountain dog with a CCLR. (D) Mediolateral views of a "tibial tuberosity advancement 2" technique in a 10-year-old mixed-breed neutered male dog (30 kg) with a CCLR. Courtesy of Dr. Diane Meiler

CCLR = cranial cruciate ligament ruptures

Extracapsular techniques

Essentially, extracapsular techniques rely on the post-surgical formation of periarticular fibrosis, after the initial stability provided by the use of extraarticular devices has faded (Kowaleski et al. 2018). These techniques are generally easier and quicker to perform and do not require special equipment.

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Techniques include the "capsular fascial imbrication" technique (Allgoewer et al. 2000) (Figure 3B), the "lateral retinacular imbrication" technique (DeAngelis and Lau 1970) and its later modification, the "fabellotibial suture" (Flo 1975), which combines the suture material and surgical knots or metallic crimp tubes, and the "tight rope" technique, in which a high molecular-weight-polyethylene polyester is used (Cook 2008).

Tibial osteotomy techniques

Tibial osteotomy techniques are currently viewed as the superior choice for CCLR repairs, since the development of postoperative arthrosis progresses slower than in other techniques (Lazar et al. 2005). The goal of these techniques is to neutralise the cranial tibial thrust by remodelling the proximal portion of the tibia.

The "cranial tibial closing wedge osteotomy" (CTWO) was the first procedure created to eliminate the cranial tibial thrust by modifying the tibial plateau angle by removing a cranial wedge of bone from the proximal tibia (Slocum and Devine 1984). Based on the same principle, years later, the "tibial plateau levelling osteotomy" (TPLO) was created by the same author, during which the tibial plateau is cut to adjust the angle (Slocum and Slocum 1993) (Figure 3C). A TPLO can be combined with a "cranial closing wedge ostectomy" to treat an excessive tibial plateau angle, a proximal tibial varus or valgus angulation or a tibial torsion.

The "tibial tuberosity advancement" (TTA) technique was introduced by Montavon et al. (2002). The stifle joint is stabilised by neutralising the cranial tibial thrust force by advancing the tibial tuberosity, changing the angle of the patellar ligament and neutralising the tibiofemoral shear force during weight bearing.

After cutting into the tibial tuberosity, a special titanium cage is placed to advance it. Stabilisation is achieved through placement of a Kyon plate on the tibial crest and the proximal tibia (Kowaleski et al. 2018) (Figure 3D). Later modifications eliminated the use of the plate and rely solely on the cage both for the advancement and stabilisation of the advanced tibial tuberosity. Techniques include the "modified Maquet procedure" as well as the "TTA Rapid" and "TTA-2" techniques (Etchepareborde et al. 2011; Kyon Pharma 2012; Samoy et al. 2014). The main advantages of using these techniques are the reduced surgical time and reduced volume of foreign material implanted into the patient (Marques et al. 2017).

The "triple tibial osteotomy" aims to reduce the patellar tendon angle to 90 degrees when the stifle joint is at a weight-bearing angle. To achieve this, a small horizontal wedge of bone is removed halfway along a vertical osteotomy in the tibial tuberosity. After removing the bone wedge, the tibial plateau is levelled. Once this is performed, the horizontal defect created by removing the wedge is closed down, thereby advancing the tibial tuberosity (Kowaleski et al. 2018).

Both TPLO (Slocum and Slocum 1993) and TTA (Montavon et al. 2002) have been found to achieve good to very good results (Lazar et al. 2005; Au et al. 2010) and are considered superior to the extracapsular techniques for CCLR treatments (Lazar et al. 2005; Gordon-Evans et al. 2013; Berger et al. 2015; Di Dona et al. 2015). However, their superiority has been called into question (Conzemius et al. 2005). The need of special equipment and technical skills as well as the high cost limit the availability of these techniques.

Surgical treatment of PL and concomitant CCLR

Until now, treatment combinations for the combination of pathologies have been based on the surgeon's technical preferences and skills. In the following sections, evidence-based evaluations of the techniques for treatment of PL and concomitant CCLR are described and discussed. Due to the differences in the study designs, especially regarding the follow-up time points and methods of examination, the comparison is limited. The data is shown in Table 2.

Traditional combination of techniques

The combination of a "wedge recession osteotomy" (WR) (Slocum and Devine 1985) and a "tibial tuberosity transposition" (TTT) (Singleton 1969) with the intra-articular "modified fascia over the top" technique (Brunnberg et al. 1992) or the extra-capsular "capsular and fascial imbrication" technique (Allgoewer et al. 2000) are able to create sufficient stability of the knee joint in cases of patellar luxation and concomitant CCLR in small breed dogs. No significant differences were observed between the different combinations. Furthermore,

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Table 2. Summary of the different features of the studies and techniques used for the treatment of patellar luxation and cranial cruciate ligament ruptures in dogs

Author	Study nature	Surgical method	Surgical efficiency	Sample	Method of follow up	By who	Time of follow up post-surgery	Complications	Breed's size
Candela Andrade et al. (2020)	retrospective and prospective	wedge R.O. + TTT + capsular fascial imbrication or fascia over the top	86.63%	30 stifles	physical examination and lameness scoring (0–5)	in-hospital re-evaluation and referring vet	6 months	3.33 % minor, 6.67% major, 6.67% catastrophic	small and toy breed dogs
Flesher et al. (2019)	retrospective	modified TPLO	81.60%	76 stifles	physical examination and radiological evaluation	in hospital re-evaluations	6–8 weeks	7.8% minor, 10.5% major	small and medium breed dogs < 15 kg
Langenbach and Marcellin- Little (2010)	prospective	modified TPLO	84.62%	13 stifles	lameness scoring (0–5) and radiological evaluation	in hospital re-evaluations and referring vet	> 6 months	15.38% major	large breed dogs > 30 kg dogs
Leonard et al. (2016)	retrospective study	TPLO-TTT	100%	13 stifles	physical examination, limb function and radiological follow up	in hospital re-evaluations	8–10 weeks	0% complication	medium and large breed dogs
Yeadon et al. (2011)	retrospective study	TTTA	71.80%	39 stifles	physical examination, lameness scoring (0–5) and radiological follow up	treating surgeon and in hospital re-evaluation	from 6 up to 20 months	10.25% minor, 17.94% major	small, medium and large breed dogs (mean: 22.3 kg)
Fauron et al. (2017)	retrospective	ECS + TTT	53.90%	32 stifles	physical examination, lameness scoring (0–5)	in hospital re-evaluation	from 6 weeks	31.25% minor, 15.62% major	small, medium and large breed dogs (mean: 23.4 kg)
Fauron et al. (2017)	retrospective	TTTA	82.50%	40 stifles	physical examination and lameness scoring (0–5)	in hospital re-evaluation	from 6 weeks	17.50% minor	small, medium and large breed dogs (mean: 23.4 kg)
Leibinger (2021) TTTA rapid	not available literature	–	–	–	–	–	–	–	–

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Table 2 to be continued

Author	Study nature	Surgical method	Surgical efficiency	Sample	Method of follow up	By who	Time of follow up post-surgery	Complications	Breed's size
NGD (2021) Offset TPLO	not available literature	–	–	–	–	–	–	–	–
Livet et al. (2019)	retrospective	modified triple tibial osteotomy	77.80%	9 stifles	physical examination, radiographic follow up and lameness scoring (0–5) evaluation	in-hospital re-evaluation and owner questionnaires	from 6–14 weeks for radiological controls to 48 months (owner's questionnaires)	33.3% minor, 11.11% major	toy, small and large breed dogs

In most studies, complications that did not require additional surgical treatment were considered minor (e.g., wound infections, seromas), while any additional surgical treatment (meniscal lesions, broken plates, patellar reluxation) was considered a major complication. Complications that resulted in limb amputation or euthanasia of the patient were considered catastrophic. In the case of Livet et al. (2019) and Leonard et al. (2016), all complications that required additional medical or surgical treatment were considered major complications

ECS = extracapsular stabilisation; R.O. = recession osteotomy; TPLO = tibial plateau levelling osteotomy; TTT = tibial tuberosity transposition; TTTA = tibial tuberosity transposition advancement

they have the added advantage of not requiring special equipment or surgical skills, which makes them inexpensive and more practical compared to other techniques (Candela Andrade et al. 2020).

Remodelling osteotomies

The treatment of both pathologies together has changed over the past few decades and traditional methods have been substituted for new remodelling osteotomies (Candela Andrade et al. 2020). These techniques alter the proximal tibial anatomy to neutralise the cranial tibial thrust as well as any varus or valgus angulations.

In the "modified TPLO" (Figure 4A, B), the tibial plateau is rotated so that its slope is changed from the horizontal plane, thereby neutralising the cranial tibial thrust and simultaneously levelling the tibial plateau.

In addition, this procedure realigns the quadriceps mechanism through medial translation or rotation of the proximal tibial segment (Kowaleski et al. 2018; Flesher et al. 2019).

For application of the modified TPLO osteotomy, a straight TPLO plate is contoured to allow proximal tibial segment medialisation (Flesher et al. 2019). Special plates such as the "offset TPLO plate" (www.ngdvet.com) have been developed to achieve a mediolateral translation of the tibial plateau segment during TPLO.

In 2016, the combination of TPLO with a tibial tuberosity transposition (TTT) was first described (Leonard et al. 2016). The combination consists of a TPLO to neutralise the CCLR and a TTT to realign the quadriceps muscle group to treat the patellar luxation.

The "tibial tuberosity transposition advancement" (TTTA) (Figure 4C, D) is another treatment possibility. It combines a tibial tuberosity advancement (TTA), used to neutralise the cranial tibial thrust, and a tibial tuberosity transposition to treat the patellar luxation. The TTT is performed by bending a fork or plate into place to achieve a corrective transposition (Kowaleski et al. 2018). Other studies have demonstrated the superiority of this technique against the combination of "extracapsular stabilisation" (ECS) and a "tibial tuberosity transposition", which had 2.7 times more complications (Fauron et al. 2017).

The "TTA Rapid" technique is a more recent variation of the TTTA. Cages have been designed

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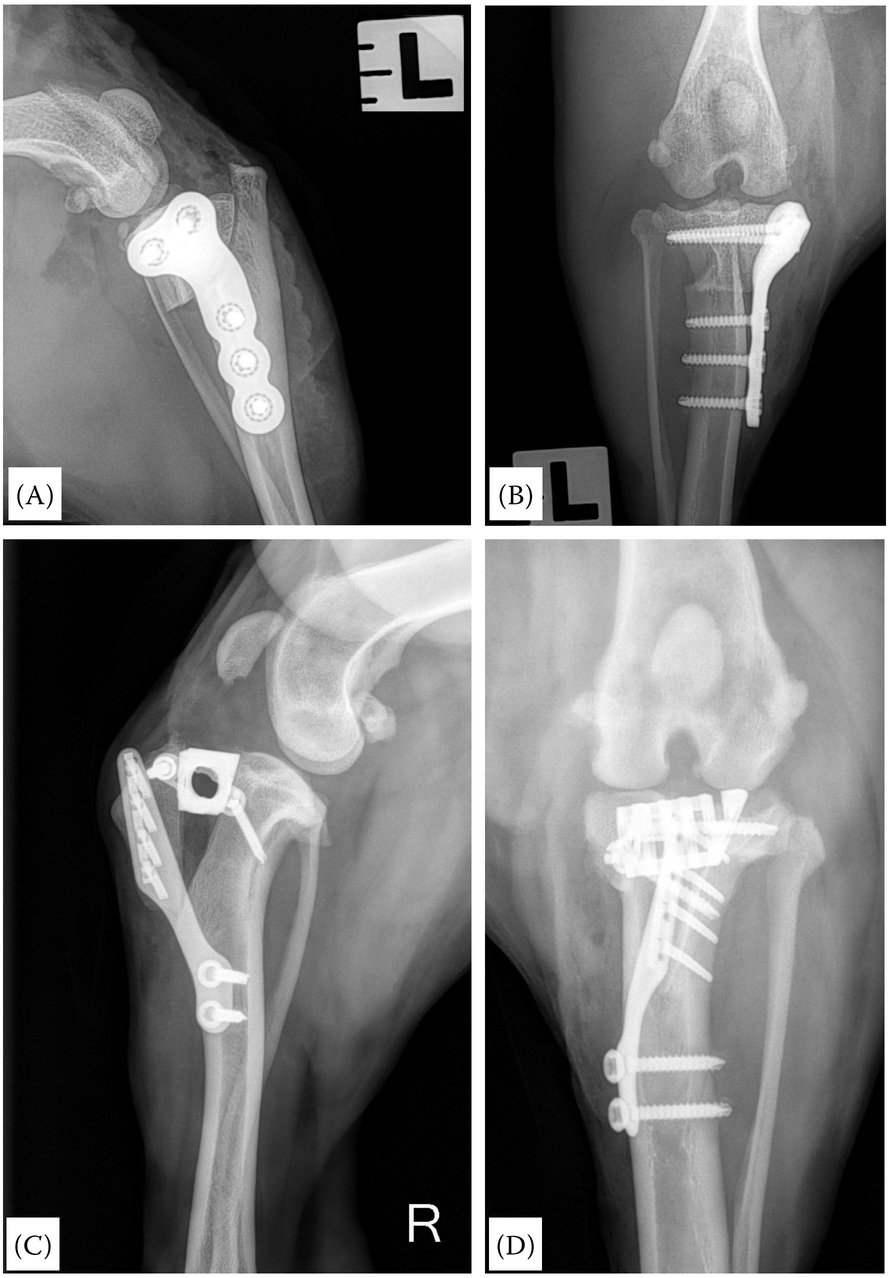

Figure 4. Mediolateral and caudocranial radiographs after a modified TPLO
(A and B) Mediolateral and caudocranial radiographs after a modified TPLO and a trochlear block recession in a 10-year-old neutered male mixed breed dog (6 kg) with medial patellar luxation grade III and concomitant cranial cruciate ligament rupture. Courtesy of Dr. Karol Bayer. (C and D) Mediolateral and caudocranial radiographs of a "tibial tuberosity transposition advancement" for treatment of a medial PL and concomitant CCLR in a 10-year-old neutered male Jack Russel Terrier (12 kg). Courtesy of Dr. Diane Meiler
CCLR = cranial cruciate ligament ruptures; TPLO = tibial plateau levelling osteotomy

as alternatives to plates, to not only advance, but also transpose the tibial tuberosity into a more lateral or medial position, depending on the direction of the patellar luxation (Figure 5).

The most recently published technique is a "modified triple tibial osteotomy" (Livet et al. 2019). This includes the combination of a mediolateral closing wedge osteotomy, a rotation of the distal tibial fragment to correct tibial abnormal deviations, and a tibial tuberosity transposition for the PL. Finally, the fragments are stabilised with a TPLO plate and Kirschner wires.

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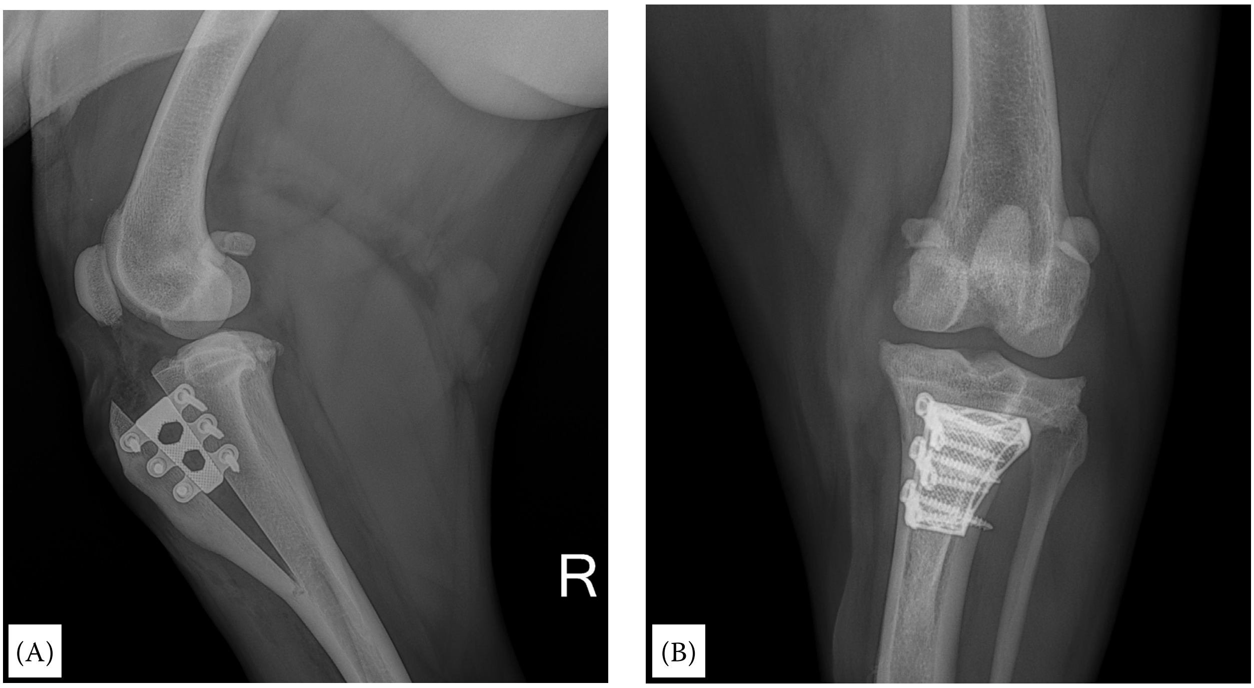

Figure 5. Radiographs after a TTA-rapid surgery
Mediolateral (A) and caudocranial radiographs (B) after a TTA-rapid surgery in a 5-year-old neutered male Boxer (28 kg) with a CCLR. Courtesy of Dr. Diane Meiler
CCLR = cranial cruciate ligament ruptures; TTA = tibial tuberosity advancement

Conclusions

Patellar luxation and concomitant cranial cruciate ligament rupture are common orthopaedic problems in small animal practice. Between 22–41% of small breed dogs and 13% of large breed dogs with patellar luxation develop a concomitant cranial cruciate ligament rupture. The pathogenesis appears to be multifactorial, including anatomical changes of the distal femur and proximal tibial segments, excessive tibial plateau angle, being overweight, older age, breed predispositions, degeneration of the ligament and severity of the patellar luxation.

The superiority of remodelling osteotomies against traditional methods for the treatment of patellar luxation and concomitant cranial cruciate ligament rupture is still under debate, at least in small breed dogs. However, the need for special equipment, special skills and substantial costs limit its use. Since the inclusion criteria, follow-up time and clinical assessment of patients after surgery varied considerably in the studies that evaluated the outcomes of the different treatment techniques, the superiority of any technique over another one remains controversial. Comparability to previous research should be a consideration in planning future studies, to improve the understanding of the multitude of surgical techniques and aid surgeons in choosing the appropriate surgical approach for their patient.

Conflict of interest

The authors declare no conflict of interest.

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