Surgical treatment of canine cranial cruciate ligament deficiency

A literature review

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Cranial cruciate ligament (CrCL) deficiency is the leading cause of degenerative joint disease (DJD) in the canine stifles. The anatomy of the cranial stifle is complex and the pathogenesis of CrCL rupture is not fully understood. Several competing theories on the pathogenesis and several techniques based on these theories have been presented mostly during the last 40 years. The main categories of techniques are intra-articular, extracapsular, and osteotomy, of which techniques of the two latter categories are still widely in use. The uncertainty about the pathogenesis and thus the correct technique of repair may be a reason for the multitude of proposed surgical techniques and the lack of preventive measures.

This literature review attempts to cover the main surgical techniques from the three categories of techniques which are currently or have lately been in use and to determine if a preferred method exists. Approximately half of the literature is from 2000–2012 and half from 1926–2000. The literature encompasses both the original publications of each technique as well as studies on the outcomes and complications of follow-up studies using larger populations of patients.

The reporting on the research regarding new surgical techniques is varied and the urge to perform surgery and not research is evident in the amount of surgical procedures reported before any peer-reviewed studies have been published. There are no meta-analyses of studies covering different techniques nor are there robust prospective double blinded placebo controlled studies on any of the alternative techniques. Most of the literature is case reports with some retrospective cohort or statistically insignificant prospective studies. Due to the non-uniform reporting, comparisons between techniques are more difficult. The literature does seem to favor TPLO, one of the oldest and the most researched technique, if the surgeon is able to invest the time and resources to acquiring the equipment and mastering the technique. If combined with the cTTA technique, a newer technique which uses some of the same equipment as the TPLO with very promising preliminary results, a surgeon could be well equipped to handle surgical treatment of CrCL deficiency.
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1 Introduction

Cranial cruciate ligament deficiency is the leading cause of degenerative joint disease (DJD) in the canine stifle (Elkins et al. 1991). Since the source of the deficiency, the complete or partial rupture of the cranial cruciate ligament (CrCL), was first described in veterinary literature (Carlin 1926), a plethora of surgical techniques have been described for use in resolving the issue. One reason for the multitude of options may be the old anecdote “to be considered an orthopedic surgeon [one] must develop a new surgical technique or modify an old technique for treatment of cranial cruciate rupture” (Olmstead 1993). A more likely one is that none of the techniques presently available and introduced in the following pages have been shown to be unequivocally superior to all others.

Another good reason for the interest in CrCL techniques stems from the fact that the market for canine CrCL treatments has been estimated at $1,32 billion in 2003, in the US (Wilke et al. 2005). At the time this would have represented a little over 15 % of the total expenditure on all veterinary care of in the US, if the relative share of CrCL treatments has stayed stable (APPA 2011 and APPA 2003). If the relative share has indeed stayed stable, this would mean that the current value of the market for CrCL treatments would be over $2 billion annually in the US alone.

The first techniques designed for CrCL deficiency, the intra-articular techniques, aimed at replacing the failed CrCL with one of a different origin. These techniques were started by Paatsama in 1952. The next wave of techniques, the extra-articular or extracapsular ones, aimed at stabilizing the joint without replacing the CrCL. These techniques followed approximately 20 years later with DeAngelis & Lau in 1970 proposing the first method. The third and most recent wave of techniques are the osteotomies, aimed at changing the biomechanics of the stifle joint thus rendering the CrCL unnecessary. These were started by Slocum & Devine in 1983 and much of the research seems to have been concentrating on them for the past 20 years. Currently there are advances in the works in all three categories with new synthetic intra-articular ligaments, new extracapsular attachment materials and new osteotomy techniques being developed by several authors and companies.
The aim of this literature review is to wade through the substantial body of literature covering CrCL deficiency, introduce the most important different surgical techniques recently or currently in use and comment on the outcomes and complications of some of these techniques where the literature required for these comments is available. The literature review will concentrate on literature from the 21st century with half of the literature picked from 2000–2012 and attempt to pick only the most relevant either original or important literature from the years 1926–1999. The ultimate objective of the literature review is to determine whether there is a technique which seems to be the most promising based on the literature.
2 Anatomy of the stifle joint

The canine stifle is a complex, condylar, synovial joint composed of three interrelated articulations: the condyloid femorotibial, the femoropatellar, and the proximal tibiofibular articulations (Robins 1990).

The primary motion of the joint is flexion and extension of the hind limb. Due to the sliding of the femoral condyles on the tibial plateau, there is also cranial and caudal displacement, compression and distraction, internal and external rotation, varus and valgus angulation, and lateral and medial translation (Arnoczky et al. 1977). All motions of the stifle involve the complex integration of the distal femur, proximal tibia, and proximal fibula, as well as the muscles of the pelvic limb, joint capsule, joint ligaments, and menisci (Robins 1990).

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**Figure 1.** Dorsal view of the canine stifle. Structures identified: 1 *Trochlea ossis femoris*, 2 lateral ridge of *trochlea ossis femoris*, 3 tendon of *M. extensor digitorum longus*, 4 *Lig. popliteum obliquum*, 5 *Lig. collaterale laterale*, 6 *Meniscus lateralis*, 7 *Tuberositas tibiae*, 8 *Lig. patellae*, 9 *Patella*, 10 *Fibrocartilagines parapatellares*, 11 *Lig. transversum genus*, 12 *Meniscus medialis*, 13 *Lig. collaterale mediale*, 14 *Lig. cruciatum craniale*, 15 *Lig. cruciatum caudale*, 16 medial ridge of the *Trochlea ossis femoris*. From Carpenter, D. H., & Cooper, R. C. (2000). Mini review of canine stifle joint anatomy. Anatomia, histologia, embryologia, 29(6), 321.

The CrCL lies intra-articularly, but extrasynovially (Slocum 1983). The CrCL is functionally composed of two parts: a smaller craniomedial band (CrMB) and a larger caudolateral band (CLB). The CrMB is under tension in both flexion and extension, whereas the CLB is under tension in extension only. (Arnoczky et al. 1977)

The function of the CrCL is to limit the cranial translation of the tibia in relation to the femur as well as the internal rotation of the tibia (Arnoczky et al. 1977). The CrCL is the main stabilizing structure of the stifle joint and thus its rupture results in mild to severe lameness depending on the extent of the damage (Slocum & Devine Slocum 1993).
3 Pathogenesis of CrCL rupture

Cruciate disease is multifactorial (de Rooster et al. 2006). Rupture of a normal CrCL naturally occurs if it is subjected to a force greater than its breaking strength. The breaking strength of the CrCL is approximately equal to four times the body weight of the dog (Gupta et al. 1969). The site of rupture of the CrCL is predominantly its midsubstance at the point where the ligament rotates 90°. Acute rupture of a healthy CrCL probably only accounts for a small percentage of cases. (Paatsama 1952) Traumatic rupture, which accounts for about 20 % of cases, is attributed to sudden hyperextension and excessive internal rotation of a partially flexed stifle (Moore & Read 1996). Traumatic rupture is more common with juvenile patients (Hayashi et al. 2004). However, the most common etiology for CrCL deficiency is associated with chronic progressive lameness consistent with a non-traumatic degenerative process. This progressive degeneration of the CrCL has been linked to a variety of factors: genetic, conformational, environmental, immune-mediated, and inflammatory. (Griffon 2010)

Previously the primary pathogenesis of CrCL rupture was thought to originate with changes in the composition of the ligament caused by aging and lack of use (Vasseur et al. 1985). The rationale behind a genetic component is based on findings of a predisposition to CrCL deficiency with some breeds, e.g. Labrador retrievers, Rottweilers and Newfoundlands, (Duval et al. 1999, Whitehair et al. 1993). Poor conformation may lead to misalignment of the stifle, which may exacerbate the degenerative processes predisposing to CrCL rupture (Johnson & Johnson 1993). Also stifles with medial patellar luxation are predisposed to CrCL rupture because cranial tibial thrust (CTT) is no longer restrained by the patellar tendon (Kaiser et al. 2001).

The mechanism of CrCL rupture is currently unknown. There are several theories for the mechanism and the currently dominant one of these is probably the active model theory (Slocum & Devine Slovum 1993).

The traditional passive model claims that correction of CrCL rupture can be accomplished with replacement of the deficient structure (Arnoczky et al. 1977). The active model argues that the traditional model fails to explain partial or complete rupture of the CrCL in the absence of trauma, and offers no
explanation for the mechanism of rupture of caudal horn of the medial meniscus (Slocum & Devine Slocum 1993). A later tibiofemoral shear force model (Montavon et al. 2002) argues that total joint force is parallel to the patellar ligament, not the functional axis of the tibia as claimed by the active model (Montavon et al. 2006).

Slocum & Devine Slocum (1993) argue that a better alternative than replacing the deficient CrCL is to alter the direction of the forces acting on the stifle joint under dynamic loading by changing the tibial plateau angle (TPA). Montavon et al. (2006) argue that turning the patellar ligament would be more beneficial than turning the tibial plateau.

Figure 2. Schematic representation of forces acting on the stifle joint. From Griffon, D. J. (2010). A review of the pathogenesis of canine cranial cruciate ligament disease as a basis for future preventive strategies. Veterinary surgery, 39(4), 400.

Regardless of the mechanism, rupture of the CrCL causes instability which in turn causes inflammation of the stifle joint. The inflammation and resulting release of inflammatory mediators such as interleukins and collagenases cause degradation of the cartilaginous matrix, which commonly progresses to DJD (Johnson & Johnson 1993). Unilateral rupture of the CrCL also leads to rupture of the contralateral CrCL in as many as 50 % of cases (Buote et al. 2009). This is partly due to the same pathology affecting the contralateral limb and partly by the added stress of weight bearing caused by not being able to use the ruptured limb.
4 Surgical techniques

Surgical techniques for the repair of CrCL deficiency can be classified into three categories: intra-articular, extracapsular and osteotomy techniques. Intra-articular techniques are no longer commonly used. However, surgery with both extracapsular and osteotomy techniques always includes intra-articular inspection of the stifle to either remove remnants of a partially or completely ruptured CrCL or to perform operations on the menisci when indicated.

Several techniques require the use of customized equipment. These include most of the osteotomy and some extracapsular techniques which require items such as custom osteotomy saws, jigs, custom compression plates or special high durability suture material. These serve as both a source of revenue for surgeons and their affiliated companies as well as barriers to entry or use of the techniques to surgeons with less well equipped clinics.

The surgical techniques can also be divided into two broad categories based on the attempted result: techniques which aim at replacing the deficient CrCL and techniques which aim at removing the need for a CrCL by changing the biomechanics of the joint. Intra-articular and extracapsular techniques are examples of the former and osteotomy techniques of the latter. The following chapters will introduce all three categories of techniques and their main alternatives.

Another perspective is that intra-articular techniques aim at removing the cranial drawer sign and retaining complete range of motion. Extracapsular techniques sacrifice range of motion for complete elimination of the drawer sign. (Slocum & Devine Slocum 1993) As osteotomy techniques primarily change the biomechanics of the stifle, many of them do not remove the cranial drawer motion (e.g. Slocum & Devine Slocum 1993, Montavon et al. 2002, Bruce et al. 2007). Instead these techniques rely on an alternative test of the cranial translation of the tibia called the tibial compression test (Henderson & Milton 1978) for assessing the success of the operation.
4.1 Intra-articular techniques

Intra-articular techniques aim at replacing the failed CrCL with an autogeneous or allogeneic ligament. These techniques were the first ones to be created for addressing the issue of CrCL deficiency in the dog. The different techniques mainly differ in the origin of the replacing ligament and its attachment within the stifle joint.

4.1.1 Paatsama operation

Paatsama called his method the plastic operation on the cruciate ligaments using fascia transplant. The operation is performed from a parapatellar approach. The fascial transplant is created from an approximately 1 cm wide strip of *fascia lata*, starting from the border of the tibia working along the border of *m. biceps femoris*. The length of the strip is the length of the surgical incision, which is double the distance from the *crista tibiae* to the patella. The strip is only dissected from the proximal end, leaving the distal end attached. (Paatsama 1952)

A tunnel is then drilled in the femur from the femoral insertion of the lateral collateral ligament through the condyle to the femoral insertion of the CrCL. Another tunnel is then drilled to the tibia from the medial border of the *crista tibiae* obliquely proximal to the tibial insertion of the CrCL. (Paatsama 1952)


The fascial strip is then threaded into the lateral femoral hole, out the femoral insertion of the CrCL, into the tibial insertion of the CrCL and out the medial tibial hole. The leg is then flexed and the transplant pulled taut to eliminate the subluxation of the tibia, after which the end of the transplant can be sutured on to the insertion of the ligamentum rectum patellae on the tibial tuberosity. (Paatsama 1952)

4.1.2 Intra-articular repair or over-the-top

Like other intra-articular techniques, the over-the-top method aims at replacing the CrCL with an autogeneous graft. The graft is created from the patellar tendon and attached to the femur (Arnoczky et al. 1979).

The surgery is performed from a craniomedial approach. The patella tendon is revealed with a curvilinear incision from the craniomedial midshaft of the femur to the distal patella and over to the proximal tibia. Once the patella tendon is revealed, a linear incision is made through the fascia lata and the fascia covered craniomedial segment of patella is osteotomized free from the patella without splitting the bone entering the joint. The strip of fascia incorporating the wedge of patella is dissected free down to its attachment to crista tibiae. (Arnoczky et al. 1979)

The patella is then displaced laterally and a small incision is made between the lateral fabella and the femur. The free end of the graft is grasped with a pair of curved mosquito forceps passed through this incision, between the femoral condyles and the graft is pulled through the joint and out laterally through the femorofabellar ligament. Tension is applied to the graft until cranial drawer motion is eliminated and the free end of the graft attached to the lateral femoral condyle with stainless steel sutures. (Arnoczky et al. 1979)

4.1.3 Modified intra-articular repair

Hulse et al. (1980) introduced a modified over-the-top method in which they substituted the medial patellar tendon replacement ligament with a graft made of a combination of fascia lata, lateral retinacular tissue and the lateral one-third of the patellar tendon. The rationale was to increase the tensile strength of the CrCL substitute. The modification also displaces the origin of the graft to the proximal tibial tuberosity and crista tibiae. (Hulse et al. 1980)


4.1.4 Under-and-over

The under-and-over technique is performed from a lateral parapatellar approach. A graft similar to that in the modified over-the-top method is prepared from a 1 to 2 cm wide section from the cranial edge of m. biceps femoris to the femorotibial joint including the lateral third of the patella. The joint capsule is
then incised parallel to the patella ligament and the patella luxated medially to reveal the joint structures. (Shires et al. 1984)


A pair of curved gall bladder forceps is then used to grasp the graft and pull it underneath the intermeniscal *ligamentum transversum genus* into the joint. A small incision is made in the femorofabellar ligament close to the femur. The forceps are passed craniocaudally under the ligament and the graft pulled through the joint and beneath the ligament. (Shires et al. 1984)

A hole is then drilled into the lateral femoral metaphysis and a spiked washer secured with a screw. The graft is then wrapped around the shaft of the screw tightening enough to prevent cranial drawer motion before securing the screw to the femoral condyle. The free end of the graft is then sutured to the fixed portion. (Shires et al. 1984)

4.1.5 Modified under-and-over

One modification of the under-and-over technique is to not use a screw and washer fastener (Patterson et al. 1991). Instead the graft is secured to the lateral femoral condyle and the femorofabellar ligament with monofilament sutures (Shires 1993).
4.2 Extracapsular techniques

Extracapsular techniques avoid introducing foreign material into the stifle joint and instead achieve the stabilization of the stifle by creating a CrCL replacing structure on the outside of the joint. These techniques were introduced in the early 1970’s with the first widely used technique being the lateral retinacular imbrication by DeAngelis & Lau (1970) and its later modifications. The latest technique in this category, Tightrope CCL (Cook et al. 2007) was originally developed in 2005 with the advent of high tensile strength suture materials became available.

4.2.1 Lateral retinacular imbrication or lateral fabellar suture (LFS)

In 1970 DeAngelis & Lau presented what they called a simplified lateral retinacular imbrication technique for the correction of CrCL rupture.

The procedure is performed from a craniolateral parapatellar approach. First a mattress suture of monofilament synthetic material or steel wire is placed in the lateral retinacular tissue. A straight cutting needle is then used to enter the tissue caudal and proximal to the lateral sesamoid bone (fabella), and directed craniodistally to emerge in the straight patellar ligament proximal to its insertion in the tibial tuberosity. The needle is then reinserted a few millimeters from the point of emergence and directed caudoproximally to emerge near the original point of entry next to the fabella. (DeAngelis & Lau 1970)


**Figure 7.** Placement of the suture. From DeAngelis, M., & Lau, R. E. (1970). A lateral retinacular imbrication technique for the surgical correction of anterior cruciate ligament rupture in the dog. Journal of the American Veterinary Medical Association, 157(1), 81.
In the original technique this first suture removed most of the cranial drawer motion. To remove the rest, another suture was placed parallel and close to the first. To operation includes inspection of the stifle joint for which the patella is retracted medially. If medial patellar luxation is observed, either transplantation of the tibial tuberosity, trochlear arthroplasty or both are performed in addition to a medial desmotomy. (DeAngelis & Lau 1970)

4.2.2 Modified LFS

Flo (1975) modified the DeAngelis (1970) technique of lateral retinacular imbrication by using a medial and lateral mattress suture which are passed around each fabella and then to the tibial tuberosity. Another lateral suture is then attached to the fascia lateral to the patella. This acts as the imbrication suture. (Flo 1975)

4.2.3 Fibular head transposition (FHT)

Smith & Torg (1985) proposed a method of preventing cranial drawer motion and minimizing rotation of the tibia by a technique called fibular head transposition. The technique was developed as a modification of a similar technique in human orthopedics (Smith & Torg 1985). The realignment and tension of the lateral collateral ligament prevents internal rotation and cranial displacement of the tibia. The FHT is mechanically similar to the lateral retinacular imbrication technique (LFS). (Matthiesen 1993)

The surgery is performed from a craniolateral approach with a parapatellar incision made through the lateral retinaculum. The proximal head of the fibula is first revealed from under the overlying structures and then freed from the tibia by incising the syndesmosis between the tibia and the fibula. The surface on the tibia where the fibula is to be attached is then roughened with a rongeur or curette. (Smith & Torg 1985)

The original technique involves drilling two holes into the tibial crest and passing a loop of steel wire with both ends exiting on the lateral surface of the tibia (Smith & Torg 1985). An alternative method involves drilling only one hole, at the level of the proposed new position of the tibia with the steel wire passed through the hole and looped around the tibial crest (Matthiesen 1993). In both cases ends of the wire are terminated on the lateral surface of the tibia.
After the wires are in position, a Steinmann pin is placed into the caudal aspect of the head of the fibula and the limb held in position with the hock flexed, stifle externally rotated and cranial displacement of the tibia eliminated (Matthiesen 1993). The fibular head is then fixed by driving the Steinmann pin into the proximal tibia. If cranial drawer motion is not significantly reduced, the pin placement should be altered (Smith & Torg 1985).


Once the fibular head is in place the wires passed through the *crista tibiae* are tightened around the free end of the Steinmann pin to eliminate rest of the cranial drawer motion and minimize internal tibial rotation (Matthiesen 1993).

### 4.2.4 Tightrope cranial cruciate ligament or Tightrope CCL (TR)

The Tightrope CCL technique (Cook et al. 2007) is based on the LFS technique originally by DeAngelis & Lau (1970). TR is also claimed to be superior to the LFS due to bone fixation at both tibial and femoral attachments, more accurate isometric placement and overall strength (Cook et al. 2007). The invasiveness of the techniques is comparable.

For the approach either a minimally invasive approach with three small skin incisions or an approach where the lateral aspect of the stifle is exposed to the level of the joint capsule from the lateral fabella to midway down the tibial tuberosity can be used.
With either approach, to place the TR, a guidewire is drilled from the midbody of the lateral femoral condyle at approximately a 30° angle proximally to the medial edge of the diaphyseal distal femur between *m. vastus medialis* and *m. sartorius*. A tunnel is then drilled with a cannulated drill using a drill guide. With the minimally invasive technique care is taken to prevent the cannulated drill from piercing the musculature on the medial side of the femur. The attachment of *m. biceps femoris* is then revealed on the tibia. A guidewire is drilled through the lateral side at the site of the *sulcus muscularis* medially in approximately a 20° angle distally to the lateral side of the tibial tuberosity. Another tunnel is then drilled with a cannulated drill using a drill guide, this time through the musculature.

![Image](image_url)

**Figure 9.** Open technique placement of the double threaded Tightrope CCL FiberTape. From the Arthrex Vet Systems TightRope CCL Multicenter Clinical Outcomes Study brochure (2010).

With the open technique the FiberTape (Arthrex Vet Systems) is threaded with the help of a leadwire through the medial side of the tibial hole, out the lateral tibial hole in the lateral femoral hole and through the medial femoral hole. After placement the proximal femoral washer plate is turned by pulling on the FiberTape thus preventing it from escaping. Finally the FiberTape is tightened by tying it over the medial femoral washer plate. With the minimally invasive technique the direction of the FiberTape is reversed and the knots tied on the medial side of the tibia. The lateral retinaculum is closed with imbrication sutures and the skin incisions in routine fashion.
4.3 Osteotomy techniques

Osteotomy techniques, unlike the previous intra-articular and extracapsular techniques rely on changing the biomechanics of the stifte joint to effectively remove the need for the CrCL thus repairing the problem of CrCL deficiency. The paradigm shift from incremental improvements in CrCL replacement to negating the need for a CrCL by altering the loading of the stifte joint started in the early 1980’s with Slocum & Devine identifying cranial tibial thrust (CCT) as an important cause of rupture of the CrCL. Slocum & Devine Slocum further improved on their method and in 1993 published their seminal paper on the technique called tibial plateau leveling osteotomy, which has become perhaps the most widely used and studied osteotomy technique for CrCL deficiency. After the turn of the century several other osteotomy techniques have been described. Some of these attempt to refine Slocum’s original assumptions (e.g. TTO by Bruce 2007), some contest the assumptions and aim at remodeling the biomechanics of the stifte by altering a different site (e.g. TTA by Montavon et al. 2002).

4.3.1 Cranial tibial wedge osteotomy (CTWO)

In 1983 Slocum & Devine identified cranial tibial thrust (CTT) as being an important cause of CrCL rupture and cranial drawer motion in dogs. They claimed that then current methods only aimed at eliminating cranial drawer motion, and a new technique was needed to also combat the CTT. A year later they proposed their first technique aimed at eliminating the CTT, called the CTWO. (Slocum & Devine 1984)

The CTWO technique is based on removing a wedge shaped fragment of bone from the proximal tibia to change the position of the proximal head of the tibia in relation to the femur. This also results in a change in the tibial axis, moving it cranially. The technique utilizes a steel jig and an osteotomy guide to direct the osteotomy. The resulting wedge, which was between 18° and 30° wide in the 1984 study, is then closed with a compression plate. The CTWO requires the use of another technique to eliminate the cranial drawer motion. In the 1984 paper the most commonly used technique was advancement of *m. biceps femoris* laterally and *m. gracilis* and *m. semitendinosus* medially. (Slocum & Devine 1984)

Figure 10 shows the angle used in the Hildreth et al. 2006 study for a corrective CTWO wedge osteotomy. The original Slocum & Devine 1983 study used an angle of 22.5° although this was realized afterwards (Slocum & Devine 1984).

4.3.2 Tibial plateau leveling osteotomy (TPLO)

In their 1993 paper in the stifle surgery compilation of the Veterinary Clinics of North America Small Animal Practice series, Slocum & Devine Slocum methodically detail the short comings of the then current intra-articular and extracapsular techniques. They propose a new osteotomy based technique, the tibial plateau leveling osteotomy. The TPLO is an evolution from CTWO, proposed nearly a decade prior. Like the CTWO, it aims not at replacing or substituting the failed CrCL, but instead on changing the biomechanics of the stifle joint to neutralize the CTT and thus negate the need for the CrCL. This is achieved by leveling the tibial plateau hence the name for the originally patented technique.

The leveling is performed by creating a radial osteotomy, with the help of a custom jig and custom radial saw, into the caudal edge of the proximal tibia. This fragment is then rotated so that the tibial plateau is perpendicular with the functional axis of the tibia. Once the fragment is in optimal position it is secured with a custom TPLO compression plate and the surgical site closed routinely.
4.3.3 Tibial tuberosity advancement (TTA)

Advancement of the tibial tuberosity for treatment of CrCL deficiency was first published as a lecture during the 1st World Orthopaedic Veterinary Congress in Munich, 2002, by Montavon, Damur and Tepic. They propose that CrCL injury is due to a tibiofemoral shear force (Montavon et al. 2002). They also contend that the total joint force of the stifle is parallel to the patellar ligament, unlike Slocum, who maintains that it is parallel to the functional axis of the tibia (Montavon & Tepic 2006). The principal concept of the TTA technique is to advance the tibial tuberosity to such an extent that the tibial plateau is perpendicular with the patellar ligament. This would reduce the tibiofemoral shear force to zero.
The surgery involves sawing apart the cranial edge of the tibial tuberosity, placing a customized spacer (a cage) of appropriate size between the tibial body and osteotomy piece and then securing the pieces with a custom metallic plate or “tension band” (Montavon et al. 2002). To accelerate healing the open wedge osteotomy can be filled with autogenous or allogeneic cancellous bone graft before standard closure of the surgical site (Montavon & Tepic 2006).

4.3.4 Proximal tibial osteotomy (PTIO)

Damur et al. (2003) suggested an alternative technique to the TPLO called the proximal tibial osteotomy or PTIO. The technique attempted to accomplish the same end result as the TPLO technique, neutralizing CTT by changing the tibial plateau angle (TPA), but with the added benefit of not requiring custom tools.

The procedure is performed from a medial parapatellar approach. Two linear osteotomies are made to create a wedge necessary for turning the tibial plateau. The pivot point of the wedge being at the level of the caudodistal end of the medial collateral ligament. A horizontal corticotomy is then made from the distal end of the wedge to the caudal edge of the tibia to enable rotation of the caudoproximal fragment. (Damur et al. 2003)

The fragment is attached with two positional screws. The distal screw is placed perpendicular to the fragment and the proximal directed through the osteotomy
plane in a caudolateral direction to the tibial tuberosity. The arthrotomy is then closed and the medial and lateral fasciae around the stifle and the femoral condyles imbricated with horizontal mattress sutures. (Damur et al. 2003)

![3D-model of the proximal tibial osteotomy with a modified attachment of the tibial fragment using a positional screw and a compression plate.](image)

**Figure 13.** 3D-model of the proximal tibial osteotomy with a modified attachment of the tibial fragment using a positional screw and a compression plate. From Kim, S. E., Pozzi, A., Kowaleski, M. P., & Lewis, D. D. (2008). Tibial Osteotomies for Cranial Cruciate Ligament Insufficiency in Dogs. Veterinary Surgery, 37(2), 120.

### 4.3.5 Triple tibial osteotomy (TTO)

Bruce et al. proposed in 2007 a technique combining a TTA and a CTWO for the treatment of CrCL deficiency. The technique is called the triple tibial osteotomy due to the three osteotomies performed: a partial tibial crest osteotomy like in the TTA and two osteotomies to create a partial tibial wedge as in the CTWO. The final result is similar to the TTA with the tibial plateau made perpendicular to the patellar ligament. (Bruce et al. 2007)

The surgery is performed from a medial parapatellar approach. The osteotomies are made with the help of a custom saw guide and osteometer. The tibial crest osteotomy (TCO) is performed first with the wedge osteotomy, which in some early cases was a complete ostectomy, but refined in later cases to a partial ostectomy, performed second. The osteotomies are performed by first drilling a transverse 2 mm hole on the tibia from which the osteotomies are started and proceeding distally and cranially or proximally as necessary (shown in Figure 12). The wedge osteotomy is reduced with the help of forceps and the site secured with a TPLO compression plate. Autogeneous cancellous bone
graft harvested from the wedge osteotomy is used to fill the TCO gap before routine closure of the surgical site. (Bruce et al. 2007)

![Triple tibial osteotomy](image)


### 4.3.6 Circular tibial tuberosity advancement (cTTA)

Verdonck & Petazzoni (2009) proposed the cTTA technique as a combination of the TPLO and TTA techniques. The key disadvantage of TTA is the opening osteotomy, which creates a bone defect as well as requiring a predetermined sized spacer (cage) for the correction of the advancement of the tibial tuberosity (Petazzoni 2010).

The cTTA combines the radial osteotomy of the TPLO with the TTA by performing the radial osteotomy not on the caudal edge of the distal tibia like in the TPLO, but on the tibial tuberosity. After radial osteotomy, the tibial tuberosity is rotated cranially and proximally until the tuberosity advances to a TTA type position with the tibial plateau slope perpendicular to the patellar ligament. The displaced tuberosity is secured with a custom T-shaped locking plate and the surgery site closed routinely. (Petazzoni 2010).
4.3.7 Modified Maquet technique (MMT)

Etchepareborde et al. (2011) proposed the use of a modified Maquet technique previously used in human stifle surgery as a modification of the TTA procedure. The technique involves a tibial crest osteotomy similar to the TTA procedure with a TTA cage used for advancing the *crista tibiae*. Unlike TTA, no tension band implant is placed to secure the cranially displaced *crista tibiae*. Instead the distal tibial crest is either secured in place with a wire or as in Figure 16, not secured at all. Also, since the *crista tibiae* is not detached distally and thus not displaced proximally, the patellar ligament is distended and patella may slide distally in the trochlear groove possibly causing *patella baja*. (Etchepareborde et al. 2011)

Figure 15. Preoperative (left) and postoperative (right) radiographs of cTTA. From Petazzoni, M. (2010). cTTA (circular Tibial Tuberosity Advancement). ESVOT-VOS proceedings 2010, 295.
5 Outcomes

The results of the different techniques presented in the previous chapters are discussed below. Earlier, the proponents of intra-capsular techniques claimed extracapsular techniques to be inferior and biomechanically unsound (Hulse 1980). A later force plate study (Conzemius et al. 2005) found that an intra-articular (over-the-top) technique was inferior to extracapsular (lateral suture) and osteotomy (TPLO) techniques, but could not statistically differentiate the preferred method from the two latter ones.

As intra-articular techniques are no longer in widespread use, their results are presented here mostly for completeness and not tabled.

5.1 Outcomes of intra-articular techniques

The fascia transplant or Paatsama technique study reports the results of only 5 clinical cases and thus the validity of the technique can not be determined (Paatsama 1952). A later study with a few more patients reported a very good result in 87 % (13/15) of the cases with 13 % (2/15) considered poor (Singleton 1963).

The initial paper on the over-the-top technique was based on 28 cases of which 61 % (17/28) were considered excellent, 32 % (9/28) good and 7 % (2/28) fair with no poor results (Arnoczky et al. 1979). A later study including 20 cases of unilateral CrCL rupture repaired with the over-the-top technique found improvement in only 15 % of the cases (Conzemius et al. 2005).

The modified over-the-top method study was performed with 16 patients of which 25 % (4/16) were sacrificed at 4 weeks, 50 % (8/16) at 8 weeks and 25 % (4/16) at 24 weeks postoperatively. At four weeks all dogs were lame with 50 % (2/4) of the dogs exhibiting mild lameness without exercise (Grade II lameness) and 50 % (2/4) showing continuous lameness (Grade III lameness). At 8 weeks 63 % (5/8) dogs were clinically normal and of the 37 % (3/8) dogs which were lame, 67 % (2/3) showed mild lameness with exercise (Grade I lameness) and 33 % (1/3) mild lameness without exercise (Grade II lameness). At 24 weeks all dogs were classified as normal. (Hulse et al. 1980)

The under-and-over technique was performed on 38 stifles in 35 dogs over two and a half years. Of the treated patients 27 returned for “objective
evaluation” (done by the authors). Of the 27 re-examined patients 93 % were eventually evaluated as sound with the time of re-evaluation being anything between 3 to 27 months postoperatively. (Shires et al. 1984)

5.2 Outcomes of extracapsular techniques

Extracapsular techniques are still frequently used, but their results do not translate well into table form due to the great variety in the reporting of the results and the tests conducted to assess clinical improvement.

Lateral retinacular imbrication (LFS) has been in constant use for over 40 years and is still being performed frequently around the world. Along with the TPLO it is one of the most studied techniques for surgical repair of CrCL deficiency.

The original LFS technique study is based on 57 operations performed on 50 patients during a 15 month period. The results of the paper are however only based on 42 operations performed on 37 patients due to the rest of the cases having been operated too recently to be included. The authors reported the results of the procedure to be satisfactory in 86 % (36/42) cases, but considered mild lameness to be acceptable, with 19 % of cases (8/37 or 22 % of patients) suffering from “occasional episodes of slight lameness”. (DeAngelis & Lau 1970)

Another study concluded that the LFS technique was superior to two intra-articular techniques (over-the-top and under-and-over) with respect to laxity and stiffness of joint at the second and third loading to 180 N in a test setting (Patterson et al. 1991). A later study with 39 cases treated with LFS found that it was superior to both the FHT and conservative treatment (Chauvet et al. 1996) A later force plate study including 47 cases of unilateral CrCL rupture repaired with the LFS technique found improvement in 40 % of the cases and a return to normal for 15 % of the cases (Conzemius et al. 2005).

The FHT technique was assessed on 4 cadaver stifles, 4 dogs with experimentally excised CrCL and 71 dogs with CrCL rupture during a 6 year period (Smith & Torg 1985). A following study on 80 cases operated over a 5 year period found the results of the FHT operation to be good in 90 % of the cases (Mullen & Matthiesen 1989). Another study found the FHT technique to be superior to both LFS and two intra-articular techniques (over-the-top and
under-and-over) with respect to laxity and stiffness under experimental loading to 180N (Patterson et al. 1991). A later study with 22 cases treated with FHT found that it was statistically significantly inferior to LFS (Chauvet et al. 1996).

The 2007 non-peer reviewed whitepaper on the TR technique based on 24 patients found the 6 month postoperative recovery of patients treated with TR was comparable to patients treated with the TPLO technique (Cook et al. 2007). Another non-peer reviewed brochure by Arthrex Vet Systems claimed multi-center clinical outcomes of 2 563 TR cases to have a 94.9 % success rate with 64.6 % of patients returning to full function and 30.3 % to acceptable function. A recent gait analysis study comparing two groups of 14 dogs treated with either TR or TPLO could not statistically differentiate the groups when lameness was measured by peak vertical force (PVF) (Böddeker et al. 2012).

5.3 Outcomes of osteotomy techniques

The 1993 paper on the TPLO technique states that surgery with either CTWO or TPLO was performed on 394 cases, but fails to separate the numbers of patients receiving TPLO treatment (Slocum & Devine Slocum 1993). Thus the results, however promising, are hard to attribute to either technique. The authors also confess that the technique does not remove the cranial drawer sign, but claim this to be insignificant as the patients return to normal activity.

A comparison study of an intra-articular (over-the-top), extracapsular (LFS) and osteotomy (TPLO) technique found TPLO to be comparable to LFS and superior to the intra-articular method. The force plate study concluded that 11 % of the patients operated with TPLO had normal limb function and improvement from the preoperative state was found in 34 % of the patients. (Conzemius et al. 2005) A recent gait analysis study comparing two groups of 14 dogs treated with either TPLO or TR concluded that TPLO leads to faster recovery and improved limb function at 4 months postoperatively, even though there was no statistical difference in lameness when measured by peak vertical force (PVF) between the TPLO and TR groups (Böddeker et al. 2012).

No statistics on the successfulness of the TTA technique are reported in the original proceedings book publication (Montavon et al. 2002). Hoffmann et al. (2006) claim there to be no peer-reviewed literature on the technique prior to their article. This is surprising since the technique been performed on over 9000
patients (Montavon & Tepic 2006). Another study found mean time to
documented radiographic healing to be 11.3 weeks (Lafaver et al. 2007). A later
force plate gait analysis study concluded that TTA would return 90 % of full limb
function, but could not return the limb to normal function (Voss et al. 2008). A
recent study concluded on 67 patients that the gap created by the TTA
operation healed equally fast with or without the use of a bone graft (Guerrero
et al. 2011).

The original study on the PTIO technique is based on the results of 100
operations performed on 87 patients with 86 % (75/87) regaining full function of
the operated limb within 4 months of the operation (Damur et al. 2003). A later
study found 93 % (53/57) of patients had full radiographic healing at 6 weeks
postoperatively (Jerram et al. 2005).

The Bruce et al. (2007) study is based on a total of 64 TTO operations
performed on 52 patients. The success of the operation was measured
objectively by scoring radiographs for osteoarthritis (OA) concluding that the
OA score was not significantly increased after the procedure (Bruce et al. 2007).

In the original cTTA study (Verdonck & Petazzoni 2009), 18 patients with CrCL
tears were treated with cTTA and their mean time to radiographic healing was 8
weeks. A later 2010 study (Petazzoni 2010) with 86 patients treated to 89 cTTA
procedures found a similar mean time to radiographic healing of 8 weeks.

Table 1 shows the publications which mention times to radiographic healing for
the patients. When the cases number is larger than the patient number, some
patients have received a bilateral CrCL operation.
Table 1. Outcomes of studies on different osteotomy techniques.

<table>
<thead>
<tr>
<th>Publication</th>
<th>Technique(s)</th>
<th>Patients / procedures</th>
<th>Radiographic healing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoffmann et al. (2006)</td>
<td>TTA</td>
<td>57 / 65</td>
<td>8–10 weeks</td>
</tr>
<tr>
<td>Lafaver et al. (2007)</td>
<td>TTA</td>
<td>101/114</td>
<td>11 weeks</td>
</tr>
<tr>
<td>Damur et al. (2003)</td>
<td>PTIO</td>
<td>87 / 100</td>
<td>16 weeks</td>
</tr>
<tr>
<td>Jerram et al. (2005)</td>
<td>PTIO</td>
<td>52 / 60</td>
<td>93 % @ 6 weeks</td>
</tr>
<tr>
<td>Bruce et al. (2007)</td>
<td>TTO</td>
<td>52 / 64</td>
<td>6–12 weeks</td>
</tr>
<tr>
<td>Verdonck et al. (2009)</td>
<td>cTTA</td>
<td>18</td>
<td>mean 8 weeks</td>
</tr>
<tr>
<td>Petazzoni et al. (2010)</td>
<td>cTTA</td>
<td>86 / 89</td>
<td>mean 8 weeks</td>
</tr>
<tr>
<td>Etchepareborde et al. (2011)</td>
<td>MMT</td>
<td>20/20</td>
<td>mean 7 weeks</td>
</tr>
</tbody>
</table>
6 Complications

All categories of techniques are prone to three types of complications: perioperative, early postoperative and late postoperative. All intraoperative and any postoperative complications which arise less than 24 hours after surgery are considered perioperative complications. Early postoperative complications arise in the first two weeks, or between 1 and 14 days after surgery. All other complications are considered late postoperative complications. The reporting on complications is varied on all methods and very brief with the earliest methods.

6.1 Complications associated with intra-articular techniques

Singleton (1963) reports 13 % (2/15) poor results with the Paatsama procedure but gives no insight as to the cause. Arnoczky (1979) listed 7 % (2/28) results of the over-the-top technique as fair, but gives no details as to the cause. Smith & Torg (1984) note no complications for their under-and-over technique.

6.2 Complications associated with extracapsular techniques

Placing two sutures as in the original LFS technique (DeAngelis & Lau 1970) results in only one of the sutures bearing all of the weight as it is not humanely possible to tighten two sutures to exactly the same tension, a prerequisite for both of the sutures halving the total weight. Placing the second suture is thus not only useless, but increases the duration of the surgery, the amount of foreign material in the patient and, should a surgical error occur, may risk the viability of the primary weight bearing suture.

The original study on the LFS technique reported continuous lameness in 12 % of cases (5/37 or 14 % of patients) and total non-weight bearing lameness in 2 % of cases (1/37 or 3 % of patients) (DeAngelis & Lau 1970). A recent study with 496 cases treated with LFS found that infection or inflammation developed in 4,2 % (21/496) of cases which was significantly lower compared to cases treated with TPLO (Frey et al. 2010).

FHT is technically complicated and thus prone to several intra and postoperative complications. A common intraoperative complication is inadvertent placement of the scalpel blade too deep while incising the tibiofibular ligaments resulting in substantial hemorrhage. Another common
intraoperative complication is fracture of the fibular head when placing the Steinmann pin or fracture of the fibular neck while tightening the steel wires around the pin after transposition. Common post operative complication include seroma formation on the lateral aspect of the proximal tibia and migration of the Steinmann pin requiring pin removal. (Matthiesen 1993)

Mullen & Matthiesen (1989) reported the complications of 85 fibular head transposition surgeries performed on 80 dogs during a 5 year period. No total complication rate was reported, but the most common complications was stated as iatrogenic fracture of the fibular head or neck, which accounted for 12,5 % of the perioperative complications, and seroma formation over the pin location, which accounted for 7,5 % of the post operative complications.

6.3 Complications associated with osteotomy techniques

The original publication on the TPLO technique (Slocum & Devine Slocum 1993) does not disclose any complication rates for the surgery. They admit cranial drawer motion is not removed, but claim this has no effect on the use of the limb and is thus not evidence of surgical failure. Pacchiana et al. (2003) reported the complication rates of 397 cases on 346 patients from a 4 year period to be 28 % with perioperative complications accounting for 5 %, short-term 46 % and long-term 49 % of the complications. These complications are grouped by patient and not by operated limb. A later study of 696 TPLO patients from a 2,5 year period (Stauffer et al. 2006) determined the complication rate to be 19 %. The Stauffer et al. (2006) study had a similar distribution of the occurrence of the complications as the Pacchiana et al. (2003) study with perioperative complications accounting for 5 %, short term 50 %, long term 45 % of the complications.

A later study found a small but significant, increase in mean DJD score 8 weeks after surgery, compared with mean preoperative score (Hurley et al. 2007). Another later study comparing extracapsular repair (LFS) with TPLO found that patients with larger OA scores were 5,78 times more likely to have had an LFS than a TPLO (Lazar et al. 2005). A recent study with 406 cases treated with TPLO found that infection or inflammation developed in 8 % (34/406) cases (Frey et al. 2010). A recent extensive study of 1146 TPLO procedures performed on 1000 patients found the overall complication to be 15 % of which
7 % were major (Fitzpatrick et al. 2010). Another very recent comparison gait analysis study of TR and TPLO found the complication rate to be greater with TPLO with 26 % (5/19) dogs excluded from further analysis compared to 13 % (2/16) for TR (Böddeker et al. 2012).

The original article for the TTA technique does not list any complications rates. The first published study on the TTA technique comprised of 65 TTA cases on 57 dogs presents numerous complications associated with the procedure with the complications grouped into perioperative, early post operative and late post operative issues. Unfortunately the paper does not differentiate between patients with multiple complications and those with single complications. Thus the frequencies of complications are confounding as the maximum number of complications is stated as the total number of complications (34 cases of edema equaling 60 % of the 57 patients) when the list of perioperative complications contains a total of 6 different complications associated with a total of 57 cases. (Hoffmann et al. 2006)

From the results it can be assumed that all cases which had edema also had one or several of the other perioperative complications, some of which are non-technique related (like diarrhea or inappetence). The same can be said for early post operative complications which has a maximum of 34 cases with edema, with 6 different complications associated with a total of 58 cases. The authors discount the early post operative edema and all of the non-technique related complications and raise as “notable” the 3 cases (5 % of the 57 patients) with incisional dehiscence and superficial infection. (Hoffmann et al. 2006)

The major issue with the readability of the statistics comes with the late post operative complications, where the most common complications was periosteal proliferation of the tibial diaphysis (9 cases or 16 % of the 57 patients), but another 15 different complications in a total of 25 additional cases. Of the five most frequent the most frequent periosteal proliferation and the third most frequent lethargy are ignored, with joint pain, medial meniscal tear and crepitus raised as “serious” and claimed to be the most common late post operative complications. (Hoffmann et al. 2006)

In addition complications occurred in 33 of 57 dogs, which is not 59 % (57,9 %) and also not the same as in Table 1 in the article (34/57 equaling 59,6 %).
authors further claim that only 12 of 57 dogs (21 %) had more serious complications, but these 12 more serious complications are not revealed anywhere and do not correspond directly to any of the frequencies presented in Table 1 of the article. (Hoffmann et al. 2006)

A later study conducted of 114 cases on 101 patients found a total of 32 % of complications of which the authors categorized 12 % as major and 19 % as minor complications (rounding explains the discrepancy in the numbers). The major complications included e.g. implant failure, tibial fracture and infection and all except two of the minor complications resolved. (Lafaver et al. 2007) A force plate study found complications in 25 % of 30 cases on 40 patients (Voss et al. 2008).

The original article on the PTIO technique admitted that due to the high incidence of complications, the technique does not appear to be a valid alternative to TPLO. (Damur et al. 2003). A later study comprised of 60 cases on 52 patients reported a total complication rate of 20 % (Jerram et al. 2005).

The original publication on the TTO technique found an overall complication rate of 36 % for the procedure (Bruce 2007). All dogs showed mild lameness and cranial draw motion at 12 weeks with 89 % also having a positive tibial compression test. Lameness subsided at 11 to 26 months long term evaluation, but the cranial draw sign was still present in all cases and 91 % still had a positive tibial compression test. Post operative complication were not grouped into short and long term complications, but two of the patients required repeat surgery due to meniscal damage and these have been classed as long term complications in Table 2. (Bruce et al. 2007)

The initial study on cTTA reported 14 % (3/21) intraoperative complications (Verdonck & Petazzoni 2009). A later study with more cases found a lower 10 % (9/89) intraoperative complication rate (Petazzoni 2010).

In Table 2, perioperative, early postoperative and late postoperative complications are represented as a percentage of all complications and the total complications column represents the percentage of complications in total out of the cases in the publication.
Table 2. Complication rates of different osteotomy techniques.

<table>
<thead>
<tr>
<th>Publication</th>
<th>Technique</th>
<th>Complications</th>
<th>Peri op</th>
<th>Early post op</th>
<th>Late post op</th>
<th>Total % / cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacchiana et al. (2003)</td>
<td>TPLO</td>
<td></td>
<td>5 %</td>
<td>46 %</td>
<td>49 %</td>
<td>28 % / 397</td>
</tr>
<tr>
<td>Stauffer et al. (2006)</td>
<td>TPLO</td>
<td></td>
<td>5 %</td>
<td>50 %</td>
<td>45 %</td>
<td>19 % / 696</td>
</tr>
<tr>
<td>Frey et al. (2010)</td>
<td>TPLO</td>
<td></td>
<td>5 %</td>
<td>50 %</td>
<td>45 %</td>
<td>19 % / 696</td>
</tr>
<tr>
<td>Fitzpatrick et al. (2010)</td>
<td>TPLO</td>
<td></td>
<td>5 %</td>
<td>50 %</td>
<td>45 %</td>
<td>19 % / 696</td>
</tr>
<tr>
<td>Böddeker et al. (2012)</td>
<td>TPLO</td>
<td></td>
<td>5 %</td>
<td>50 %</td>
<td>45 %</td>
<td>19 % / 696</td>
</tr>
<tr>
<td>Hoffmann et al. (2006)</td>
<td>TTA</td>
<td></td>
<td>44 %</td>
<td>44 %</td>
<td>12 %</td>
<td>59 % / 57</td>
</tr>
<tr>
<td>Lafaver et al. (2007)</td>
<td>TTA</td>
<td></td>
<td>5 %</td>
<td>17 %</td>
<td>78 %</td>
<td>32 % / 114</td>
</tr>
<tr>
<td>Damur et al. (2003)</td>
<td>PTIO</td>
<td></td>
<td>61 %</td>
<td>6 %</td>
<td>33 %</td>
<td>31 % / 100</td>
</tr>
<tr>
<td>Jerram et al. (2005)</td>
<td>PTIO</td>
<td></td>
<td>67 %</td>
<td>33 %</td>
<td>0</td>
<td>20 % / 60</td>
</tr>
<tr>
<td>Bruce et al. (2007)</td>
<td>TTO</td>
<td></td>
<td>70 %</td>
<td>22 %</td>
<td>9 %</td>
<td>36 % / 64</td>
</tr>
<tr>
<td>Verdonck et al. (2009)</td>
<td>cTTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20 % / 28</td>
</tr>
<tr>
<td>Petazzoni (2010)</td>
<td>cTTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25 % / 12</td>
</tr>
<tr>
<td>Etchepareborde et al. (2011)</td>
<td>MMT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25 % / 12</td>
</tr>
</tbody>
</table>
7 Ancillary procedures

Signs of both partial and complete rupture of CrCL require inspection of the stifle joint to identify the state of the CrCL and removal of any remains of the ruptured CrCL. In addition the amount of OA changes as well as the state of the menisci should be checked and menisci operated if necessary.

Most of the authors of the different techniques discussed in this review advocate a complete or partial meniscectomy when damage to the menisci is observed (e.g. DeAngelis & Lau 1970, Slocum & Devine 1993, Bruce et al. 2007). For example a study of 397 cases on 346 patients treated with TPLO performed a meniscal release on 67 % (267/397) of the cases. Subtotal or total meniscectomy was performed on 9 % (36/397) of the cases. (Pacchiana et al. 2003). However, a study on the effect of medial meniscal release (MMR) on TPLO operated patients found that since performing a TPLO neutralizes the tibial thrust, the wedge effect created on the medial meniscus is also greatly reduced and thus MMR may no longer be indicated (Pozzi et al. 2006). A later study on the effects of transection of the medial caudal meniscotibial ligament on cadavers treated with TPLO found that transection eliminates the load bearing function of the medial meniscus and thus significantly changes the medial femorotibial contact mechanics. This leads to abnormal cartilage stress, which can accelerate the degenerative changes in the joint. (Pozzi et al. 2010)

Partial meniscectomy is indicated for longitudinal, bucket-handle, radial, horizontal, and complex tears for which peripheral circumferential collagen fiber integrity or a “rim” can be preserved after resection. Segmental meniscectomy is indicated for all types of tears in the caudal aspect of the meniscus when an intact rim cannot be preserved. Segmental meniscectomy should be performed in conjunction with complete resection of any pathologic tissue. Total meniscectomy is indicated for tears extending beyond the caudal aspect of the meniscus and for which an intact rim could not be maintained. The goals in performing the meniscal resection are to remove all grossly damaged, displaced and pathologic tissue while preserving as much functional meniscal tissue as possible. (Cook & Pozzi 2010)
8 Conservative treatment

Non-surgical management has been considered a reasonable alternative for dogs less than 15 kg in weight. The study on non-operative management of CrCL rupture found that 85.7% of the small patients were either normal or improved after 6 months. (Vasseur 1984)

However, left untreated, a ruptured CrCL will cause instability in the stifle joint. The disadvantage of conservative management is that even with small dogs, this instability lasts from 4 to 5 months (Vasseur 1984). The extended period of instability may cause meniscal damage and accelerate the progression of DJD. Vasseur (1984) suggest that non-operative management of dogs less than 15 kg in weight is a valid alternative. However, since unilateral CrCL rupture frequently leads to bilateral rupture and any extended period of instability in the stifle joint accelerates the progression of DJD, early surgical treatment of dogs of all sizes is preferred. Surgical treatment should especially be considered with small breed dogs predisposed to patellar luxation due to the compound instability created by the deficient CrCL and luxated patellar ligament.

If conservative treatment of complete or partial CrCL is chosen, it should consist of restricted exercise with optional active range of motion physiotherapy, non-steroidal anti-inflammatory drug therapy and, if necessary, weight management.
9 Prevention

Despite the relatively high cost and morbidity associated with CrCL deficiency and its treatments, research efforts aimed at developing preventive measures remain in their infancy. The main reason for the discrepancy is the currently limited understanding of the origin of CrCL deficiency. (Griffon 2010)

Genetic screening appears promising as a long-term option in selected breeds. For breeds where genetic screening is not applicable and where the CrCL deficiency is unilateral, immunomodulating therapies might soon become available for use in reducing the incidence of contralateral disease. (Griffon 2010)
10 Discussion

The current literature on repair of CrCL deficiency is varied in both content and methodology. There are no meta-analyses of the different methods or double blind prospective studies and only a few robustly designed prospective studies and prospective or retrospective cohort or case control studies. Most of the literature is documented case studies with fairly random numbers of patients, moderately suspect statistics and possibly deliberate bias in the presentation of the results. It is also almost customary to see new techniques presented and adapted well before any peer-reviewed research to support their efficacy has been published. In addition some of these new techniques are visibly backed by the company that manufactures the custom equipment required to perform operations using the new technique.

New cross sectional studies comparing the different techniques for resolving CrCL rupture are needed. These studies need to be done with objective methodology, such as by using gait analysis and evaluating sufficient numbers of both treated and untreated patients. Careful planning is needed to minimize the risk of bias in those parts of the assessment of the patients where subjective evaluation is still required. Although double blinding in the way that some dogs receive an operation and some do not is clearly unethical, the blinding could be done by randomly selecting the technique to be used. If the technique information is then kept from the person performing the force plait gait analysis, a double blinding of sorts can be thought to have been made.

Although the first techniques to combat CrCL deficiency, intra-articular techniques are no longer in use, at least not widely. Modifications of early 1970s extracapsular techniques as well as the more recent osteotomy techniques, however, are. The most used extracapsular technique requires no special equipment bar perhaps a drill and some suitable suture material (DeAngelis & Lau 1970), although the latest arrivals in this field are based on custom equipment (Cook et al. 2007). Most of the osteotomy techniques on the other hand require custom saw bits (Slocum & Devine Slocum 1993, Montavon et al. 2002, Bruce et al. 2007 and Verdonck & Petazzoni 2009) or compression plates for proper application and the ones which do not seem to be prone to failure (Damur et al. 2003).
Development of techniques not requiring custom or at least not requiring specific patented equipment should be encouraged. On the extracapsular technique side the opposite seems to be happening, as new suture materials have recently been introduced and with them new extracapsular techniques being introduced (Hulse et al. 2011). Similarly all osteotomies developed in the last decade require some amount of specialized equipment to be performed efficiently. Some of the osteotomies can be performed with standard tools, but many preferably require the custom equipment marketed by the inventors of the technique (e.g. radial saw by Slocum enterprises for TPLO and cage and tension band by Kyon veterinary surgical products for TTA). To enable more surgeons to perform corrective CrCL surgery, there is a need for a technique which involves less custom equipment. Since the patent for the TPLO technique has expired, it and the cTTA technique which is based on using the same radial saw are superior in this respect. TTO can also be performed without custom equipment, but has an unfortunately high perioperative complication rate. However, the introduction of new techniques has also created more competition in the field of manufacture of surgical instruments which has dramatically decreased the prices of the instrument for all of the techniques.

TTO surgery involves an extensive amount of osteotomies, all of which increase the time required for healing. The technique did not remove the cranial draw motion in any cases post operatively or negate the tibial compression test in a majority of cases. The technique also has a relatively high complication rate of 36 % with the most common complication being the complete fracture of the TCO at its distal end. The 2007 study claims that 100 % of the responders both felt the surgery resulted in a marked improvement in the quality of life of their dogs and that they would have the procedure performed again if they had another dog with the same condition. The paper however fails to validate the questionnaire itself and consequently any and all results of the questionnaire part are worthless.

Computer assisted force plate or treadmill gait analysis is considered the gold standard in assessing post operative use of limb by the patients. Gait analysis studies are however rare and most of the techniques described in this literature review have only been studied with palpation (cranial draw motion and tibial...
compression test), radiographic findings and owner questionnaires all of which are subjective to a great extent.

The reporting of complications with different techniques is colorful to say the least. The most common current grouping of complications is division into three temporally separate groups: perioperative, short term post operative and long term post operative. In the last 25 years the reporting of complications has improved significantly. Where the 1989 study on fibular head transposition by Mullen et al. only reports the most common perioperative and postoperative complication, studies from the last 5 years account in great detail the different complications encountered.

However, even in more recent studies, the reporting of complications is still varied. The Hoffmann et al. (2006) study on TTA attempts to discount minor complications such as tissue swelling or incisional discharge to significantly lower the complication rate from 59 % to 21 %. On the other hand the Hoffmann et al. (2006) study includes non-surgery technique related complications such as diarrhea or inappetence. Another study which includes complications caused by non-technique related mishandling of patients (inappropriate application of bandaging) as part of the total complications is the Pacchiana et al. (2003) study on TPLO. While diarrhea and incorrect application of bandages are obviously complications in themselves, they are clearly not related to the surgical technique in the same way as a tibial fracture or a broken implant are.

The Hoffmann et al. (2006) study lists 27 distinct complications, but gives no indication as to which of the patients had multiple complications. They then report in Table 1 that 34 (of 57) dogs equaling 59,6 % had tissue swelling but incorrectly claim this to be 59 % of the cases in the text on page 222. The same mathematical error is repeated for inappetence, where 6 (of 57) or 10,5 % (correct in Table 1) is claimed to be 10 % on page 222. The same mathematical inconsistencies are repeated a few pages later with the total of dogs with any kind of complication claimed to be 33 of 57 dogs, which is both not consistent with Table 1 on page 223 and not 59 % (33/57 = 57,8 %).

It also seems that the motives of some of the authors are to either decrease the apparent complications associated with a specific technique (e.g. Hoffmann et al. 2006 with TTA) or to increase them (e.g. Pacchiana et al. 2003 with TPLO).
More than anything the reporting of complications is in desperate need of standardization and after that universal adaption of those standards. Currently it is next to impossible to compare any of the complication rates of different studies. This leads ultimately to the fact that it is not possible to pick the best alternative from the multitude of different surgical techniques. It does seem that TPLO which is one of the oldest osteotomy techniques and has been studied the most has one of the lowest complication rates and appears suitable for most patients. TPLO is by far not the simplest of methods and the learning curve is shallow meaning it takes a long time to master the technique. However, should you put in the effort to master the TPLO technique, you could use the technique on most patients. And if you invested in the equipment necessary for TPLO, you could also attempt surgery with the newer and promising cTTA technique as it uses the same radial saw as that used in TPLO. This combination of techniques and the equipment necessary for performing both might be the best investment currently.
11 References


