REVIEW

Cranial cruciate ligament rupture in small dogs (<15 kg): a narrative literature review

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Small breed dogs (<15 kg) affected by cranial cruciate ligament rupture secondary to cranial cruciate ligament disease are usually middle-aged (mean age at presentation: 5.4 to 9.8 years); terrier breeds, miniature and toy poodles are over-represented. Small breed dogs have a different morphology of the proximal tibia compared to medium and large breed dogs with a steep tibial plateau angle (mean tibial plateau angle 28.8° to 36.3°), absent base of the flare of the tibial tuberosity and a caudally bowed fibula. There is a lack of evidence regarding the optimal management of cranial cruciate ligament rupture in small dogs. The treatment options consist of conservative management, extracapsular stabilisation, cranial closing wedge ostectomy, tibial plateau levelling osteotomy and tibial tuberosity advancement. The limited evidence available shows that conservative management is likely to result in prolonged recovery time (average time to recovery approximately 4 months). There is paucity of reports focussing on extracapsular stabilisation in small breed dogs, and questions have been raised regarding the early failure of the extracapsular suture subject to higher loads due to the steep tibial plateau angle of small breed dogs. Cranial closing wedge ostectomy and tibial plateau levelling osteotomy have been reported to have low major complication rates and good subjective outcomes. It is controversial whether tibial tuberosity advancement is a suitable technique in dogs with steep tibial plateau angle, which includes most small breed dogs.

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INTRODUCTION

Cranial cruciate ligament (CCL) rupture secondary to CCL degeneration is a common cause of pelvic limb lameness in the dog and numerous studies have been published on this subject over the past several years (Bergh et al. 2014, Kowaleski *et al.* 2018).

While most reports have focussed on CCL rupture in medium and large dogs or on dogs of any weight, a few have reported specifically in small dogs (<15 kg) (Tables 1–3).

These reports have identified differences in the signalment of small breed dogs affected by CCL rupture compared to large breed dogs and in the morphology of the proximal tibia. Such differences could be linked to the pathogenesis of CCL disease and rupture in small dogs and may influence the choice of surgical technique.

The aims of this paper are to comprehensively review the literature published on the subject of CCL rupture in small dogs (until January 2021), summarise the differences that have been identified between small and large dogs, assess whether there is any evidence supporting the optimal management of this condition in small dogs and put the findings into context for the veterinarian in practice. In this review paper, a small dog is <15 kg in weight.

SIGNALMENT (AGE, BREED, SEX, NEUTERING STATUS)

Age

Vasseur (1984) found that small dogs (<15 kg) presented later in life (28 dogs, average age 9.8 years) with lameness related to CCL

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Table 1. Summary of studies reporting the age at presentation of small breed dogs (bodyweight <15 kg) affected by CCL disease

Article	Number of dogs	Mean age at presentation (in years, ±standard deviation)	Age range (in years)
Vasseur (1984)	28	9.8	5 to 16
Kunkel *et al*. (2009)	14	7.3±3.2	1 to 11
Garnett & Daye (2014)*	82	7	1 to 15
Witte & Scott (2014)	21	5.4±2.7	Not known
Aertsens *et al*. (2015)	52	8	2 to 13
Cosenza *et al*. (2015)	69	8.5±2.8	Not known
Barnes *et al*. (2016)†	26	7	1.8 to 11
Campbell *et al*. (2016)	45	6.7±2.5	1.8 to 13.3
Rappa & Radasch (2016)†	85	7.7	1 to 14
Dyall & Schmökel (2017)	40	7.8	1 to 14
Janovec *et al*. (2017)	82	6.1±2	Not known
Knight & Danielski (2018)	66	6.4±2.7	Not known
Ferreira *et al*. (2019)	30	8	3 to 13

*This study included a small proportion of medium breed dogs, median bodyweight was 12.5 kg (range 4.5 to 31.9 kg)
†These studies included dogs with bodyweight <18 kg

Table 2. Summary of studies reporting the TPA of small breed dogs (bodyweight <15 kg) affected and not affected by CCL disease. Studies using the TPA as a patient selection criteria (*i.e.* enrolling dogs with a TPA higher or lower than a set value) were excluded from this table

Article	Small dogs with CCL rupture		Small dogs without CCL rupture	
	Number of dogs	Mean TPA (°) ±standard deviation and/or range	Number of dogs	Mean TPA (°) ±standard deviation and/or range
Vedrine *et al*. (2013)	–	–	30	30±4
Garnett & Daye (2014)*	82	31.1 (range 16 to 47)	–	–
Aertsens *et al*. (2015)	52	30.1±5.3 (range 18 to 46.2)	–	–
Cosenza *et al*. (2015)	69	29±3.4	–	–
Witte (2015)	–	–	12	32±5.8 (range 24 to 44)
Campbell *et al*. (2016)	45	36.3 (range 27 to 46)	–	–
Dyall & Schmökel (2017)	40	28.8±4 (range 19 to 36)	–	–
Janovec *et al*. (2017)	82	32±5.74	51	29.18±7.28

*This study included a small proportion of medium breed dogs, median bodyweight was 12.5 kg (range 4.5 to 31.9 kg)

Table 3. Summary of studies published in the peer-reviewed literature reporting complication rate and outcome after surgery to address the CCL deficient stifle in small breed dogs (bodyweight <15 kg)

Article	Surgical procedure	Number of cases (stifles)	Minor complications (%)	Major complications (%)	Total complications (%)	Outcome
Rappa & Radasch (2016)*†	Extracapsular	85	16	14	30	Owner assessed, 96% of owners reported full or acceptable function. Duration of follow-up unclear
Campbell *et al*. (2016)	Cranial closing wedge ostectomy	55	26	2	28	Owner assessed, 94% of owners satisfied 2 years after surgery
Garnett & Daye (2014)‡	TPLO	98	29	7	36	Not assessed
Witte & Scott (2014)†	TPLO	29	10.4	3.4	13.8	Mean lameness score 6 to 8 weeks after surgery: 0.4/5 Owner assessed outcome 12 months after surgery: no lameness in all cases
Cosenza *et al*. (2015)	TPLO	79	11.4	5	16.4	Median lameness score 6 to 8 weeks after surgery: between 0/4 and 1/4
Barnes *et al*. (2016)*	TPLO	26	3.4	0	3.4	Lameness score 6 to 8 weeks after surgery: between 0/4 and 1/4 in 96% of cases
Knight & Danielski (2018)	TPLO	66	22.7	0	22.7	Not assessed
Dyall & Schmökel (2017)†	TTA	48	2	14.6	16.6	79% of stifles were free of lameness 72 weeks after surgery Owner assessed: 95% owners rated long term outcome good or excellent
Ferreira *et al*. (2019)	TTA	35	0	6	6	Veterinarian assessed: 91% of dogs not lame 12 weeks after surgery

*These studies included dogs with bodyweight <18 kg
†These studies defined minor complications as those complications that resolved without any intervention and major complications as those complications that resolved with surgical or medical management
‡This study included a small proportion of medium breed dogs, median bodyweight was 12.5 kg (range 4.5 to 31.9 kg)

rupture compared to dogs with bodyweight greater than 15 kg (57 dogs, average age 4.8 years). Similarly, Aertsens *et al.* (2015) found that small dogs (<15 kg) presented for treatment of CCL rupture at a median age of 8 years (n=52) while large dogs (>15 kg) presented at a median age of 4.5 years (n=52). Other recent studies investigating treatment options for small dogs with CCL rupture report a mean age at presentation of 5.4 to 8.5 years (Table 1) (Kunkel *et al.* 2009, Garnett & Daye 2014, Witte & Scott 2014, Cosenza *et al.* 2015, Barnes *et al.* 2016, Campbell *et al.* 2016, Rappa & Radasch 2016, Dyall & Schmökel 2017, Janovec *et al.* 2017, Knight & Danielski 2018, Ferreira *et al.* 2019).

Furthermore, Vasseur *et al.* (1985) found that in dogs affected by CCL disease, the ligament undergoes degeneration and decrease of material properties (modulus, maximum stress and strain energy) with aging of the dog. The changes found in dogs weighing <15 kg were less severe than those in heavier dogs and occurred later in life, supporting the observation that CCL disease and rupture tends to occur at an older age in small dogs.

Breed

Studies investigating the epidemiology of CCL rupture have reported West Highland White Terriers, Miniature and Toy Poodles and Yorkshire Terriers to have a higher incidence compared to other small breed dogs (Witsberger *et al.* 2008, Taylor-Brown *et al.* 2015).

The different incidence of CCL rupture in certain breeds could indicate that the condition may have a genetic basis. Heritability of CCL rupture has been studied in Newfoundlands, Boxers and Labrador Retrievers (Wilke *et al.* 2006, Temwichitr *et al.* 2007, Clements *et al.* 2010, Comerford *et al.* 2011). However, the genetics of CCL disease in small breed dogs have not yet been investigated to our knowledge.

Sex and neutering status

Comerford *et al.* (2011), Taylor-Brown *et al.* (2015) and Slauterbeck *et al.* (2004) found that CCL rupture had a higher incidence in neutered female and male dogs. Adams *et al.* (2011) found the condition to be twice as common in female dogs compared to male dogs, irrespective of neutering status. These findings relate to dogs of any size and are not specific to small breed dogs.

Elevated oestrogen levels in women have been associated with increased incidence of anterior cruciate ligament rupture at specific times in the menstrual cycle; however, there have not been any studies that have determined the effect of sex hormones on CCL disease in dogs (Comerford *et al.* 2011).

Taylor-Brown *et al.* (2015) have suggested that neutered dogs could be at increased risk of CCL rupture due to increased incidence of obesity following neutering, but this is controversial. Adams *et al.* (2011) found no significant difference in bodyweight or in body condition between neutered *versus* entire dogs affected and not affected by CCL rupture.

BODYWEIGHT

Duval *et al.* (1999) and Whitehair *et al.* (1993) found that dogs with greater bodyweight had a higher prevalence of CCL rupture. In particular, Whitehair *et al.* (1993) found that dogs with bodyweight higher than 22 kg were at higher risk of CCL rupture. Both of these studies evaluated the size of the dog rather than their body condition, meaning they could not conclude whether the higher prevalence was due to the increased body size alone or related to the animals being overweight.

Adams *et al.* (2011) investigated whether obesity is a risk factor for CCL rupture. The study combined the data related to small and large breed dogs. Given the retrospective nature of the study, a body condition score was not available for the dogs included in the study. Investigation of the effect of obesity on the risk of CCL rupture was carried out by comparing the bodyweight of the animals included in the study with the average weight in relation to breed and sex of a reference population. The difference in bodyweight for each animal (below the lower range, or above the upper range) of the reference value was calculated as a percentage. All dogs were then categorised as either "underweight," "normal," "overweight" or "obese" based on the percentage difference from the reference population. They found that dogs categorised as "obese" were almost four times as likely to sustain CCL rupture compared to dogs categorised as "normal." The reason for these findings remains unknown and has not been verified elsewhere. Adams *et al.* (2011) hypothesised that in obese animals, there is increased loading of the limbs and increased tension on the ligaments within the joints, which could predispose the ligaments to rupturing. However, this has not been investigated to date.

ETIOPATHOGENESIS OF CRANIAL CRUCIATE LIGAMENT DISEASE AND PROXIMAL TIBIAL CONFORMATION IN SMALL BREED DOGS

The aetiopathogenesis of CCL disease is not fully understood. The condition in dogs (large or small breed) is likely to have a multifactorial origin involving genetics, conformation factors and an inflammatory component that altogether create an imbalance between the biomechanical forces placed on the ligament and its ability to sustain these loads, eventually leading to rupture of the CCL and joint instability (Cook 2010, Griffon 2010, Comerford *et al.* 2011).

In regard to the biomechanical forces acting on the canine CCL, a widely accepted theory that has been developed in recent years sets out that during weight bearing the main force counteracted by the CCL is the cranial tibial thrust (CTT). The generation of the CTT has been described by two different biomechanical concepts. Henderson & Milton (1978) and Slocum & Devine (1983) described this force as the cranial component of the axial compressive load that lies along the inclined tibial plateau surface. According to this theory, the magnitude of the cranial force should increase with an increasing caudodistally directed slope of the tibial plateau (Henderson & Milton 1978, Slocum & Devine 1983, Warzee *et al.* 2001). In other words, the CCL of dogs with a very steep tibial plateau angle (TPA) would be under greater load and therefore more likely to rupture compared to the CCL of dogs with a less steep TPA (Fig 1A).

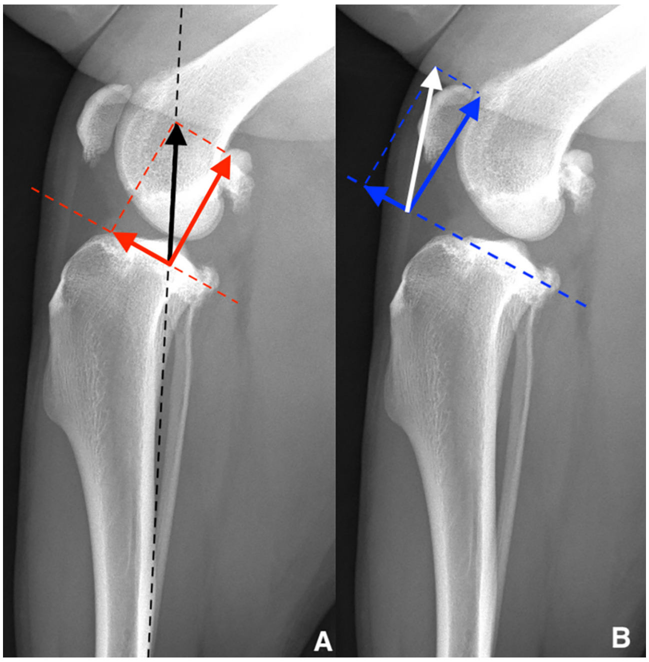

FIG 1. (A) Tibiofemoral forces in the stifle joint according to Slocum & Devine (1983). The axial compressive force generated during weight bearing (black arrow) is parallel to the tibial axis. If the CCL is deficient and the femur can move along the tibial plateau slope (distal dotted red line) this force can be resolved into two orthogonal components (red arrows), one perpendicular and one parallel to the tibial plateau. The component parallel to the tibial plateau represents the tibiofemoral shear force resulting in cranial tibial thrust. (Boudrieau 2009, Kowaleski *et al*. 2018). (B) Tibiofemoral forces in the stifle joint according to Tepic *et al*. (2002). The joint reaction force generated during weight bearing (white arrow) is parallel to the patellar ligament. If the CCL is deficient and the femur can move along the tibial plateau slope (distal dotted blue line) this force can be resolved into two orthogonal components (blue arrows), one perpendicular and one parallel to the tibial plateau. The component parallel to the tibial plateau represents the tibiofemoral shear force resulting in cranial tibial thrust (Boudrieau 2009, Kowaleski et al. 2018)

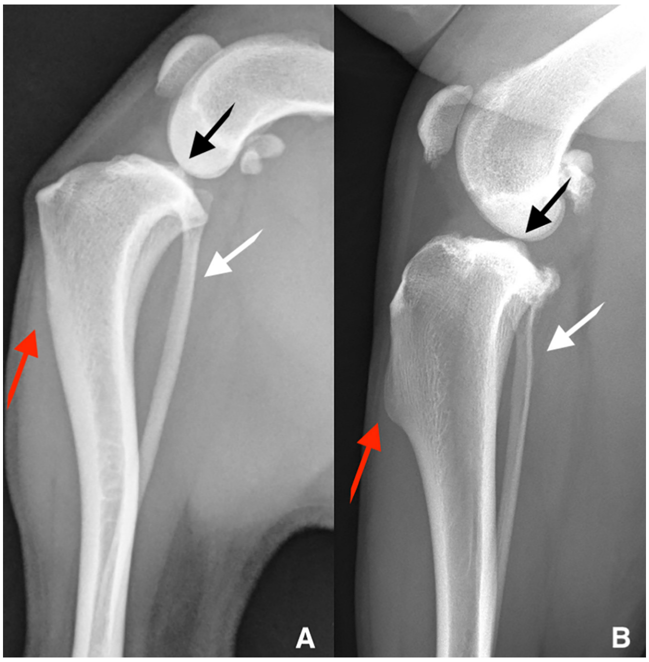

FIG 2. Proximal tibial conformation in a small breed dog (A) and in a large breed dog (B). Note the steeper caudodistally directed tibial plateau slope in A compared to B (black arrow), the absence of the base of the flare of the tibial tuberosity in A compared to B (red arrow) and the caudal bowing of the fibula in A compared to B (white arrow)

According to an alternative biomechanical model presented by Tepic *et al.* (2002), the direction and magnitude of the CTT is determined by the "patellar tendon angle" (PTA), which is the angle between the patellar ligament and tibial plateau; a PTA greater than 90° generates CTT (Fig 1B).

Several studies have reported the average TPA in large breed dogs affected by CCL rupture to range from 22° to 28° (Slocum & Devine 1983, Wilke *et al.* 2002, Aertsens *et al.* 2015). Although steeper TPAs have been reported in large breed dogs, they are considered to be uncommon (Talaat *et al.* 2006, Duerr *et al.* 2007).

Conversely, the average TPA of small breed dogs with CCL rupture has been reported from 28.8° to 36.3°, which is steeper compared to large breed dogs (Table 2) (Garnett & Daye 2014, Aertsens *et al.* 2015, Cosenza *et al.* 2015, Campbell *et al.* 2016, Dyall & Schmökel 2017, Janovec *et al.* 2017).

Some authors (Selmi & Padilha Filho 2001, Macias *et al.* 2002) have hypothesised that the steep TPA may be the cause of increased strain on the CCL ultimately leading to CCL rupture in small breed dogs. However, Vedrine *et al.* (2013) and Witte (2015) reported similarly steep TPA (30°±4° and 32°±5.8°) in small breed dogs not affected by CCL rupture, suggesting that it is unlikely that a steep TPA may be the sole causative factor for CCL rupture in small breed dogs (Table 2).

The steeper tibial plateau slope in small breed dogs is usually accompanied by caudal bowing of the proximal fibula and a barely distinguishable base of the flare of the tibial tuberosity (Fig 2). It has been hypothesised that in small breed dogs there may be a slower growth of the caudal aspect of the proximal tibial physis or an imbalance between the quadriceps and gastrocnemius muscles causing irregular distribution of forces on the tibial plateau; but none of these hypotheses has been investigated (Selmi & Padilha Filho 2001, Macias *et al.* 2002, Aertsens *et al.* 2015).

TREATMENT OPTIONS

Treatment options for CCL rupture in dogs of any size consist of conservative management or surgical management. Surgical management is commonly been divided into intra-articular reconstruction, extracapsular stabilisation and osteotomy procedures (Kowaleski *et al.* 2018).

Currently, intra-articular techniques have fallen out of favour in dogs of any size (Comerford *et al.* 2013, Kowaleski *et al.* 2018), having been replaced by osteotomy techniques (Kowaleski *et al.* 2018). To our knowledge, no data has been published regarding intra-articular techniques specifically in small breed dogs.

Osteotomy procedures include cranial closing wedge ostectomy (CCWO), tibial plateau levelling osteotomy (TPLO), tibial tuberosity advancement (TTA), triple tibial osteotomy (TTO) and CORA-based levelling osteotomy (CBLO). To our knowledge, no data has been published regarding TTO and CBLO in small breed dogs. In the following sections, we focus on what is reported in the literature in small breed dogs, *i.e.* conservative management, extracapsular techniques, CCWO, TPLO and TTA.

CONSERVATIVE MANAGEMENT

Two historical publications report conservative management in small breed dogs and compare it to conservative management in large breed dogs. Case management consisted of strict rest for 3 to 8 weeks and NSAIDs for 10 to 14 days or intermittently when needed (Pond & Campbell 1972, Vasseur 1984). Dogs were treated conservatively either because of mild instability and/or instability of less than 4 to 8 weeks duration (Pond & Campbell 1972) or because of concurrent medical problems and/or financial constraints (Vasseur 1984).

Pond & Campbell (1972) reported that 90% of small breed dogs undergoing conservative management had a good outcome (no detectable lameness as reported by the owner) *versus* 78% of large breed dogs; but how long the dogs took to recover is not clear.

Vasseur (1984) found that 85% of small breed dogs treated conservatively had a good outcome (assessed by a veterinary surgeon during a re-examination) *versus* only 19% of large breed dogs.

In this study, recovery for small breed dogs was slow and took an average of 4 months; 19% of small dogs with an apparent resolution of lameness had clinically evident muscle atrophy, 67% had increased medial buttress, 100% had evidence of radiographic progression of OA, and 43% had cranial drawer instability.

No more recent studies have evaluated the outcome of conservative management using objective measures of limb function, *i.e.* force platform gait analysis nor have compared the outcome between conservative management and modern surgical treatment options in small breed dogs.

Two recent questionnaire studies have investigated the most common practices in the management of CCL rupture in small dogs by veterinarians. Comerford *et al.* (2013) found that in the UK 7% of practitioners treat CCL rupture in small breed dogs in the first instance by conservative management, 15% by surgical management and 78% assess each case individually and decide between surgical and conservative management depending on the severity of lameness, age, bodyweight, degree of instability and duration of lameness. In this survey conservative management consisted of exercise restriction, NSAIDs, weight loss and rehabilitation (*i.e.* hydrotherapy and physiotherapy).

Duerr *et al.* (2014) reported that in the USA less than 10% of veterinary surgeons would recommend conservative management for a small breed dog with complete CCL rupture. Conservative management in this publication consisted of exercise restriction, rest, glucosamine/chondroitin sulphate/omega-3 fatty acids supplementation and rehabilitation. Other non-surgical treatment options that were less likely to be recommended were stifle orthoses, shockwave therapy, stem cell therapy and therapeutic ultrasound.

There is no published evidence in the peer-reviewed literature to support the use of shockwave therapy, stem cell therapy or therapeutic ultrasound in small or large breed dogs undergoing conservative management for CCL rupture. The use of stifle orthoses has been reported for conservative management of CCL rupture in medium and large breed dogs (Hart *et al.* 2016) but not in small breed dogs. In this report, 86% of owners were satisfied with outcome following the use of orthoses to treat CCL rupture however, 46% of owners in the orthosis group reported skin lesions associated with the device (Hart *et al.* 2016).

Regarding the use of glucosamine/chondroitin sulphate/omega-3 fatty acids supplementation, there is weak evidence in the literature to support the use of nutraceuticals for symptomatic control of osteoarthritis for dogs of any size. Amongst the nutraceuticals available, omega-3 fatty acids have the greatest strength of evidence (Aragon *et al.* 2007, Vandeweerd *et al.* 2012).

Rehabilitation has been shown to improve function in dogs of any size after surgical treatment of CCL rupture (Monk *et al.* 2006, Au *et al.* 2010). Although it is reasonable to assume that rehabilitation as part of conservative management of CCL rupture is likely to be beneficial, no studies have evaluated this.

Given the lack of evidence in the literature, it is difficult to draw evidence-based conclusions regarding when conservative management may be indicated and what is the most appropriate protocol for conservative management. Furthermore, the success rate of conservative management is also unclear and the time to recovery is likely to be prolonged (the average recovery time as reported by Vasseur (1984) is approximately 4 months).

SURGICAL MANAGEMENT: EXTRACAPSULAR STABILISATION

Extracapsular stabilisation for CCL rupture in dogs was first reported by DeAngelis & Lau (1970). Subsequently, several variations of the technique have been described. Extracapsular techniques involve the placement of a suture outside the joint capsule that spans the stifle joint to mimic the function of the CCL in restraining cranial translation of the tibia with respect to the femur. In other words, the CTT generated during weight bearing is resisted by the suture material. However, the procedure is not uniform; the position of the suture attachment points, the method of attachment, and the type of suture vary from one modification of the technique to another (Kowaleski *et al.* 2018). A common feature to all of these techniques is that they rely on periarticular fibrosis for long-term stability, as the stability created by the suture is only temporary.

Comerford *et al.* (2013) reported that extracapsular stabilisation is the most common type of surgical management adopted by veterinary surgeons in the UK to treat CCL rupture in small breed dogs. Although extracapsular techniques are very popular, two questions have been raised regarding their suitability in small breed dogs. Given that small breed dogs have been reported to have a steeper TPA compared to large breed dogs as previously outlined, the degree of CTT generated during weight bearing may be higher in these dogs. As a consequence, the strain the suture material has to counteract may be higher. This could lead to premature failure of the suture material and consequently poorer outcome in dogs with high TPA. Extrapolating and contrary to common perception, the argument follows that extracapsular suture may indeed be less appropriate and effective in small breed compared to large breed dogs. Although this point has been raised by multiple authors (Aertsens *et al.* 2015, Witte 2015), this specific aspect has not yet been investigated in the peer-reviewed literature.

A second consideration is that given the different morphology of the proximal tibia in small breed dogs compared to large breed dogs (Vedrine *et al.* 2013, Aertsens *et al.* 2015, Janovec *et al.* 2017), the quasi-isometric points that have been identified for large breed dogs may be less isometric in small breed dogs. Isometric points are two points (one located on the distal femur and one located on the proximal tibia) that remain equidistant throughout stifle joint range of motion and therefore represent optimal anchorage points for the extracapsular suture (Kowaleski *et al.* 2018). Given the complex shape of the stifle joint and the lack of a centre of rotation, true isometric points do not exist. However, quasi-isometric points have been identified in medium and large breed dogs. The preferred femoral attachment site has been reported to be F2 and the preferred tibial attachment site has been reported to be either T2 or T3 (Fig 3) (Roe *et al.* 2008, Hulse *et al.* 2010).

Witte (2015) investigated the quasi-isometric points of the stifle of small breed dogs in a cadaveric study. He found that the F2-T1 combination was the most favourable in nine of 12 small breed dog stifles however, in the other three of 12 stifles various combinations other than F2-T1 were more favourable. No common feature (breed, bodyweight, anatomical measurements and stifle morphology) was identified to link these three cases or differentiate them from the other nine cases. The findings of this study suggest that the optimal attachment site combination for extracapsular suture in small breed dogs may be different compared to medium and large breed dogs and is not universal for all dogs. Further studies are necessary to establish whether the individual variation in optimal attachment sites for extracapsular suture in small breed dogs results in worse or more unpredictable outcome following surgery.

FIG 3. Femoral and tibial anchorage sites. F1: centre of the lateral fabella; F2: caudal femoral cortex at the level of the distal pole of the lateral fabella; T1: 2 mm caudal from the point of the tibial tuberosity; T2: 2 mm distal to the femoro-tibial joint cranial to the extensor groove; T3: 2 mm distal to the femoro-tibial joint surface caudal to the extensor groove (Witte 2015, Kowaleski *et al.* 2018)

There is paucity of clinical studies in the literature reporting complication rate and outcome following extracapsular stabilisation of the CCL deficient stifle in small breed dogs.

Rappa & Radasch (2016) reported complication rate and outcome for 85 small and medium breed dogs undergoing extracapsular stabilisation for CCL rupture performed with the Arthrex Canine Cranial Cruciate Ligament Repair Anchor System. This system consists of FiberWire suture material attached to a titanium bone anchor located in the distal femur (F2) and passed through a tibial bone tunnel originating at T3. The reported overall complication rate was 30% (14% major complications and 16% minor complications). Owner assessed outcome was favourable in 96% of cases.

On the basis that in small dogs the weak attachments of the fabellar and perifabellar tissue may predispose the proximal fabellar anchor point of a tibio-fabellar suture to fail, Kunkel *et al.* (2009) reported a transcondylar toggle system for stifle stabilisation in small dogs and cats with CCL rupture. This system used a transcondylar bone tunnel in the distal femur and a medially placed custom-made toggle (manufactured by Securos) as a proximal anchor point for an extracapsular suture. However, the authors experienced slippage of the drill bit and aiming device while drilling the transcondylar bone tunnel in approximately 56% of cases and therefore recommended that modifications to the aiming device would be needed before the system could be recommended. The system is currently not commercially available.

SURGICAL MANAGEMENT: CRANIAL CLOSING WEDGE OSTECTOMY

The CCWO technique was first described by Slocum & Devine (1984) to stabilise the CCL deficient canine stifle. Slocum & Devine (1983) described, as we discussed previously (Fig 1A), a force generated in the stifle during weight bearing created by the slope of the tibial plateau called the CTT. This force is normally counteracted by the intact CCL. When the CCL fails, the CTT force causes cranial subluxation of the tibia relative to the femur during weight bearing. The aim of the CCWO was to eliminate CTT by levelling the tibial plateau and therefore providing functional stifle stability during the stance phase of the gait (Slocum & Devine 1984).

The technique involves removing from the proximal tibia a cranially based wedge of bone distal to the most proximal point of the tibial tuberosity (Fig 4A). The aim is to achieve a postoperative TPA of approximately 6° (Warzee *et al.* 2001). Multiple

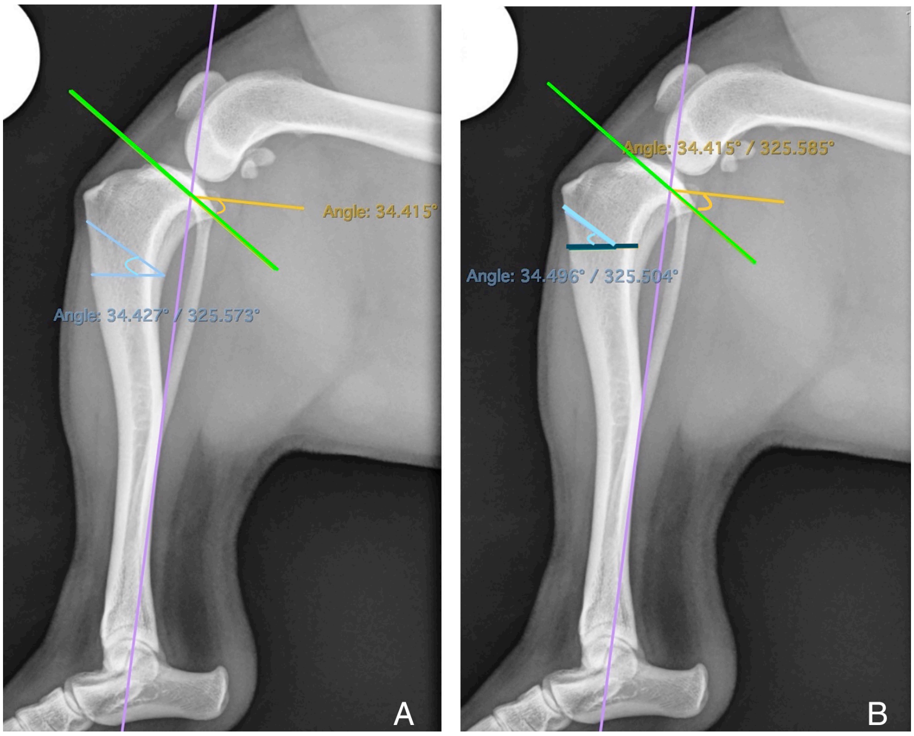

FIG 4. (A) Example of preoperative planning for the "classic" cranial closing wedge ostectomy. In this example the TPA is determined by drawing the tibial plateau axis (green line), the tibial mechanical axis (purple line) and a reference line perpendicular to the mechanical axis of the tibia (yellow line). A cranially based wedge ostectomy is then drawn with the base just distal to the base of the tibial tuberosity (light blue lines). In this example, the angle between the osteotomy lines is equal to the TPA. (B) Example of preoperative planning for the modified cranial closing wedge ostectomy described by Wallace *et al*. (2011). The TPA is determined as described for (A). The first osteotomy is made perpendicular to the long axis of the tibia (dark green line) and a second osteotomy is performed at an angle to the first one (light blue line) intersecting the first osteotomy at two thirds of its cranial to caudal length. The angle between the two osteotomy lines is equal to the TPA, and is the same as (A)

modifications of the technique have been described varying the position of the ostectomy in relation to the tibial tuberosity, the post-reduction alignment of the cranial or caudal cortices, the size and shape of the bone wedge and the method of fixation (locking or non-locking TPLO plates with or without pin and tension band wire).

Bailey *et al.* (2007) reported that more distal CCWO and post-reduction alignment of the caudal cortices resulted in a higher than expected post-operative TPA. In other words, the desired postoperative TPA is more likely to be achieved if the cranial cortices are aligned and the ostectomy is performed as proximally as possible. Although the study only included large breed dogs, the results are likely to be equally applicable to small breed dogs.

Wallace *et al.* (2011) showed that CCWO performed as originally described in 1984 causes shortening of the tibia. Tibial shortening may be more pronounced in Terrier breeds with steep TPA where a larger wedge of bone must be removed to level the tibial plateau. They speculated that tibial shortening may be problematic for a number of reasons. Firstly, craniodistal displacement of the tibial tuberosity may lead to patella baja and may lead to increased strain on the patella ligament and consequent patellar desmitis. Secondly, increased strain and bending of the fibula could predispose to fibular fracture. Finally, removal of a cranially based wedge of bone from the tibia might result in greater recurvatum of the tibia which may alter the contact mechanics of the stifle and crurotarsal joints. They also speculated that abnormal loading may result in cartilage wear and lameness, but this has not been proven.

To avoid these potential problems, the authors of this cadaveric study describe a modification of the CCWO technique where a smaller triangular wedge of bone is removed. The first osteotomy is performed perpendicular to the long axis of the tibia at the base of the flare of the tibial tuberosity and the second osteotomy is performed at an angle to the first one (the angle is equal to the TPA) intersecting the first osteotomy at two thirds of its cranial to caudal length (Figs 4B and 5A, B). Advantages of this technique are that a smaller volume of bone is removed from the tibia, allowing greater preservation of bone stock in the proximal tibia for implant placement and resulting in lesser degree of tibia shortening compared to the "classic" CCWO technique. One disadvantage of this technique is that not all the cross-sectional area of the proximal or distal segments contributes to load sharing at the reduced ostectomy site, which could potentially increase the strain on the implants and therefore increase the risk of implant failure; however, this is a theoretical consideration that is likely not relevant clinically. To mitigate this, the authors suggest that if the osteotomy is performed more proximally on the tibia (with the more proximal osteotomy starting just below the tip of the tibia tuberosity, light blue line Fig 4B), the cross-sectional area of the tibia is greater, and there is more cancellous bone which heals more quickly compared to cortical bone (Wallace *et al.* 2011).

FIG 5. Postoperative radiographs of a cranial closing wedge ostectomy performed with the modified technique described by Wallace *et al.* (2011). The osteotomy has been stabilised with a TPLO locking compression plate and with a pin and figure-of-eight-tension band wire. (A) medio-lateral view, (B) caudo-cranial view. The modified CCWO leaves a characteristic appearance on the mediolateral view to the double osteotomy surfaces of the proximal and distal segments, which are not in contact caudally

Frederick & Cross (2017) have reported the short-term outcome of the modified CCWO as described by Wallace *et al.* (2011) in a case series of 19 cases including small, medium and large dogs. In this report, the surgery was performed by removing a wedge of bone equal to the TPA with the most proximal osteotomy starting 3-mm distal to the patellar ligament insertion; the surgeon also attempted to align the cranial cortices, although this was not always possible due to soft tissue tension. The osteotomy was stabilised with locking or non-locking TPLO plates and with a pin and figure-of-eight tension band wire. The overall complication rate was 21% with two major complications (surgical site infection necessitating implants removal) and three minor complications that resolved without surgical treatment. Subjective clinical outcome 8 weeks after surgery was adequate in all cases. The authors comment that given the very proximal position of the osteotomy with this technique, they recommend to always supplement plate fixation with cranial pin and figure-of-eight tension band wire to protect the tibial tuberosity and prevent loss of reduction at the osteotomy site in the postoperative period (Frederick & Cross 2017).

Christ *et al.* (2018) and Terreros & Daye (2020) reported the short-term and long-term outcome after another modification of the CCWO technique aimed at minimising the length of the cranial tibial wedge and optimising bone contact at the osteotomy. We refer the readers to the original papers for a full description of the surgical technique. Both studies include dogs of any size with a small number of small breed dogs included. Christ *et al.* (2018) reported a 6% cumulative complication rate and subjective clinical outcome adequate in all cases 8 weeks after surgery. Terreros & Daye (2020) reported 10% major complications, 20% minor complications and good long-term outcome assessed via owner questionnaire in all cases but one.

Only one publication has reported the outcome of the procedure in small breed dogs (Campbell *et al.* 2016). In this case series of 55 cases, the size of the wedge removed from the tibia was equal to the TPA minus 5°. The proximal osteotomy was positioned just distal to the insertion of the patellar ligament and the distal osteotomy was positioned perpendicular to the long axis of the tibia with the apex of the wedge intersecting on the caudal cortex (*i.e.* the "classic" CCWO technique was performed). The osteotomy was stabilised with a non-locking Slocum-style TPLO plate. In some cases, a pin and tension band was placed to further stabilise the osteotomy and compress the cranial cortices. The mean postoperative TPA achieved was 7.5° (range 2° to 13°). The mean reduction in tibial length was 3 mm. The overall complication rate at 10 weeks after surgery was 28%. The major complication rate was 2% (1/55 dogs required revision surgery). A total of 94% of owners were satisfied with the outcome 2 years after surgery.

SURGICAL MANAGEMENT: TIBIAL PLATEAU LEVELLING OSTEOTOMY (RADIAL CUT)

TPLO was first reported by Slocum & Slocum (1993). The purpose of the procedure was, similarly to a CCWO, to eliminate CTT by levelling the tibial plateau and therefore providing functional stifle stability during the stance phase of the gait. This was achieved by performing a radial osteotomy centred over the intercondylar eminences of the tibia and rotating the proximal tibial plateau fragment to obtain the target TPA of 5° to 7° (Slocum & Slocum 1993, Warzee *et al.* 2001) (Fig 6A, B). The procedure has become increasingly popular in medium and large breed dogs (Kowaleski *et al.* 2018) and it is slowly becoming more popular in small breed dogs in recent years.

There are two main considerations that should be taken into account when performing the procedure in small dogs. Firstly, the small size of the proximal tibial fragment in small breed dogs (a radial osteotomy of 10- to 15-mm radius) makes it technically challenging to fit implants in the proximal tibial fragment, allowing very little margin for error when deciding the position of the osteotomy and when placing screws (Witte & Scott 2014).

Secondly, often small breed dogs have a steep TPA and therefore need larger rotation of the proximal tibia fragment compared to dogs with lower TPA. This may lead to a lack of caudal buttressing of the tibial tuberosity, *i.e.* rotation such that the cranial

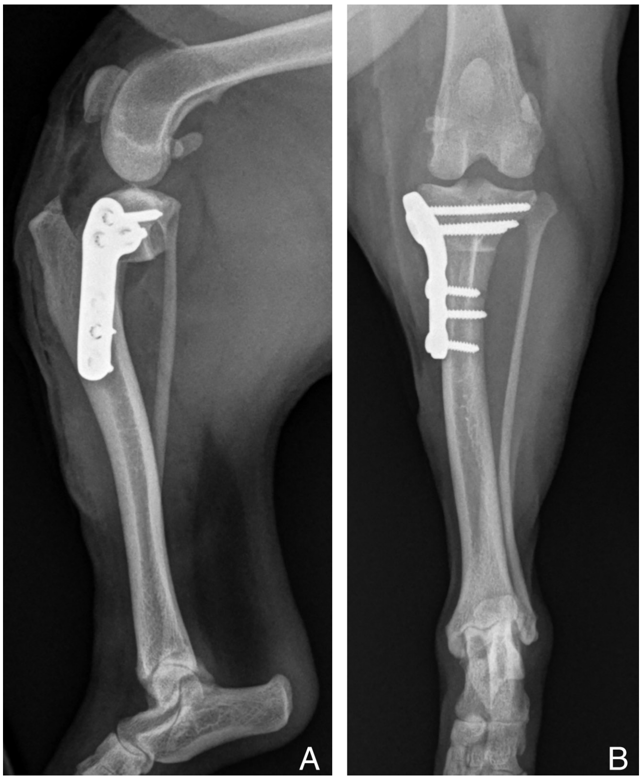

FIG 6. Postoperative radiographs of a TPLO performed in a small breed dog. The osteotomy has been stabilised with a Synthes TPLO locking compression plate. (A) medio-lateral view, (B) caudo-cranial view

aspect of the tibial plateau is located distal to the insertion point of the patellar ligament as assessed by mediolateral radiographic projections. Rotation of the tibial plateau below the insertion of the patellar ligament together with excessive narrowing of the tibial tuberosity (tibial tuberosity width <10 mm) have been reported as risk factors for tibial tuberosity fracture in large breed dogs in some reports, but other reports have disagreed (Talaat *et al*. 2006, Bergh *et al*. 2008). Risk factors for tibial tuberosity fracture in small breed dogs are currently not known but the complication has been reported rarely in small breed dogs.

Seven case series have reported the outcome of TPLO in small breed dogs. Petazzoni (2004) reported TPLO in 15 small breed dogs (18 stifles). The osteotomy was stabilised with a DCP plate or T-plate or 2-mm Slocum TPLO plate. 14/15 patients had complete resolution of lameness when subjectively evaluated by a veterinary surgeon 8 weeks after surgery. One dog developed a complication (tibial tuberosity fracture) which resulted in persistent lameness.

Vezzoni (2010) reported the surgical technique to perform TPLO in small breed dogs using an implant system (Fixin locking plate system, TraumaVet, Rivoli, Italy) consisting of a stainless-steel T- or L-shaped plate with titanium alloy bushing inserts and titanium screws with a conical head that locks into the plate by conical coupling.

Witte & Scott (2014) reported TPLO surgery in 19 small breed dogs with high TPA (>30°) using the T-shaped locking plates described by Vezzoni (2010). They reported a 13.8% complication rate with failure of the caudal screw in the proximal fragment in three cases (no revision surgery needed) and SSI in one case. All dogs had good long-term outcome as assessed by the owner questionnaire.

Cosenza *et al*. (2015) reported TPLO surgery in 69 small breed dogs (79 stifles) using the L-shaped locking plates described by Vezzoni (2010). They reported a 16.4% complication rate. The major complications needing further surgical treatment (5%) included: intra-articular screw placement, screw failure, plate breakage, tibial tuberosity fracture and osteomyelitis. The number of dogs that required rotation of the tibial plateau below the insertion of the patellar ligament was not reported. Subjectively assessed median lameness scores were between 0/4 and 1/4 6 to 8 weeks after surgery in all cases.

Garnett & Daye (2014) reported TPLO surgery in 82 small and medium breed dogs (98 stifles) using 2.0 mm non-locking Slocum-style TPLO plates and 2.7 mm locking Slocum-style TPLO plates. They reported 36% overall complication rate and 7% major complications requiring repeat surgery. Tibial tuberosity fracture occurred in 6/98 stifles (6% of procedures). The number of dogs that required rotation of the tibial plateau below the insertion of the patellar ligament was not reported in this study. Although the overall complication rate is higher in this study compared to other reports, most of the complications did not require any further treatment.

Barnes *et al*. (2016) reported TPLO surgery in 26 dogs weighing <18 kg (29 stifles) with steep TPA (>35°). The osteotomy was stabilised in all cases using 2.4-, 2.7- or 3.5-mm short six-hole Slocum-style TPLO locking compression plates (Synthes, West Chester, PA, USA). The complication rate was 3.4%. The only complication reported was minor: patellar ligament desmitis in one of 29 cases. Short-term clinical lameness assessment (6 to 8 weeks after surgery) was 0/4 or 1/4 in all cases. Tibial tuberosity fracture did not occur despite rotation of the tibial plateau segment below the insertion point of the patellar ligament in 55% of cases. The mean measurement of the minimum width of the tibial tuberosity segment in this study was 5.9 mm. The authors hypothesised that tibial tuberosity width <~6 mm may be a risk factor for tibia tuberosity fracture in small and medium breed dogs however, tibial tuberosity width is not the only risk factor for tibial tuberosity fracture. Furthermore, the canine population in this study represents a broad range of bodyweight and size therefore meaningful conclusions regarding safe limit of tibial tuberosity width following TPLO cannot be made.

The lower complication rate reported in this paper compared to the complication rates reported by Witte & Scott (2014) and Cosenza *et al*. (2015) may be in part attributed to the different type of plates used in these studies. The conically coupled T-shaped and L-shaped plates used by Witte & Scott and Cosenza et al. allow the application of a maximum of two screws in the proximal fragment and the locking mechanism relies on a Morse taper fit between the titanium screw head and the titanium bushing that inserts into the plate. This locking plate system does not allow for axial compression of the osteotomy. Conversely, the TPLO locking compression plate used by Barnes et al. allows placement of three screws in the proximal fragment, the locking mechanism relies on threads that lock the stainless-steel screw head into the stainless-steel plate, and the plate allows for axial compression of the osteotomy, which may make the construct more stable, and decrease gap strain at the osteotomy site. Although we are not aware of biomechanical studies directly comparing these two types of plates in settings comparable to TPLO surgery, it appears reasonable to assume that the TPLO locking compression plate would provide more stable fixation compared to the Fixin plate given the larger number of screws in the proximal tibia fragment, the nature of the locking mechanism and the ability to apply axial compression. Biomechanical comparison of Fixin plates and locking compression plates (LCP plates) in a fracture gap model has shown that LCP plates have greater bending strength and stiffness and torsional strength compared to Fixin plates (Blake *et al.* 2011, Cabassu *et al.* 2011).

Finally, Knight & Danielski (2018) have reported TPLO surgery in 66 small breed dogs with TPA >30°. The osteotomy was stabilised with non-locking Slocum-style TPLO plates in 30 cases and Slocum-style locking compression TPLO plates in 36 cases. No major complications occurred. Minor complications occurred in 22.7% of cases and resolved with medical management in all cases. Rotation of the proximal tibial fragment below the insertion of the patellar ligament was present in 33% of cases; however, none of the dogs developed tibial tuberosity fracture. The mean tibial tuberosity width in this study was 6.8 ±1.3 mm. Similarly to Barnes *et al.* (2016), the authors of this study hypothesise that a tibia tuberosity width <~6 mm may be a risk factor for tibial tuberosity fracture in small breed dogs.

SURGICAL MANAGEMENT: TIBIAL TUBEROSITY ADVANCEMENT AND DERIVED TECHNIQUES

TTA was introduced for surgical treatment of CCL rupture by Montavon *et al.* (2002). The authors described an alternative biomechanical stifle model adopted from human medicine where the direction and magnitude of the CTT is not determined by the slope of the tibial plateau (as described by Slocum & Devine in 1983) but by the "patellar tendon angle" (PTA), which is the angle between the patellar ligament and tibial plateau; a PTA greater than 90° generates CTT (Fig 1) (Tepic *et al.* 2002). Stabilisation of the stifle joint is achieved by performing a frontal plane tibial osteotomy and advancing cranially the tibial tuberosity and the insertion of the patellar ligament in order to achieve a PTA equal to 90° at maximal stifle joint extension during weight bearing (Montavon *et al.* 2002).

In the "classic" TTA surgical procedure, stability of the tibial osteotomy is attained with a custom-designed tension-band plate and cage (Kyon). More recent modifications of the technique have eliminated the plate and rely on the cage to provide advancement and stability of the tibia tuberosity. Examples of these modifications of the original technique include the Modified Maquet Procedure (Orthomed), the TTA Rapid (Leibinger medical), the TTA-2 (Kyon) and the Fusion TTA (Fusion implants).

Whether TTA or its modifications should be employed to treat CCL rupture in dogs of small or large breed with a steep TPA is controversial. Anecdotally, the procedure is not recommended in dogs with a TPA greater than 30° (Boudrieau 2009, Kowaleski *et al.* 2018) or even greater than 25° (Vezzoni 2008). This is because the amount of advancement of the tibia tuberosity needed to achieve a PTA of 90° may be greater than the largest cage size available (15 mm). Further advancement may be achieved by transposing the cage distally; however, additional buttress support (to prevent catastrophic tibial tuberosity fracture) may be required proximal to the cage if the cage is transposed more than a few millimetres. A method to calculate the desired distal displacement of the cage has been described in four giant breed dogs (Burns & Boudrieau 2008). Large amount of advancement of the tibia tuberosity was needed in these dogs due to their large size and their height rather than because of a steep TPA. Distalisation of the cage has not been described in small breed dogs with steep TPA undergoing TTA surgery.

It has also been suggested that in dogs with a steep TPA the stifle joint is in a relative position of hyperextension because of the altered angulation of the tibial plateau (Boudrieau 2009, Kowaleski *et al.* 2018). Because of this abnormal conformation, the stifle range of movement is limited and the limb cannot be fully extended. If TTA surgery is performed in these dogs, the joint remains in the hyperextended position, as this malformation remains unaddressed. However, if surgery is performed to lower the TPA (*e.g.* TPLO surgery) the abnormal tibia conformation is also corrected (Boudrieau 2009, Kowaleski *et al.* 2018).

In spite of the above limitations and concerns regarding the application of TTA, two case series have reported TTA surgery in small breed dogs in recent years.

Dyall & Schmökel (2017) reported TTA Rapid in 40 small breed dogs (48 stifles, bodyweight <15 kg) with a 14.6% major complication rate (cortical fissures, tibial fracture and late meniscal tears) and long-term outcome rated good or excellent by 95% of the clients. Median follow-up was 72 weeks. The late meniscal injury rate was 4.7%. The mean TPA of the affected stifles in this study was 28.8° ±4.0° (range 19° to 36°). The authors did not mention the need to distalise the cage to achieve the desired PTA of 90° but they did comment that one of the concerns was the need for relatively large cages compared to the small size of the dogs, which could overstretch the elasticity of the cranial tibial cortex leading to fissures and fracture. Their rate of cranial cortical fissures was 8.3% but no significant correlation was found between cortical fissuring and the degree of advancement.

Ferreira *et al.* (2019) reported "classic" TTA surgery in 30 dogs (35 stifles) weighing less than 15 kg. They reported a 5.7% major complication rate (one intra-articular screw and one wound dehiscence). Twelve weeks after surgery 91% of dogs were not lame, 6% were mildly lame and 3% were moderately lame as evaluated by a veterinary surgeon. The authors did not report the TPA of the dogs and did not comment on the need for large advancement relative to the size of the dogs. Follow-up was 12 weeks. No late meniscal injuries were reported.

DISCUSSION

Reviewing the literature published on the subject of CCL rupture in small dogs has highlighted some differences between small and medium/large breed dogs affected by CCL rupture. Various studies have suggested that small breed dogs tend to present with CCL rupture later in life (mean age at presentation 5.4 to 9.8 years, Table 1) compared to large breed dogs. Terrier breeds (West Highland White and Yorkshire), Miniature and Toy Poodles are over-represented. Obesity has been suggested to be a risk factor for CCL rupture (although this applies to dogs of any size rather than just small breed dogs).

Small breed dogs have a different morphology of the proximal tibia compared to medium/large breed dogs. The mean TPA of small breed dogs has been reported to range from 28.8° to 36.3° (Table 2), which is steeper compared to the average TPA of medium/large breed dogs (22° to 28°). Additionally, in small breed dogs the base of the flare of the tibial tuberosity is often absent and the fibula is usually bowed caudally (Fig 2).

The treatment options that have been reported for small breed dogs affected by CCL rupture consist of conservative management, extracapsular stabilisation, CCWO, TPLO and TTA. One of the aims of this paper was to assess whether there is any evidence regarding the optimal management of CCL rupture in small dogs or in other words, whether one treatment option is superior compared to the others. Unfortunately, at present is not possible to answer this question. The gold standard study design to assess efficacy and safety of an intervention and from which conclusions can be made to alter treatment paradigms are prospective controlled blinded randomised clinical trials (Level 2 evidence, Table 4) (Lu 2009, Katz *et al.* 2011, Bergh *et al.* 2014), but none exist. Until such studies are available, superiority of one treatment option over the others cannot be proven. Given that all the studies published on treatment options for small breed dogs with CCL rupture (Table 3) are observational case series (Level 4 evidence, Table 4), a direct comparison of the outcomes between types of treatment cannot be made. Unfortunately, although the evidence provided by these studies is useful, their results cannot be directly compared due to confounding variables as a result of different methodologies; *e.g.* different inclusion criteria, outcome measurements, categorisation of complications, follow-up times etc.

Below we will highlight and summarise the main findings related to treatment options reported in the case series included in this review, and we will add our personal experience as experts in the field (Level 5 evidence, Table 4) with the intention to put the findings into context and to inform and guide the veterinarian in practice.

Conservative management in small breed dogs

There is paucity of supportive information in the literature, regarding what the optimal protocol is or what is the likely success rate of conservative management. Therefore, it is difficult to draw evidence-based recommendations. Based on the results of Vasseur (1984), the main conclusion that can be made regarding this treatment option is that recovery for small breed dogs is likely to be prolonged, with an average recovery time of approximately 4 months.

Given the authors' experience, we do not recommend conservative management in small dogs unless they are only very mildly lame, or dogs that are not surgical candidates due to financial constraints or co-morbidities. The conservative management protocol we use consists of NSAIDs for 2 to 4 weeks, nutraceuticals containing omega-3 fatty acids, strict rest with short lead walks only and rehabilitation therapy.

Extracapsular stabilisation in small breed dogs

There is also paucity of reports assessing complication rate and outcome for this treatment option. One case series (Rappa & Radasch 2016) assessed outcome with a commercially available titanium bone anchor located in the distal femur and a tibial bone tunnel (14% major complication rate, 96% good or acceptable outcome). No publications have assessed the indications, the outcome and the time to recovery after placement of a "classic" tibio-fabellar suture or any other modifications of the original technique (Table 3). Questions have been raised regarding the success rate of this technique because of early failure of the suture in small dogs with steep TPA and individual variability in the location of quasi-isometric points in small breed dogs (Witte 2015). However, further studies are needed to find evidence-based answers and to be able to comment further on advantages and disadvantages of extracapsular stabilisation.

The authors' experience of extracapsular suture placement in small (and large) dogs is overall disappointing. Recovery from surgery is very slow, it is very difficult to achieve meaningful isometric points for suture placement and to reliably stabilise cranio-caudal stifle instability whilst maintaining a good range of stifle movement. *Re*-examination at 6 to 8 weeks often shows recurrent cranial drawer instability suggesting implant failure. Given the above, and the much-improved outcomes with the osteotomy techniques as described below, we would rarely if ever perform extracapsular stabilisation techniques.

CCWO in small breed dogs

One case series (Campbell *et al.* 2016) (Table 3) reported major complications to be very low (2%) and the outcome as assessed by owners good (94% of owners were satisfied with the outcome 2 years after surgery). These results suggest this surgical technique is a reasonable choice to stabilise the CCL deficient stifle in small breed dogs. However, there are a few considerations to be made regarding the implications of performing a CCWO.

Table 4. Levels of evidence

Question	Step 1 (Level 1)	Step 2 (Level 2)	Step 3 (Level 3)	Step 4 (Level 4)	Step 5 (Level 5)
Does this intervention help? (treatment benefits)	Systematic review of randomised trials or *n*-of-1 trials	Randomised trial or observational study with dramatic effect	Non-randomised controlled cohort/ follow-up study	Case series, case–control study or historically controlled studies	Mechanism-based reasoning

Taken from "The Oxford 2011 Levels of Evidence". Oxford Centre for Evidence-Based Medicine (2011). http://www.cebm.net/index.aspx?o=5653. Accessed February 8, 2021

Table 5. Summary of studies published in the peer-reviewed literature reporting incidence of tibial tuberosity fracture following TPLO surgery to address the CCL deficient stifle in small breed dogs

Article	Percentage of stifles that developed tibial tuberosity fracture (%)	Percentage of stifles with rotation of the proximal fragment below the insertion of the patellar ligament	Average width of the tibial tuberosity after osteotomy
Garnett & Daye (2014)*	6	Not reported	Not reported
Witte & Scott (2014)	0	Not reported	Not reported
Cosenza *et al*. (2015)	1.2	Not reported	Not reported
Barnes *et al*. (2016)**	0	55%	5.9 mm
Knight & Danielski (2018)	0	33%	6.8 ±1.3 mm

*this study included a small proportion of medium breed dogs, median bodyweight was 12.5 Kg (range 4.5-31.9 Kg)
**this study included dogs with bodyweight <18 Kg

Wallace *et al.* (2011) highlighted that the "classic" CCWO surgery causes shortening of the tibia; and this gets worse the higher the TPA of the dog. The mean reduction in tibial length in small dogs as reported by Campbell *et al.* (2016) was 3 mm but it is not known whether such amount of tibial shortening is clinically relevant. In this study, the dogs were reported to have good function after surgery but no studies have performed objective gait analysis in small breed dogs that underwent CCWO surgery.

The surgeon should also be aware that, as outlined by Bailey *et al.* (2007), depending on whether the osteotomy is positioned more proximally or distally on the tibia and whether the cranial or caudal cortices are aligned after performing the osteotomy, there is a variation in the TPA achieved by the surgery. In order to achieve the target TPA of 5° to 7°, it is important to remove a wedge of bone of appropriate size (depending on the specific CCWO technique used) and, given that the soft tissue tension does not always allow to align the cranial cortices, a degree of variation in the TPA achieved post-surgery should be expected.

Finally, studies assessing stability of the osteotomy, complication rate and outcome with different methods of osteotomy fixation have not been published and therefore the optimal method of fixation (Slocum-style TPLO locking or non-locking compression plate with or without pin and figure-of-eight tension band wire) is not proven, although it is reasonable to assume that a TPLO locking compression plate with cranial pin and tension band wire is most stable.

The authors' experience of the CCWO technique is positive; we would perform this in small dogs with lameness associated with CCL rupture, expecting good recovery and excellent limb function, minimal lameness, and low complications. The osteotomy is inherently less stable than the radial cut TPLO. Our technique would be the modification described by Wallace *et al.* (2011), stabilised with a TPLO locking compression plate, and a cranial pin and figure-of-eight-tension band wire.

TPLO in small breed dogs

This has been reported more frequently than other treatment options in small breed dogs, with low major complication rate and good subjective outcome in all reports (Table 3). In particular, the two most recent case series (Barnes *et al.* 2016, Knight & Danielski 2018) have reported a 0% major complication rate with osteotomy fixation performed with TPLO locking compression plates.

However, objective outcome measures have not been reported in small breed dogs undergoing this procedure. This technique is technically difficult in small dogs due to the small size of the proximal tibia, which allows little room for error when choosing the position of the osteotomy in order to have enough bone available to be able fit the implants in the proximal fragment (Witte & Scott 2014). The surgeon should expect a significant learning curve to be present when starting to perform this procedure.

Given that small breed dogs with steep TPA often need rotation of the proximal fragment below the point of insertion of the patellar ligament, the risk of tibial tuberosity fracture has been hypothesised to be higher for these dogs. However, the incidence of tibial tuberosity fracture reported in the literature in small breed dogs is low (Table 5). It has been suggested that in small breed dogs the surgeon should aim for an average minimum tibial tuberosity width of approximately 6 mm in order to prevent tibial tuberosity fracture and that rotation beyond the point of insertion of the patellar ligament may not be a risk factor for tibial tuberosity fracture in small breed dogs (Barnes *et al.* 2016, Knight & Danielski 2018). However, further studies (including biomechanical studies) are needed to substantiate these statements.

The authors' experience of the radial TPLO technique is very positive and this would be our preferred technique for a small dog with CCL rupture, with a good expectation of recovery of excellent limb function, minimal lameness, and low complications. The osteotomy is inherently more stable than the CCWO technique given the integrity of the cranial tibial cortex, and there is no tibial shortening or long axis shift. But in very small dogs, the technique is very challenging owing to the small size of the bones; precision and accuracy is key as there is minimal room for error.

TTA in small breed dogs

It is controversial whether TTA should be performed in dogs with a steep TPA (TPA > 25° to 30°) (Vezzoni 2008, Boudrieau 2009, Kowaleski *et al.* 2018), which would include most small breed dogs. Although two case series have been published reporting TTA in small breed dogs (Dyall & Schmökel 2017, Ferreira *et al.* 2019), the surgeon should be careful when deciding to employ this technique in small breed dogs until further evidence has become available.

The authors have no experience of TTA in small breed dogs, other than revising major complications arising from TTAs performed by other surgeons; the main complications being tibial fractures, late meniscal tear, and persistent stifle instability and lameness that resolves on conversion of TTA to TPLO. We do not electively perform TTAs due to the relatively high complication rates reported (and experienced) with the procedure, and the reservations as outlined above that TTA may not be appropriate for (small) dogs with steep TPA.

In conclusion, we have reviewed the literature published on the subject of CCL rupture in small dogs, we have identified the differences between small and large dogs, and we have put the findings into context for the veterinarian in practice.

We have not been able to find strong enough evidence to enable us to absolutely recommend what is the optimal management for small dogs affected by CCL however, the weight of available evidence points towards TPLO.

Given the lack of studies comparing treatment options, we can only recommend that clinicians treating small breed dogs affected by CCL rupture base their decision making on a thorough assessment of each individual case and on the evidence collected from the available observational case series reviewed throughout this paper, combined with personal experience.

Conflict of interest

VB has no conflict of interest to declare. GIA is a consultant for Veterinary Instrumentation, Sheffield, UK.

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