Cranial cruciate ligament injury in the dog: pathophysiology, diagnosis and treatment

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Abstract
Cranial cruciate ligament (CCL) disease in the dog is a multifactorial complex problem that requires a thorough understanding of the biomechanics of the stifte joint to be understood. Successful treatment of rupture of the CCL should be based on managing underlying anatomical and conformational abnormalities rather than attempting to eliminate the tibial cranial drawer sign. The cranial and caudal cruciate ligaments, the patella ligament and quadriceps mechanism, the medial and lateral collateral ligaments, the medial and lateral menisci and the joint capsule provide stability of the joint and load-sharing. The function of the stifte is also significantly influenced by the musculature of the pelvic limb. An active model of biomechanics of the stifte has been described that incorporates not only the ligamentous structures of the stifte but also the forces created by weight-bearing and the musculature of the pelvic limb. This model recognises a force called “cranial tibial thrust”, which occurs during weight-bearing, and causes compression of the femoral condyles against the tibial plateau.

In middle-aged, large-breed dogs, forces acting on the CCL together with conformation-related mild hyperextension of the stifte and slightly increased tibial plateau slopes are suspected to cause progressive degeneration of the ligament. Palpation of cranolateral stifte laxity has become pathognomonic for CCL rupture; however, chronic periarticular fibrosis, a partial CCL rupture, and a tense patient, may make evaluation of instability of the stifte difficult.

Surgical treatment is broadly separated into three groups: intracapsular, extracapsular, and tibial osteotomy techniques. Tibial osteotomy techniques do not serve to provide stability of the stifte but rather alter the geometry of the joint to eliminate cranial tibial thrust such that functional joint stability is achieved during weight-bearing. Visualisation of both menisci is a critical aspect of CCL surgery, irrespective of the technique being performed. Regardless of the surgical technique employed, approximately 85% of dogs show clinical improvement. However, many of these dogs will demonstrate intermittent pain or lameness. Post-operative management is an integral part of the treatment of CCL rupture, and significant benefits in limb function occur when formalised post-operative physiotherapy is performed.

Key points
- The cranial cruciate ligament (CCL) has two parts, a craniomedial band and a caudolateral band.
- The magnitude of cranial tibial thrust is a function of both the slope of the tibial plateau and the compressive forces of weight-bearing.
- CCL rupture can occur in young, large-breed dogs due to abnormal conformation of the stifte.
- Partial CCL rupture frequently precedes complete rupture, especially in middle-aged large-breed dogs.
- Regardless of surgical technique, 85% of dogs show clinical improvement following surgery.
- Intracapsular autografts can only support 25% of the load of a normal CCL.
- Large-size nylon used for extracapsular stabilisation is not necessarily stronger than small-size nylon, due to additional stresses at the level of the knot.
- Arthrotomy and meniscal examination are critical components of surgery for CCL rupture.
- Tibial osteotomy techniques alter the slope of the tibial plateau, eliminating cranial tibial thrust.
- Post-operative rehabilitation may be the most important component in successful clinical recovery.

Introduction
Injury of the CCL is the most commonly diagnosed orthopaedic condition of the stifte in dogs (Dupuis and Harari 1993; Harari 1995; Moore and Read 1996a; Vasseur 2003). Despite the frequency of this potentially debilitating condition there remains considerable debate and discussion on the subject amongst veterinary surgeons. Notwithstanding the numerous publications in

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the veterinary literature on the aetiology, diagnosis and treatment of CCL injury, standard protocols have yet to be established for the most appropriate management of this joint disease. The lack of consistent and straightforward answers to the difficulty of managing cruciate ligament injury appears to lie in the belief that this is a simple problem. In reality, CCL injury in the dog is, more commonly, a multifactorial complex problem that requires a thorough understanding of the biomechanics of the stifles joint related to functional anatomy, patient conformation, and gait analysis if it is to be solved. Successful treatment of rupture of the CCL should therefore be based on managing the underlying anatomical and conformational abnormalities rather than classically attempting to eliminate tibial cranial drawer sign. The purpose of this article is to review the most current veterinary literature, with emphasis placed on contemporary surgical techniques that attempt to address these issues.

**Functional anatomy**

The stifles joint has most motion in two planes: flexion/extension and rotation. Slight cranio-caudal and medial/lateral movements also occur (Harari 1995; Vasseur 2003). The cranial and caudal cruciate ligaments, the patella ligament and quadriceps mechanism, the medial and lateral collateral ligaments, the medial and lateral menisci and the joint capsule provide stability of the joint and load-sharing. The CCL originates on the caudomedial aspect of the later al femoral condyle and runs across the intercondylar notch to insert on the cranial intercondylar area of the tibia. The CCL has two distinct parts, the cranio-medial band and the larger caudolateral band, which spiral laterally 90° between attachments (Moore and Read 1996a; Vasseur 2003). The caudal cruciate ligament originates at the lateral aspect of the medial femoral condyle and runs caudodistally to the lateral edge of the popliteal notch of the tibia. The cruciate ligaments receive their blood supply from the synovial sheaths that surround them. The mid-section of both ligaments have a poorer blood supply than the proximal and distal ends (Vasseur 2003).

The menisci are semilunar fibrocartilaginous discs located between the femoral condyles and the tibial plateau (Vasseur 2003). They are wedge-shaped in cross-section and have thicker peripheral borders. The peripheral aspect of both menisci has a vascular synovial plexus whereas the central part is nourished by diffusion of synovial fluid. The menisci provide stability and lubrication of the joint and appear to play a role in proprioception. They are attached to the tibial plateau by cranial and caudal ligaments and the lateral meniscus also has an attachment to the femur. This meniscofemoral ligament allows the lateral meniscus to move more freely within the joint during motion. Conversely, the medial meniscus is firmly attached to the tibial plateau and medial collateral ligament (Vasseur 2003; Figure 1).

The function of the stifles is significantly influenced by musculature of the pelvic limb. The actions of the quadriceps muscle group, caudal thigh muscle group (semimembranosus, semitendinosus, biceps femoris), and extensor group (gastrocnemius, superficial digital flexor) of the tibiotarsal joint contribute to normal stability of the stifles (Slocum and Slocum 1993).

**Biomechanics of the stifles**

Traditionally, the stifles has been described as a two-dimensional structure moving in a single plane, with only ligaments controlling the stability and range of motion of the joint. In the traditional model of the stifles, the CCL prevents cranial displacement of the tibia relative to the femur (Slocum and Slocum 1993). During flexion of the stifles, the cranio-medial band of the CCL is taut whereas the caudolateral band and the lateral collateral ligament relax, allowing internal rotation of the tibia on the femur. Flexion is limited by contact between the musculature of the thigh and the tarsal region, not by ligaments. During extension, both bands of the CCL and the lateral collateral ligaments tighten and external rotation of the tibia relative to the femur occurs. Extension is limited by contact between the CCL and the intercondylar notch, which restricts hyperextension of the joint.

A more active model of the biomechanics of the stifles, described by Slocum and Slocum (1993), incorporates not only its ligamentous structures but also the forces created by weight-bearing and the musculature of the pelvic limb. This model recognises a force called “cranial tibial thrust”, which occurs during weight-bearing, by compression of the femoral condyles against the tibial plateau. The CCL, the caudal horn of the medial meniscus and the flexor muscle group of the stifle balance this force, preventing cranial translation of the tibia. The magnitude of cranial tibial thrust is dependent on both the degree of compression during weight-bearing and the slope of the tibial plateau. The tibial plateau slopes caudodistally and varies between dogs due to anatomical and conformational differences (Dejardin 2003). The amount of tibial compression is also variable and depends on the size and activity level of the dog. This active model of biomechanics has provided veterinary orthopaedic surgeons with a novel and satisfactory theory for the pathogenesis of CCL injury.
Pathogenesis

It is commonly accepted that CCL injury is not a single entity in all dogs, and typically occurs in four broad groups of dogs, as follows:

1. Small miniature or toy-breed, middle-aged dogs that present with CCL injury following mild to moderate exercise, which is secondary to medial patellar luxation (Moore and Read 1996a). When the quadriceps muscles contract with a medially-luxated patella there is excessive internal rotation of the tibia during extension of the stifle that increases forces on the CCL. Medial luxation of the patella also reduces cranial stability of the joint, leading to a further increase in forces on the CCL. In addition, many of these dogs have a genu varum (bow-legged pelvic limbs) that further stresses the CCL.

2. Large to medium-sized active, athletic dogs that suffer an acute traumatic injury to the CCL during strenuous exercise or work. The healthy CCL can sustain a load of approximately four times the dog’s bodyweight (Johnson et al 1989). Hyperextension of the stifle forces the CCL against the cranial aspect of the intercondylar notch, crushing the ligament and deforming the ligament to the point of injury (Slocum and Slocum 1993). Excessive internal rotation can also result in sudden overload of the CCL, causing complete rupture.

3. Young large-breed dogs with conformational abnormalities that develop acute lameness after mild or moderate activity. In these dogs, prominent hyperextension of the stifle is present in a normal standing position. It is theorised that this results in impingement of the CCL on the intercondylar notch, as well as functionally increasing the caudodistal slope of the tibial plateau (Slocum and Slocum 1993; Harari 1995; Moore and Read 1996a). The resultant increase in strain on the CCL during even normal activity causes damage to the inter-ligamentous fibres. This damage is unable to adequately heal due to poor vascularity of the centre of the CCL and the ongoing strain on the ligament. When this is coupled with difficulty in restricting the dog’s activity, complete rupture of the CCL rapidly occurs. The width of the intercondylar notch has also been implicated in contributing to CCL damage, as it has proven to be narrower in dogs with CCL rupture than in similar individuals with an intact CCL (Aiken et al 1995; Fitch et al 1995ab). More recently, it has been shown that the normal CCL in Rottweilers is weaker than that of racing greyhounds (Winfield et al 2000). If this situation exists in other large-breed dogs, then relative strength of the CCL may also contribute to complete CCL rupture in this group of dogs.

4. Middle-aged, medium- to large-breed dogs that have a history of chronic pelvic-limb lameness that become acutely lame following only mild exercise (Harari 1995). There remains some considerable debate as to the cause of CCL injury in this group of dogs. Many investigators believe that osteoarthritis of the stifle, resulting from immune-mediated degeneration or genetic factors, is the inciting cause of damage to the CCL (Whitehair et al 1993; Galloway and Lester 1995; Moore and Read 1996a; Vasseur 2003). Although plasmacytic lymphocytic synovitis has been implicated as an inciting cause of CCL rupture, there are still several unanswered questions. Is plasmacytic lymphocytic synovitis simply a manifestation of severe osteoarthritis? Why does the stifle appear to be the only joint affected? Why is the CCL the only affected ligament within the stifle joint? When applying the active model of biomechanics of the stifle, as previously discussed, a more practical theory emerges. These dogs typically have a tibial plateau slope of 25–30° and though they are somewhat active they may be overweight. The tibial plateau slope has been shown to be significantly greater in dogs with CCL rupture than in similar dogs with normal stifle joints (Morris and Lipowitz 2001).

The forces acting on the CCL with possible conformation-related mild hyperextension of the stifle and a slightly increased tibial plateau slope are suspected to cause progressive degeneration of this ligament (Slocum and Slocum 1993). This is clinically manifested by the presence of effusion of the stifle, degenerative joint disease and lameness, but without significant instability. A positive cranial drawer sign can occasionally be demonstrated with the limb in flexion. At this stage of the clinical course, a diagnosis of partial CCL rupture can frequently be made (Scavelli et al 1990; Strom 1990). The degenerative process continues, resulting in release of inflammatory cytokines (interleukins 1 and 6, and tumour necrosis factor) and metalloproteinas (stromelysin) that initiate degradation of the cartilage matrix and the already damaged CCL (Hay et al 1997). Osteoarthritic of the stifle rapidly develops and eventual complete rupture of the CCL occurs. This model of CCL rupture helps to explain the presence of significant degenerative joint disease within the stifle joint at the time of diagnosis of complete ligament rupture and the chronic history of pain and lameness without demonstrable instability that typically precedes complete rupture in this group of dogs.

Damage to the medial meniscus occurred in 40–80% of dogs that had CCL rupture (Bennett and May 1991b; Williams et al 1994; Harari 1995; Johnson and Hulse 2002; Vasseur 2003). This meniscus is less mobile than its lateral counterpart. In the normal canine stifle, the increase in femorotibial instability that occurs with CCL rupture results in crushing of the caudal horn of the medial meniscus between the medial femoral condyle and the tibial plateau, during normal activity (Vasseur 2003). Most commonly, a longitudinal tear occurs in the caudal body of the meniscus, that is frequently attached at both ends, the so-called “bucket-handle” tear. The displaced portion of meniscus often moves back and forth under the femoral condyle during manipulation of the joint, causing a clicking sound. Less common types of medial meniscal injuries include peripheral capsular detachment and transverse tears (Moses 2002). Lateral meniscal injuries do occur but are most frequently associated with traumatic injury to the stifle.

Rupture of the contralateral CCL occurred in 37% of dogs within 1 year following surgical treatment of the initially injured CCL (Doverspike et al 1993). This figure may indeed increase with further time post surgery. More than half of the dogs in that study had degenerative changes in the contralateral stifle at the time of surgery on the initially affected limb, and subsequently developed contralateral CCL injury, indicating that the pathogenic processes described above are frequently present in both stifle joints.

In a study in 1993, the highest prevalence of dogs that had CCL injury was among those aged between 7 and 10 years (Whitehair et al 1993). Amongst this group, CCL rupture was more common in females than in males, and dogs that had CCL rupture generally weighed >22 kg. Smaller dogs tended to have CCL rupture.
at an older age (>7 yrs). That study suggested that degeneration of the CCL occurred from 5 years of age in large-breed dogs and from 7 years of age in small-breed dogs. A more recent study showed that several larger breeds of dog (Rottweiler, Akita, Mastiff, Labrador Retriever, and Saint Bernard) were predisposed to injury of the CCL at a younger age (<2 years; Duval et al 1999). This younger group of dogs was considered to have a “straight” appearance to the conformation of the stifle joint that resulted in early CCL injury.

As it is probable that the pathogenesis of CCL injury differs between dogs, it would seem logical that the appropriate surgical management of CCL injury should take into account these differences.

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**Diagnosis**

Lameness due to CCL injury can vary depending on the time since injury and degree of damage to the ligament and menisci. Immediately following complete rupture of the CCL there is acute inflammation and haemarthrosis that is typically presented as non-weight-bearing lameness. After a further 2–3 weeks the inflammation decreases and affected dogs improve but may show intermittent periods of lameness due to ongoing inflammation and instability of the joint. Over time, there is a gradual increase in the severity of lameness as meniscal damage and degenerative changes occur within the joint (Moore and Read 1996b; Johnson and Hulse 2002; Vasseur 2003).

Classically, diagnosis of CCL injury is made by palpation of the affected limb. Orthopaedic examination generally begins with the dog in a standing position, to allow comparison with the contralateral limb. Palpation of both pelvic limbs can reveal muscle atrophy of the gluteal and quadriceps muscle, a partial CCL rupture, and a tense patient may make evaluation of instability of the joint. Over time, there is a gradual increase in the severity of lameness as meniscal damage and degenerative changes occur within the joint (Moore and Read 1996b; Johnson and Hulse 2002; Vasseur 2003).

Palpation of craniocaudal stifle laxity has become pathognomonic for CCL injury; however, chronic periarticular fibrosis, a partial CCL rupture, and a tense patient may make evaluation of instability of the stifle difficult. If stifle lameness is suspected, then heavy sedation or general anaesthesia may be necessary to confirm stifle laxity. The cranial drawer sign is elicited by using the fingers of the upper hand to firmly grasp the prominent bony landmarks of the lateral fabella, patella and distal femur. The fingers of the lower hand are used to grasp the fibular head, tibial crest, and tibia. With the upper hand stabilised, a positive cranial drawer sign is elicited if the lower hand can displace the tibia cranially. This test should be performed through the full range of motion of the joint as dogs with partial CCL rupture may only have cranial drawer with the limb in flexion due to disruption of only the cranialmedial band of the CCL (Scavelli et al 1990; Strom 1990).

A small amount of cranial drawer movement is frequently noted in normal immature dogs; this can be misdiagnosed as CCL rupture. The test should also be performed in the contralateral limb for comparison. Dogs very rarely injure the CCL prior to completion of skeletal growth, therefore further diagnostic tests such as radiographs should also be performed to rule out bony injury such as avulsion of the tibial crest or fracture of the distal femoral physis.

The tibial compression test has also been described to diagnose CCL injury. This test mimics the actions of the musculature of the stifle, providing a subjective measure of cranial tibial thrust. The dog is placed in lateral recumbency and one hand is used to flex the hock whilst the other holds the distal aspect of the cranial femur, and the index finger is extended along the patellar ligament to the tibial crest. By flexing the hock, a positive test is elicited by cranial displacement of the tibial crest and the index finger (Moore and Read 1996b). Veterinarians with smaller hands may find the tibial compression test easier to perform, especially in larger dogs (Figure 2).

![Figure 2. Demonstration of hand positioning for the tibial compression test, to diagnose cranial cruciate ligament injury in the dog.](image-url)
fracture, or erosive arthritides. Radiographs of the contralateral stifles can be useful for comparison or may demonstrate degenerative changes consistent with bilateral disease. Contrast arthrography does not provide sufficiently superior demonstration of joint pathology to warrant routine use (Hay et al 1996).

Ultrasonography can be used to demonstrate pathological changes in soft tissue but is relatively inaccurate for confirming rupture of the CCL (Gnudi and Bertoni 2001). Magnetic resonance imaging (MRI) has become the preferred imaging modality for evaluation of soft tissue structures of synovial joints in humans. This technology has been described in dogs, and changes in the articular cartilage and subchondral cyst-like lesions were seen as early as 2 weeks following CCL transection (Widmer et al 1991; Baird et al 1998). However, due to the high cost of this procedure, it seems unlikely that MRI will be used commonly to diagnose CCL injury in dogs in the near future.

Most stifles (80%) in which CCL rupture has occurred have normal synovial fluid cytology. However, joints in which only partial CCL rupture has occurred have been shown to have significantly higher nucleated cell counts (Griffin and Vasseur 1992). This finding helps to confirm the theory that CCL injury is a progressive process, following an early inflammatory phase of ligament degeneration and cartilage degradation.

Arthroscopy provides a minimally invasive tool for confirming a diagnosis of CCL injury. Although accurate, arthroscopy requires specialised equipment and training to correctly identify intra-articular pathology. Meniscal injuries can be treated using arthroscopic techniques. Arthroscopic CCL replacement techniques have been described in dogs, and the results have been satisfactory, but lack of operator experience and preference for surgical techniques that alter the tibial slope have delayed its more mainstream use (Johnson and Hulse 2002).

**Treatment**

**Medical treatment**

Medical treatment of CCL rupture was successful in resolving clinical signs in approximately 80% of dogs weighing <15 kg (Vasseur 2003). Medical management typically consists of restriction of activity, weight reduction, and analgesic medication. Radiographic signs of degenerative joint disease do progress in this group of dogs despite apparent clinical improvement. The authors generally recommend surgery even for small dogs in order to stabilise the stifle joint and assess the degree of meniscal injury, and concurrent patella luxation.

**Surgical treatment**

Surgical treatment of CCL rupture is strongly recommended in dogs >15 kg, as less than 20% of this group respond favourably to medical management (Vasseur 2003). Regardless of the surgical technique employed, approximately 85% of dogs show clinical improvement, but many of these dogs will demonstrate intermittent stifle pain or lameness (Harari 1995; Moore and Read 1996b; Johnson and Hulse 2002; Vasseur 2003).

Surgical treatment is broadly separated into three groups: intracapsular, extracapsular, and tibial osteotomy techniques.

**Intracapsular techniques**

Intra-articular replacement or reconstruction of a ruptured CCL using various biological or synthetic materials has been described. It is beyond the scope of this article to describe each of these techniques; suffice it to say that the broad principle of each is to mimic the biomechanical function of the CCL. Placement of an autogenous fascia lata/patella ligament graft attached at the tibial crest through the joint and over the top of the lateral condyle is the most common intracapsular technique employed (Korvick et al 1994). The graft may be passed initially under the intermeniscal ligament or through a tibial bone tunnel, exiting at the insertion point of the CCL (Bennett and May 1991a). Most surgeons recommend enlargement of the intercondylar notch (notchplasty) to minimise impingement of the graft on the medial wall of the lateral femoral condyle (Fitch et al 1995ab; Johnson and Hulse 2002; Vasseur 2003).

In *vitro* biomechanical comparative analysis of intact CCL and autografts showed that the latter could only support 25% of the average maximum load of the CCL (Johnson et al 1989). The graft undergoes necrosis, revascularisation, and structural remodelling during the healing phase but achieves only 26% of the strength of the intact CCL by 26 weeks post-operatively (Dupuis and Harari 1993). Intracapsular techniques have also been shown to provide less immediate post-operative stiffness than extracapsular techniques (Patterson et al 1991). Some surgeons recommend augmentation of the graft with an extracapsular suture to support the graft while remodelling occurs (Harari 1996; Moore and Read 1996b).

Successful results have been reported for various synthetic grafts described for intracapsular stabilisation of CCL-deficient stifle joints. However, no single graft material was shown to maintain stiffness and strength while concurrently minimising synovitis due to foreign body reaction (Stead et al 1991; Laitinen 1994; Vasseur et al 1996). All intracapsular techniques resulted in continued progression of osteoarthritis of the stifle and up to 17 months after surgery, limbs which were operated on were re-evaluated at 6 and 12 weeks following surgery (Coetzee and Lubbe 1995).

**Extracapsular techniques**

Extracapsular stabilisation of the CCL-deficient stifle joint is probably the most common method used in New Zealand for treating CCL injury. Extracapsular techniques are generally easier and quicker to perform and require little specialised equipment. The modified retinacular imbrication technique (MRIT) appears to be the most widely used (Piermattei and Flo 1997). This technique consists of placing a suture of heavy, non-absorbable, monofilament nylon around the lateral fabellum, through a tunnel drilled in the tibial crest and secured back on to itself using either a knot or metal crimp (Figure 3). Variations of this technique include the additional placement of a similar medial suture and advancement of the biceps femoris and sartorius muscles. Autogenous fascial strips and orthopaedic wire have also been advocated to reduce complications or provide superior stability (Aiken et al 1992; Harari 1995; Moore and Read 1996b; Stork et al 2001). Typically, 85–90% of dogs show clinical improvement following surgery using extracapsular techniques; however joint instability is common 6–12 weeks after surgery and osteoarthritis of the stifle joint often progresses (Moore and Read 1996b). Chronic, low-grade bacterial contamination of the joint has not been associated
with a poor clinical outcome following extracapsular stabilisation (Hill et al 1999).

There are several general concerns regarding extracapsular suture techniques. It is logical that the stronger the suture material used the more stability would be provided to the joint. However, a recent study has shown that the larger the diameter of the suture material used the less force was required for failure, due to difficulty in tying tightly configured knots and the additional stresses at the level of the knot (Caporn and Roe 1996). In an effort to overcome this problem, a metal tube crimp-clamp system was developed which, while stronger than a surgical knot, still maintains a weak point at the level of the crimp (Anderson et al 1998).

The placement of a lateral suture to stabilise the stifle does provide immediate post-operative stability but may be detrimental to normal joint kinematics, as the stifle is fixed in external rotation. Normal internal rotation of the tibia during stifle flexion is eliminated; this increases compression of joint surfaces and may cause further damage to articular cartilage and menisci.

The lateral fabellum is required to provide the proximal anchor point for the suture. This sesamoid bone is maintained in anatomical position by the pull of the gastrocnemius muscles and the strong femorofabellar ligament. The stability of the fabellum relative to laterally applied force has not been evaluated in clinical trials; in fact, the authors frequently see laterally displaced lateral fabellae on follow-up radiographs of dogs treated using the MRIT, indicating movement of the bone and probable loosening of the suture. Furthermore, the position of the hole in the tibial crest should be as proximal and cranial as possible to provide adequate stabilisation of the stifle joint. Positioning the hole too caudally or too distally will result in inferior stifle stability and may limit extension of the stifle (Figure 4). Pressure necrosis of bone by the suture at the tibial hole is suspected to cause loosening of the suture.

As the suture is placed outside the joint capsule, it is tempting to forego arthrotomy, to simplify the procedure. Unfortunately, many dogs are lame due to medial meniscal injury as well as joint instability, therefore stifle arthrotomy and evaluation of the menisci are a critical component of CCL surgery. The success rate of surgery without arthrotomy has not been reported but is expected to be lower than after removal of ligament remnants and evaluation of menisci.

Many surgeons agree that extracapsular techniques have a poorer success rate in large- and giant-breed dogs. The fibular head transposition technique was developed to alleviate these concerns. This technique involves advancing the fibular head and associated lateral collateral ligament to prevent cranial drawer motion. The technique was very popular in the late 1980s and early 1990s but has become less commonly used following research demonstrating a high percentage of complications, including instability of the stifle, injury of menisci, fracture of the fibula, and continued osteoarthritis (Dupuis et al 1994; Chauvet et al 1996).

Tibial osteotomy techniques
The main areas of controversy and debate amongst veterinary surgeons about the treatment of CCL rupture have been the continued development of osteoarthritis following surgery and the lack of joint stability by 6–12 weeks post-operatively that accompanies all intracapsular and extracapsular techniques. It is generally accepted that the long-term joint stability achieved is due to periarticular fibrosis.

With these limitations in mind, and considering the discussion on the role of the tibial slope and pelvic-limb conformational abnormalities in the development of partial and complete CCL rupture, several techniques have been described in which the proximal aspect of the tibia is surgically altered. These techniques do not serve to provide stifle stability but rather alter the geometrical relationship of the tibia to the femur, aiming to improve joint congruence and reduce compressive forces on the tibial cartilage. Techniques include tibial tuberosity advancement, tibial tuberosity stapling, and tibial tuberosity osteotomy, each with its own advantages and disadvantages. The selection of the appropriate technique depends on various factors, including the dog’s breed, body weight, age, and the degree of bone stock.

Figure 3. The extracapsular modified retinacular imbrication technique for cranial cruciate ligament repair in the dog.

Figure 4. Radiograph showing a tibial hole for extracapsular cruciate surgery in a dog, that has been placed too distally on the tibial crest (arrow).
etry of the joint to eliminate cranial tibial thrust, such that joint stability is achieved during weight-bearing.

The tibial slope is measured on a lateral radiograph of the entire tibia with both the stifle and tibiotarsal joints included. The X-ray beam should be centred on the stifle joint although this is frequently not possible in large-breed dogs as the length of the tibia makes this impossible for most radiographic cassette sizes. The functional tibial axis is drawn through a point on the tibial intercondylar eminences to the centre of the talus. The tibial plateau is determined by identifying the small step evident at the point of attachment of the CCL and by location of the insertion of the caudal cruciate ligament. The tibial slope angle is measured as the angle between the tibial plateau line and a line perpendicular to the functional tibial axis line (Caylor et al 2001; Warzee et al 2001; Reif et al 2002; Figure 5).

Figure 5. Method of measuring the tibial plateau slope in the stifle joint of the dog.

In 1993, Slocum and Slocum described the cranial tibial wedge ostectomy. This procedure involves a stifle arthrotony, removal of CCL remnants and meniscal evaluation. A closing-wedge ostectomy is performed immediately distal to the tibial crest and stabilised using a medially-applied 2.7 mm or 3.5 mm dynamic compression plate and screws. The wedge angle is calculated to be 5–6° less than the tibial plateau angle. This technique has been reported to have a good to excellent success rate in 86% of dogs and has a faster return to weight-bearing than other surgical techniques (Watt et al 2000). There was, however, a serious complication rate of 5%, including tibial fracture and implant failure. Commonly, there is an alteration in the femoropatellar relationship on post-operative radiographs due to hyperextension of the stifle. The clinical relevance of this is uncertain. Extreme care must be taken when performing the ostectomy to ensure the cuts are parallel because valgus or varus tibial deformity can result from reduction when they are not.

Slocum and Slocum (1993) further modified the technique and produced the tibial plateau levelling ostectomy (TPLO). This technique has been patented and requires attendance at a certified training course and purchase of essential instrumentation and stabilisation plates. The procedure involves a medial arthrotony and evaluation of intra-articular structures including medial meniscal release, if indicated. A tibial jig and bi-radial bone saw are used to create a curved proximal tibial ostectomy. The proximal tibial fragment is rotated a calculated distance to provide a tibial slope that approaches 6.5°, and the ostectomy is stabilised using a specially designed bone plate (Dejardin 2003). Closure is routine. Dogs require 8 weeks of rest for bone healing to occur then a rehabilitation programme is commenced. A recent study reported no significant difference between the TPLO and MRIT procedures for post-operative limb function 6 months after surgery, based on force plate analysis; however dogs in both groups had medial meniscal surgery that may have additionally affected post-operative limb function (Conzemius et al 2002). The TPLO procedure has been performed in dogs with partial CCL rupture (viewed arthroscopically) without removal of the ligament or meniscal release. Nearly 80% of dogs had an intact CCL on repeat arthroscopy, indicating that this procedure may be of benefit in cases of partial CCL injury that are diagnosed early (Whitney and Chandler 2002). Research and clinical studies on the TPLO are ongoing and more information will become available over the next few years. Anecdotal, the technique appears to be a common procedure performed by referral veterinary surgeons on large-breed dogs in the United States and surgeon satisfaction and clinical results appear very high. The technique appears to provide better early limb function, a more rapid return to weight-bearing, and less progression of osteoarthritis of the stifle compared with more traditional methods. Complications of this technique include inadequate tibial plateau correction, implant failure, and fracture of the tibial tuberosity (Dejardin 2003).

Montavon (1999) has described a modification of the TPLO technique that levels the tibial slope by performing a proximal intra-articular tibial wedge ostectomy (Figure 6). The ostectomy is stabilised using two bone screws placed in a craniocaudal position. The original description of this technique includes an aponeurotic fascial sling cranial to the proximal tibia to provide some additional stifle stability. The authors have modified the Montavon technique by altering the apical point of the wedge to allow for more accurate levelling of the tibial slope and eliminating the aponeurotic sling. A medial meniscal release is included and ostectomy stability is provided by supporting a single craniocaudal screw with a bone plate and screws applied to the medial aspect of the proximal tibia (Figure 7). A prospective clinical study of this technique is currently underway and preliminary results indicate excellent early limb function, rapid return of thigh musculature circumference, no loss of stifle range of motion, and minimal post-operative complications, but some progression of osteoarthritis of the stifle. Long-term (1 year) results will be recorded and reported at the completion of the study.

More recently, Tepic et al (2002) challenged Slocum and Slocum’s (1993) concept of biomechanics of the stifle by stating that the total force of the stifle is nearly parallel to the patellar ligament. They have also stated that any surgical correction should make the tibial plateau perpendicular to the patellar ligament and not the Achilles tendon mechanism as in the TPLO technique. Montavon et al (2002), using this theory, described an alternative
technique that advances the tibial tuberosity in order to position the patellar ligament perpendicular to the tibial plateau. This novel procedure requires special surgical implants and is still being developed, but initial results are encouraging.

Meniscal surgery
Injury to the medial meniscus, the mechanism of which was discussed above, is common in dogs with CCL rupture. The incidence appears to be greater (>80%) in cases with more chronic injury (Vasseur 2003). Conservative treatment is not recommended, as most meniscal tears occur in the avascular portion of the cartilage. Therefore, healing is unlikely to occur and an untreated meniscal flap will result in continued stifle pain and lameness following surgery (Williams et al 1994). Visualisation of both menisci is a critical aspect of CCL surgery, irrespective of the technique being performed. The menisci are easily visualised using a Hohmann retractor or stifle distractor (Veterinary Instrumentation, Sheffield, UK). Partial meniscectomy (removal of torn pieces of meniscus only) provides better support of the articular cartilage and is preferable to total meniscectomy (Williams et al 1994). Removal of the entire medial meniscus results in inflammation of the stifle and increased degenerative changes within the joint. Primary repair of peripheral meniscal injuries in dogs was recently reported, and no further meniscal surgery was deemed necessary (Moses 2002).

Release of the intact medial meniscus has been recommended as a component of the TPLO technique for CCL rupture (Slocum and Slocum 1998). The technique allows the caudal horn of the medial meniscus to move caudally, minimising entrapment by the femoral condyle during the normal range of stifle motion. Meniscal release is performed by transecting the caudal ligament of the medial meniscus at its attachment to the caudal aspect of the tibial plateau. The results of this technique have not been reported, however, it appears that post-operative meniscal injuries are rare in dogs that have had medial meniscal release. There is a reported 13.8% risk of meniscal injury after either intra- or extra-capsular stabilisation of stifles that have intact menisci, particularly in dogs >15 kg, and it may be that medial meniscal release will reduce or prevent this feature after CCL surgery (Metelman et al 1995). There are currently no data available evaluating the effect of medial meniscal release on stability of the stifle or on degenerative changes; however, removal of the caudal pole of the meniscus in sheep was shown to cause the same degree of degeneration of the stifle as total meniscectomy (Simpson et al 1999).

Post-operative rehabilitation
Post-operative management is generally confined to one or two paragraphs in textbooks and articles published on CCL surgery, but may actually be more important in the overall outcome following surgery than the choice of surgical technique. Many veterinarians appear reluctant to promote early use of the limb and recommend a support bandage be placed around the operated limb for up to 1 month following surgery (Dupuis and Harari
1993; Harari 1995; Johnson and Hulse 2002). Far greater emphasis is now placed on early post-operative rehabilitation after joint surgery because it has been shown that excessive immobility of the joint causes adverse biochemical and metabolic changes in articular cartilage (Keller et al 1994). Athletic working dogs (e.g. sheepdogs, police dogs, detection dogs) are an elite group of animals that can benefit greatly from post-operative physiotherapy, to encourage more rapid and complete return to normal function. Recent research has shown that significant benefits in limb function occur when formalised post-operative physiotherapy is performed on dogs following extracapsular CCL surgery (Johnson et al 1997; Marsolais et al 2002). This can begin the day following surgery, with cold therapy (ice packs), gentle passive range-of-motion exercises and massage. Each animal requires an individualised protocol that should include walking on a leash and swimming. A significant benefit of the tibial plateau levelling procedures is the ability to begin more intensive physiotherapy 6–8 weeks after surgery in dogs with radiographic signs of osteotomy healing. Intra- and extra-capsular procedures that rely on post-operative stifle stability generally need more time before more strenuous physical activity can be commenced. There are now established commercial dog rehabilitation centres in New Zealand, and several human physiotherapists have developed an interest in canine rehabilitation.

Conclusion

The most significant recent advance in our knowledge of CCL injury is an understanding that the aetiology of CCL injury is complex. Whilst traumatic CCL ruptures do occur, there is now general agreement amongst veterinary surgeons that the majority of affected dogs have underlying conformational, anatomical, pathological, and/or breed-related abnormalities that contribute to the injury. This understanding has led to the development of innovative techniques to surgically alter the functional anatomy of the stifle joint with the intention of providing better post-operative outcomes. Whether these new techniques provide a step forward in the treatment of CCL injury remains to be seen, but both laboratory and clinical research are underway worldwide to determine if the treatment of this debilitating and controversial problem in dogs has made any significant progress.

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