CRANIAL CRUCIATE LIGAMENT DISEASE:
DIAGNOSIS AND SURGICAL MANAGEMENT
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STIFLE ANATOMY

Clinically-relevant features of each bone
a. Distal femur – The medial and lateral femoral condyles articulate with the tibia, and the femoral trochlea articulates with the patella. The femoral condyles are separated by a notch called the intercondylar fossa.
b. Proximal tibia – The articular surface is divided into medial and lateral condyles to correspond with those of the femur, separated by a non-articular region called the intercondylar eminence. The medial and lateral intercondylar tubercles are projections on either side of the eminence. Caudally, the popliteal notch separates the tibial condyles. The extensor groove is a small notch at the cranial margin of the lateral tibia that allows passage of the long digital extensor tendon.

Joint articulations and movement
The primary motion of the stifle joint is flexion and extension in the sagittal plane; normal range of motion is approximately 140 degrees. Because the femoral condyles are not perfectly spherical, a small amount of craniocaudal translation of the tibia with respect to the femur occurs normally during flexion and extension. The secondary type of motion is rotary movement of the tibia on the femur in the transverse plane.

Ligaments
a. Cranial and caudal cruciate ligaments – These ligaments are intra-articular but extrasynovial. They are designated cranial/caudal based on location of the tibial attachment and are named “cruciate” because the CrCL and CdCL cross each other.
   i. Cranial cruciate ligament (CrCL) – Attachments are from the caudomedial aspect of the lateral femoral condyle to the cranial intercondylar region of tibia. The CrCL has a larger caudolateral part and smaller craniomedial band (named based on tibial attachments). The craniomedial band is taut in both flexion and extension, while the caudolateral part is taut in extension and is lax in flexion. The CrCL is the primary restraint against tibial translation with respect to the femur (cranial drawer), and it is also the primary restraint against hyperextension. Both the CrCL and CdCL limit internal rotation.
   ii. Caudal cruciate ligament (CdCL) – Attachments are from the lateral aspect of the medial femoral condyle to medial edge of popliteal notch of tibia. The CdCL is the primary restraint against caudal tibial translation with respect to the femur (caudal drawer), and it is a secondary restraint against hyperextension. Both the CrCL and CdCL limit internal rotation.

b. Lateral and medial collateral ligaments
   i. Lateral collateral ligament – Attachments are from the lateral epicondyle of the femur to head of the fibula. In the middle, the lateral collateral ligament is only loosely attached to the joint capsule, and it is not attached to the lateral meniscus.
   ii. Medial collateral ligament – Attachments are from the medial epicondyle of the femur to medial border of tibial metaphysis. In the middle, the medial collateral ligament blends with the joint capsule and has a strong attachment to the medial meniscus.
**Medial and lateral menisci**

a. **Shape, attachment** – The menisci are C-shaped disks of fibrocartilage. The menisci are crescent in shape and triangular in cross-section (thick and convex on periphery, taper to thin axial edge), which allows them to adapt to the articular surfaces of the femur and tibia and improve congruity.

Each meniscus has a cranial and caudal tibial attachment, namely the cranial and caudal meniscotibial ligaments. The intermeniscal ligament is a transverse fibrous band connecting the cranial meniscotibial ligament of each meniscus. The meniscofemoral ligament attaches the lateral meniscus (caudal axial border) to the femur (intercondylar fossa).

b. **Composition** – Primarily type I collagen fibers, some cells, extracellular matrix (proteoglycans and glycoproteins). Collagen fibrils are highly structured to allow compressive forces to be dissipated. Proteoglycans also have high capacity to resist compressive loads.

c. **Blood supply** – Blood vessels in the synovium provide supply to the peripheral 15-25% of the menisci. The most axial portion of the menisci is avascular, and there is a transition zone of marginal vascularity between the vascular and avascular zones.

d. **Function** – Load bearing/distribution, shock absorption, joint stability.

The menisci bear 40-70% of load across the stifle joint. As the joint is loaded, contact between the femoral condyle and meniscus increases; the larger contact area created by the meniscal-articular interface protects the chondrocytes against mechanical damage. The menisci contribute to joint stability by improving congruity and acting as a caudal wedge, minimizing cranial tibial subluxation (especially in the CrCL deficient stifle).

**Sesamoid bones**

a. **Patella** - Largest sesamoid in the body; the patellar ligament (extension of tendon of quadriceps femoris muscle) attaches the patella to the tibial tuberosity.

b. **Lateral and medial fabellae** - In the lateral and medial heads of origin of the gastrocnemius muscle, respectively; lateral fabella is larger and more spherical.

c. **Popliteal** - Within the tendon of origin of popliteus muscle

**PATHOGENESIS OF CrCL DISEASE**

**CrCL Disease**

a. **Why does the CrCL tear?**

The term “CrCL disease” encompasses the various disorders affecting the CrCL, including traumatic avulsion of the tibial or femoral attachment of the CrCL, acute traumatic rupture secondary to excessive strain, and progressive degeneration of unknown cause. CrCL disease is the most common cause of hindlimb lameness in the dog, and progressive degeneration is by far the most common type of CrCL disease. Avulsion of the CrCL from its tibial or femoral attachment is uncommon and occurs in skeletally immature dogs. Acute traumatic rupture of the CrCL is rare, often occurs concurrently with other stifle pathology (CdCL tear, collateral ligament tear), and is characterized by the absence of arthritis in the joint.

The cause of progressive degeneration of the CrCL is unknown despite extensive research aimed at answering this important question. Histologic examination of ruptured CrCL fibers revealed lack of collagen fiber maintenance and loss of fibroblasts among other changes, which implicates progressive mechanical overload as a cause of failure. A repair response was identified that resulted on covering of the torn ends of the CrCL, but importantly no bridging scar was identified between the two ends.
Factors that affect the prevalence of CrCL disease include breed, gender, and neutering status. Breeds with the highest prevalence of CrCL disease include the Rottweiler, Newfoundland, and Staffordshire Terrier. Female dogs have a higher prevalence of CrCL disease than male dogs, and several studies have found that neutering increases the prevalence of CrCL disease. Studies have had inconsistent results in finding an association between increased tibial plateau angle and CrCL disease.

b. Effect of loss of CrCL function
Experimental studies have shown that peak vertical force of a normal hindlimb is 70% of a dog’s weight. After CrCL transection, PVF was 25% of body weight at 2 weeks, 32% at 6 weeks, and 37% at 12 weeks. Approximately 10mm of cranial tibial translation occurred after experimental CrCL transection; 2 years later, 5mm of cranial tibial translation was still present.

c. Rupture of the contralateral CrCL
Rupture of the contralateral CrCL occurred in 37% of dogs at a mean of 17 months following initial diagnosis of unilateral CrCL rupture in one study. In another study of Labrador Retrievers, 48% ruptured the contralateral CrCL at a median time of 5.5 months following the initial CrCL diagnosis. Age, sex, weight, and tibial plateau angle have not been found to be reliable predictors of contralateral rupture.

**Meniscal Tears**

a. Why does the medial meniscus tear far more often than the lateral meniscus?
Most meniscal tears involve the caudal horn of the medial meniscus; the most common shape of meniscal tear is the bucket handle tear. The lateral meniscus has attachments to the femur that allow it to move with its femoral condyle during rotation. The medial meniscus is not attached to the femur; on the contrary, its strong attachments to the joint capsule and medial collateral ligament render it relatively immobile and therefore susceptible to tearing during cranial drawer motion of the CrCL-deficient stifle.

b. Incidence of meniscal tears
The reported incidence of meniscal tears varies, but in one large study of 1,000 dogs, 33% of dogs presented with a meniscal tear at the time of the first CrCL surgery. Risk factors for meniscal tears have been difficult to identify, but available data suggests that meniscal tears are more common in dogs with complete CrCL rupture.

**EXAMINATION FINDINGS IN CrCL DISEASE**

**Historical findings**

Hindlimb lameness that is worse following periods of exercise or rest is typically reported. The severity of the lameness is variable, ranging from subtle lameness noted only after strenuous exercise to severe weight-bearing lameness.

**Physical exam findings**

a. Palpation
Typical physical exam findings include pain during stifle range of motion, especially (hyper)extension. In chronic cases, periarticular fibrosis is present on the medial aspect of the joint and is referred to as “medial buttress.” Stifle joint effusion can be appreciated as the absence of clearly defined borders of the patellar ligament. Dogs with CrCL disease often sit with the affected leg projecting out to the side rather than flexed and tucked under their body. A clicking sound associated with a meniscal tear (“meniscal click”) may be noted during stifle range of motion, but it is an unreliable indicator of meniscal tears.

b. Cranial drawer test
During the cranial drawer test, the examiner attempts to translate the tibia cranially with holding the femur steady. The following hand positions are used for this test: right thumb on the lateral fabella, right index finger on the patella, left thumb on the fibular head, left index finger on the tibial tuberosity. It is important to perform this test with the stifle in both flexion and extension because many partial CrCL tears will only result in cranial drawer with the stifle in flexion. Cranial translation of the tibia indicates rupture of the CrCL, but CrCL pathology may still be present even if the cranial drawer test is negative. In other words, a positive test confirms CrCL disease, but a negative test does not rule out CrCL disease.

c. Tibial thrust/compression test
The tibial thrust test also checks for stifle instability, but it does so by simulating weight bearing. This test may be performed with the dog either standing or in lateral recumbency. The following hand positions are used for this test: right index finger over the patellar ligament with the tip of the finger resting on the tibial tuberosity, the rest of the right hand grasps the femur, left hand grasps the plantar surface of the metatarsal bones. The right hand stays steady, while the left hand is used to flex and extend the tarsus, simulating weight bearing. Cranial motion of the tibial tuberosity indicates stifle instability due to CrCL disease.

RADIOLOGY OF THE STIFLE

Diagnostic imaging of the affected stifle is recommended in all cases to verify expected secondary changes in routine cases, to confirm stifle pathology in challenging cases, and to rule out other disorders such as fracture or neoplasia. Sedation is recommended to obtain diagnostic quality radiographs; sedation also provides an opportunity to palpate the stifles with the patient in a more relaxed state.

Standard radiographic views include the AP and lateral view of the affected stifle. A lateral view of the contralateral stifle should be considered to screen for early CrCL disease or as a means of comparison for the affected stifle. Specific views are required for pre-operative planning of the osteotomy procedures. Radiographic changes in cases of CrCL disease reflect stifle joint effusion and osteophytosis. Joint effusion is visible as a soft tissue opacity within the joint replacing the normal infrapatellar fat pad density. Osteophytosis is commonly observed on the distal aspect of the patella, the trochlear ridges of the femur, the tibial insertion of the CrCL, and the tibial condyles.
SURGICAL TREATMENT OF CrCL DISEASE

Intra-articular inspection/treatment

a. Arthroscopy versus arthrotomy
Arthroscopy provides the benefits of being minimally invasive and providing magnification of intra-articular structures; it is considered the gold standard for joint evaluation. The cost of additional equipment and added surgical time, especially for inexperienced arthroscopists, are considered the disadvantages of arthroscopy. In a study evaluating arthroscopy and arthrotomy for the diagnosis of meniscal tears, arthroscopy was more sensitive and specific for making an accurate diagnosis of meniscal injury.

b. Should we debride the CrCL?
Experimental studies have shown that the CrCL remnants may act as a source of ongoing inflammation, but debridement of the remnants has not been definitively shown to reduce inflammation.

c. Treatment of meniscal tears +/- meniscal release
Preservation of as much meniscal tissue as possible is the goal of meniscal treatment in light of the important functions of the meniscus. Not surprisingly, meniscal injury (and meniscectomy) appears to be associated with a worse long-term outcome. While normal meniscal tissue should be preserved, damaged meniscal tissue should be removed via partial meniscectomy in most cases of meniscal tears. Meniscal release involves transecting an attachment of the medial meniscus (typically the caudal meniscotibial ligament [CMMTL]) to allow the caudal horn of the medial meniscus to displace caudally in the joint, avoiding impingement between the tibia and femur and thereby at least theoretically reducing the risk of post-operative meniscal tears.

What are the effects of meniscectomy and meniscal release on the joint? Removal of the caudal horn of the medial meniscus causes a focal area of high pressure in the corresponding region of the proximal tibia (>10 MPa). Smaller (30% radial width) partial meniscectomies had minimal effects on meniscal function, but larger (75% radial width) partial meniscectomies resulted in significant changes. Following meniscectomy, meniscal regeneration is incomplete, resulting in regeneration of a thin, small segment of tissue with reduced function compared to the normal meniscus.

Meniscal release at the CMMTL results in a 140% increase in peak contact pressure and a 50% decrease in contact area in the stifle joint. However, in clinical patients, subjective assessment of outcome was similar between those patients that had a meniscal release and those that did not.

d. Post-operative meniscal tears
Post-operative meniscal tears are most commonly due to persistent joint instability or failure to identify the tear at the time of the first surgery. Postliminary meniscal tears are meniscal tears that occur after the initial surgical procedure. Latent meniscal tears are tears that are present at the time of the initial surgery but are identified post-operatively due to failure to identify them at the time of the initial surgery. The incidence of post-operative meniscal tears (including postliminary and latent) is 2.8-17.4%, typically occurring with the first few months after surgery.

The ability of a particular stabilization procedure to protect the meniscus against post-operative tearing may depend in part on the motion of the stifle joint. Specifically, the protective effect may be maximal during straight-line walking or running. In more challenging...
gaits, internal-external rotation may be more relevant than simple craniocaudal translation and may explain the development of post-operative tears in apparently stable stifles.

**Stabilization techniques**

**a. Extracapsular stabilization**

*i. Technique* – Extracapsular stabilization techniques rely on periarticular fibrosis for long-term stability; the suture itself only provides stability for a relatively short time. The lateral fabellotibial suture (LFS) technique is the most commonly performed extracapsular stabilization procedure. Heavy, non-absorbable suture material (nylon leader line) is passed around the lateral fabella in the strong fibrous origin of the lateral head of the gastrocnemius muscle. The suture is passed from lateral to medial through a hole drilled in the proximal tibia. The suture is passed back to the lateral side either through a second hole drilled in the proximal tibia or under the patellar ligament. The ends of the suture can be secured using hand-tied knots or metal crimps, but metallic crimps have been shown to be mechanically superior.

**ii. Outcome and complications** – Based on owner and clinician assessment in one study, approximately 80% of dogs had good to excellent function. Based on force plate analysis in another study, only 40% of dogs improved, and 15% of dogs returned to normal function.

In a retrospective study of 363 LFS procedures, complications were recorded in 63 procedures (17.4%) and required a second surgery in 26 cases (7.2%). Increasing body weight and young age were associated with a higher rate of complications. Complications included surgical site infection, incisional complications, implant complications, and postliminary meniscal tears.

**iii. Technique modifications** – A variety of other extracapsular techniques are available, which are essentially modifications of the LFS technique described above. The TightRope procedure is one such popular modification that uses a braided polyester suture secured at anchorage points that more closely approximate isometric points of the stifle joint.

**b. Tibial Plateau Leveling Osteotomy (TPLO)**

*i. Technique* - The theoretical basis for TPLO is based on a model by Slocum. In this model, the joint reaction force during weight bearing is parallel to the longitudinal axis of the tibia; this force can be divided into a cranially directed shear force and a joint compressive force that is perpendicular to the tibial plateau. Cranial tibial thrust is eliminated by TPLO because leveling the tibial plateau changes the joint reaction force so that it is perpendicular to the tibial plateau. In other words, the joint reaction force consists only of a compressive force perpendicular to the plateau after TPLO.

Biomechanical analysis of cadaver models has shown that reducing the tibial plateau angle (TPA) to approximately 6.5 degrees neutralizes cranial tibial subluxation. Reducing the TPA to angles less than 6.5 degrees induces caudal tibial subluxation and increases strain on the CdCL. Pre-operative planning is performed to measure each dog’s TPA and estimate the position of the osteotomy and implants. These measurements are performed on stifle radiographs with positioning specific to the TPLO. It is also essential that these measurements be performed using a program able to account for radiographic magnification.

A medial approach to the proximal tibia is performed. The TPLO jig is secured to the tibia with both a proximal and distal pin. Use of a jig is recommended since it aids in proper
orientation of the osteotomy, stabilizes the tibial segments during rotation and implant placement, and facilitates limb alignment. TPLO performed without use of the jig has been shown to result in craniolateral deviation of the osteotomy and increases the risk of fibular fracture and fixation failure. Many surgeons use a sponge to protect the soft tissues caudal to the tibia while the osteotomy is being performed. Several landmarks and intra-operative measurements are used to ensure correct positioning of the osteotomy. A chart is available with pre-determined calculations that dictate the rotation distance necessary for a given TPA and saw blade size. Once the proximal tibial segment is rotated, it is secured in its new position using a plate and screws; locking screws are preferred since they maintain the post-operative TPA better and result in improved osteotomy healing compared to standard screws.

ii. Outcome and complications - Many studies have documented good to excellent limb function following TPLO in the majority of patients. Most intra-operative complications are a result of technical error that can be minimized with experience and careful attention to detail. Short-term complications include primarily incisional complications. Long-term complications include patellar ligament thickening, tibial tuberosity fracture, osteomyelitis, implant loosening or breakage, postliminary meniscal tear, and increase in TPA during the healing process (so-called “rock-back”). Significant controversy surrounded reports of proximal tibial neoplasia following TPLO; this apparent association appears to have involved a specific type of TPLO plate that is no longer in use.

c. Tibial tuberosity Advancement (TTA)

i. Technique - The theoretical basis for TTA is based on a model by Montavon and Tepic. In this model, the joint reaction force is parallel to the patellar ligament; this force can be divided into a cranially directed shear force and a joint compressive force. Advancing the tibial tuberosity such that the patellar ligament is perpendicular to the tibial plateau neutralizes the cranially directed shear force.

Biomechanical analysis of cadaver models have confirmed that advancing the tibial tuberosity neutralizes cranial tibial subluxation. Pre-operative planning is performed to measure the distance the tibial tuberosity must be advanced to achieve a patellar ligament angle of 90 degrees and estimate the position of the osteotomy and implants. These measurements are performed on stifle radiographs with positioning specific to the TTA. It is also essential that these measurements be performed using a program able to account for radiographic magnification.

A medial approach to the proximal tibia is performed. A specific drill guide is used to pre-drill holes for the custom-designed tension-band plate. Several landmarks and intra-operative measurements are used to ensure correct positioning of the osteotomy. The osteotomy is performed bicortically distally and through the medial cortex proximally. The TTA plate/fork combination is secured into the tibial crest before the proximal portion of the osteotomy is completed. The tibial tuberosity is advanced and maintained in its advanced position with the cage implant. The implant fixation is completed by securing the cage and the distal aspect of the plate with screws. A bone graft is placed to fill the entire osteotomy gap.

ii. Outcome and complications - Many studies have documented good to excellent limb function following TTA in the majority of patients. Most intra-operative complications are a result of technical error that can be minimized with experience and careful attention to detail. Minor complications include those associated with the incision, while major complications include
postliminary meniscal tears, tibial fracture, patellar luxation, osteomyelitis, and implant complications.

Case selection plays an important role in the outcome and complications of all stabilization procedures; specific criteria to consider in case selection for TTA include shape of the tibial crest, tibial plateau angle, and the presence of angular or torsional limb deformities. In dogs with a low patellar ligament attachment point, and thus a smaller tibial crest, a smaller plate must be used and the relative position of the cage must be altered, such that the risk of tibial tuberosity fracture may be higher. With excessive TPA, the distance of tibial tuberosity advancement necessary to stabilize the stifle may exceed the maximum currently available cage size (15mm). Finally, concurrent angular and torsional deformities cannot be corrected with the TTA technique.

d. Other stabilization techniques

Both intra-articular stabilization techniques and other tibial osteotomies are performed for stabilization of the CrCL-deficient stifle in dogs but will not be discussed in detail in this lecture. Intra-articular techniques use either biologic tissues or synthetic grafts to replace the CrCL. Lack of post-operative compliance and mechanical limitations of currently available grafts likely contribute to the lack of popular use of intra-articular techniques in dogs.

A variety of other tibial osteotomies have been performed less commonly than TPLO and TTA. The cranial tibial closing wedge osteotomy (CTWO) and CORA based leveling osteotomy (CBLO) stabilize the stifle joint through the same biomechanical principle as TPLO in that the tibial plateau angle is reduced to eliminate cranial tibial subluxation. The triple tibial osteotomy (TTO) achieves stifle stability through by combining the biomechanical principles of TPLO and TTA; the tibial plateau angle is reduced and the patellar ligament angle is reduced to 90 degrees.

e. Studies directly comparing outcomes of stabilization techniques

With so many stabilization techniques available, it can be difficult to decide which procedure is the “best” procedure. Despite the fact that CrCL disease is the most common cause of hindlimb lameness and the dog, relatively few studies directly compare the outcome of different stabilization procedures using objective data. During this lecture, we will review the results of studies that are currently available.

References