

Meniscal Injury in Dogs With Cranial Cruciate Ligament Rupture

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Abstract: Meniscal damage is common in dogs with naturally occurring rupture of the cranial cruciate ligament (CrCL). Appropriate diagnosis and treatment of meniscal injuries is critical to avoid chronic lameness in these patients. Given the frequency, expense, and clinical importance of meniscal injuries, a thorough understanding of the meniscus is important for general practitioners and veterinary surgeons alike. Research over the past 7 years has produced an abundance of new information regarding the importance of meniscal pathology, diagnostic methods, and potential treatment options at the time of CrCL surgery. This manuscript highlights recent advances that can benefit clinical practitioners and summarizes research developments that promise new therapies in the near future.

Although isolated injuries of the canine meniscus are rare, meniscal damage occurs in 40% to 60% of dogs with naturally occurring rupture of the cranial cruciate ligament (CrCL).^{1,2} Rupture of the CrCL is common, with an estimated 1.2 million surgeries performed annually in the United States, more than 90% of which are done by general practitioners.³ Appropriate diagnosis and treatment of meniscal injuries is essential for alleviating lameness and optimizing surgical outcome in these patients; meniscal injury that is not identified at the initial surgery or that occurs after stifle stabilization can cause persistent lameness.^{4,5}

Anatomy and Function

The meniscal cartilages are two C-shaped fibrocartilages anchored within the stifle joint by several ligamentous attachments to the tibia, the femur, and each other.⁶⁻¹⁰ Specifically, each meniscus is attached cranially and caudally to the tibia by meniscotibial ligaments and to the other by an intermeniscal ligament that connects the cranial poles. In addition, the medial meniscus is attached to the medial joint capsule and medial collateral ligament, while the lateral meniscus has a ligamentous attachment caudally to the femur and is relatively less attached to the lateral joint capsule (**FIGURES 1 and 2**). As a result, the medial meniscus is firmly anchored

to the tibia and often slides cranial to the femoral condyles during cranial tibial translation, whereas the lateral meniscus is more free to move and therefore maintains a more neutral position during episodes of femorotibial subluxation.¹¹ The menisci are triangular in cross-section, with a thicker outer rim that tapers to a thin, almost translucent center edge. The menisci are largely avascular, with only the abaxial 25% having a blood supply.¹²

The menisci and their ligamentous attachments are important contributors to joint function in that they enhance congruency between the femoral condyles and tibial plateau. In so doing, they increase the area of load distribution with the femoral condyle while decreasing the area of direct femorotibial contact, distributing compressive force over a larger surface area. The menisci also cushion the impact between the articular cartilages by transferring compressive load radially through their ligamentous attachments, generating a force known as *hoop stress*.^{13,14} The menisci also contribute to the cranial-caudal, varus-valgus, and rotational stability of the stifle^{15,16} and are well innervated to assist proprioception and coordinate muscle contraction to stabilize the joint.¹⁷ Furthermore, they provide joint lubrication and prevent entrapment or pinching of the synovium by the articular cartilage.^{18,19} The relative importance of the

FIGURE 1

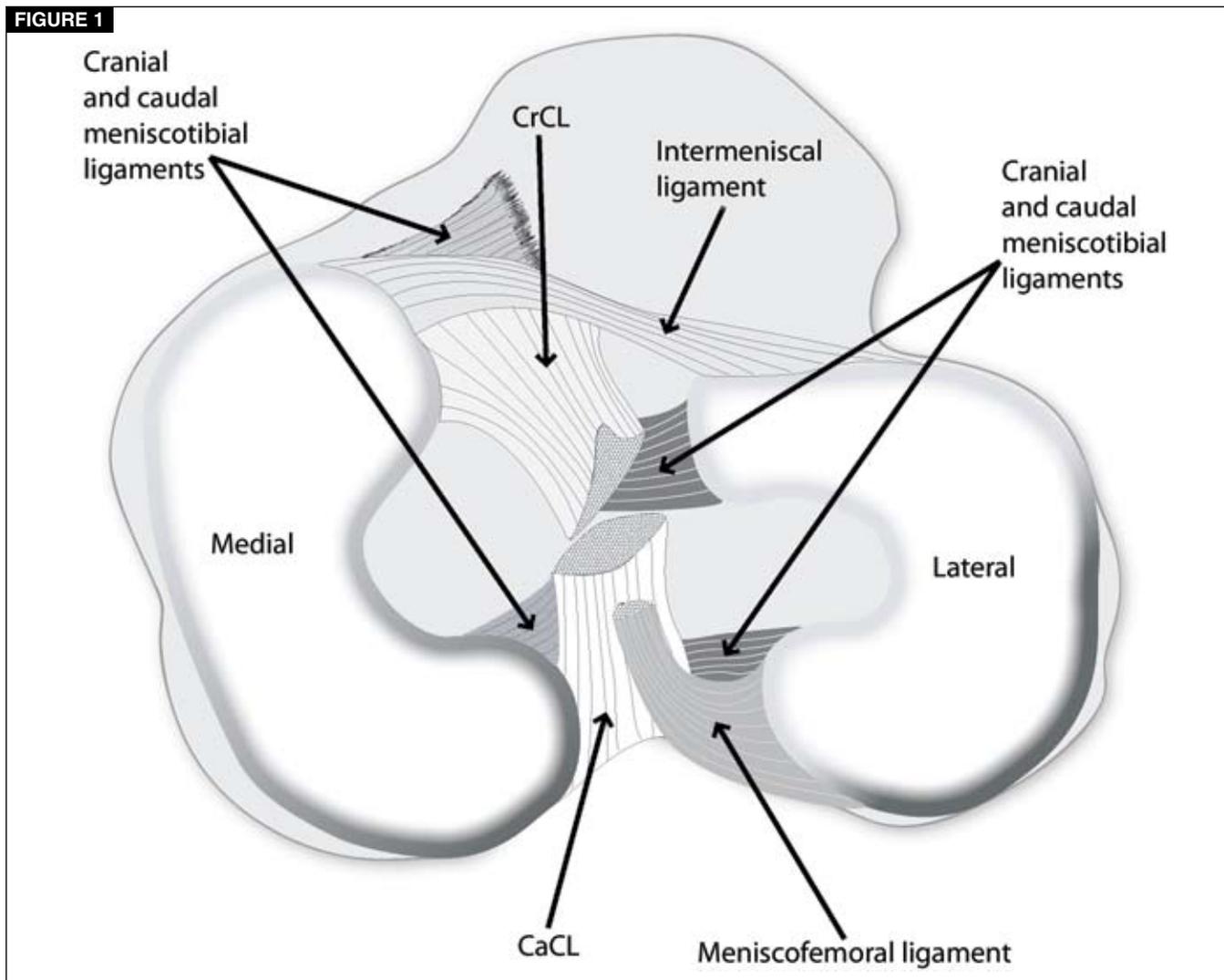


Illustration of the canine menisci and their ligamentous attachments.

CaCL = caudal cruciate ligament, CrCL = cranial cruciate ligament.

canine menisci in resisting cranial instability of the tibia is greatly increased when the CrCL is ruptured because the menisci act as a wedge between the tibia and femur, serving as the primary passive restraint to further cranial tibial translation.²⁰

Pathology

Most meniscal tears arise in conjunction with rupture or degeneration of the CrCL, with reported rates of meniscal tears at 5% to 80% in dogs with naturally occurring partial or complete CrCL rupture.^{4,9,21-32} Of dogs with experimental severing of the CrCL, 80% to 100% develop medial meniscal tears as determined by gross evaluation or magnetic resonance imaging (MRI).^{33,34} The disparity among reported studies in frequency of meniscal pathology is likely due to differences in the sensitivity of the various modalities used to identify meniscal tears, the status of the ligament at the time of evaluation (partial versus complete rupture), and the

duration of CrCL insufficiency (meniscal pathology is more likely with chronic stifle instability).^{11,24,35} The true frequency of meniscal tears is probably close to 60% in naturally occurring cases; Ralphs and Whitney² found medial meniscal pathology in 58% of 100 dogs with cruciate-deficient stifles evaluated using arthroscopy. Arthroscopy has been shown to be more sensitive for detecting meniscal pathology than arthrotomy, the modality employed by many authors who report a lower prevalence of meniscal damage.³⁶

Tears of the medial meniscus can be longitudinal (including the classic “bucket handle”), transverse, or radial; maceration/fibrillation of the caudal pole, detachment of the abaxial margin from the joint capsule, and folding of the caudal pole cranially (**FIGURE 3**) are also seen. Tears can be partial or full thickness. Injury is probably due to repeated trauma to the caudal pole by the femoral condyle. This trauma occurs when the tibia displaces cranially and the medial meniscus is “dragged” forward and backward

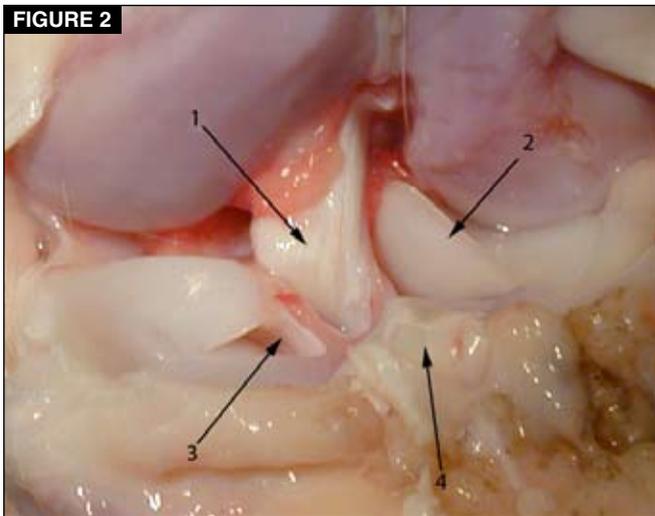


FIGURE 2
Anatomy of the canine menisci and their ligamentous attachments: (1) caudal cruciate ligament; (2) caudal horn of the lateral meniscus extending toward the femoral condyle; (3) caudal meniscotibial ligament of the medial meniscus; (4) severed insertion of the CrCL.

underneath the femoral condyle.³⁷ The importance of this mechanism in meniscal pathology is supported by studies demonstrating cyclic cranial tibial subluxation during the stance phase in CrCL-deficient stifles followed by return of the tibia to a nonsubluxated position during the swing phase of gait.^{38,39} Likewise, enhanced load sustained by the caudal horn of the meniscus in CrCL-deficient stifles—as well as computed tomography (CT) and ultrasonography images of the caudal horn of the meniscus displaced cranial to the femoral condyle with CrCL rupture—is consistent with this mechanism of injury.^{40–42} Repeated compression during uncontrolled internal rotation of the tibia with CrCL deficiency is also a proposed mechanism of injury and may contribute to meniscal pathology.⁹

The caudal pole of the lateral meniscus is usually spared injuries similar to those seen in the medial meniscus because it is not as firmly adhered to the joint capsule and because the lateral meniscus is attached to the femur caudally by the meniscofemoral ligament. As a result, the lateral meniscus relocates caudally with the femur during cranial tibial subluxation, preventing it from being crushed by the femur. Accordingly, damage to the lateral meniscus has been presumed rare, with reports of longitudinal lateral meniscus tears in as few as 7.5% of stifles with complete experimental transection of the CrCL.³⁴ However, a study using arthroscopy identified a higher frequency of lateral meniscus lesions (77%) than medial meniscal lesions (58%) in CrCL-deficient stifles.² The lesions of the lateral meniscus in that study were usually radial tears on the cranial–axial aspect of the meniscus rather than longitudinal or bucket-handle tears; the authors suggested these radial tears were secondary to compression between the intercondylar emi-

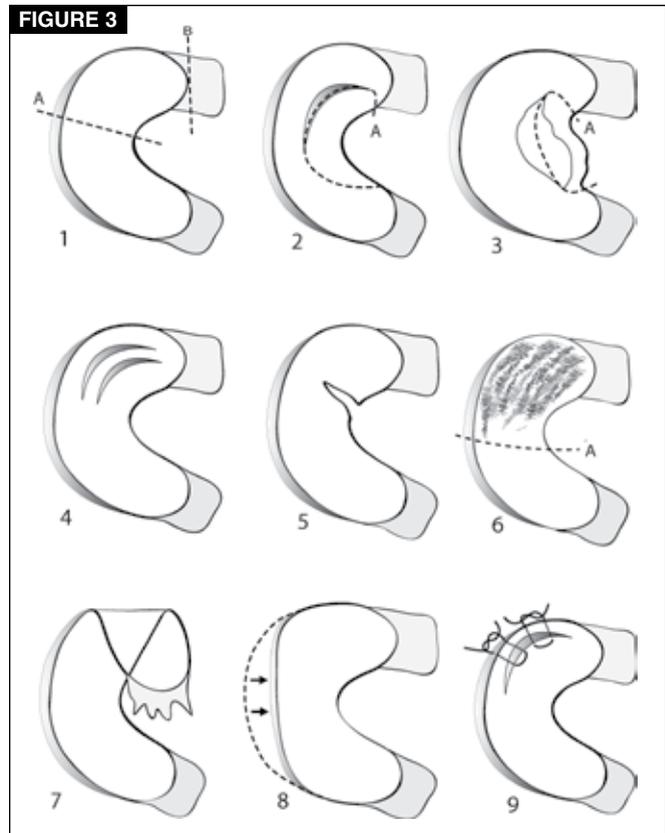


FIGURE 3
Meniscal pathology, meniscal releases, and meniscectomies. (1) Normal meniscus. A = abaxial meniscal release, B = axial release. (2) Single longitudinal tear. A = partial meniscectomy. (3) Bucket-handle tear. A = partial meniscectomy. (4) Double longitudinal tear. (5) Radial tear. (6) Fibrillated caudal pole. A = hemimeniscectomy. (7) Folded caudal pole. (8) Peripheral capsular detachment. (9) Single longitudinal tear in the vascular portion of the meniscus; inside-out repair.

nence of the tibia and the condylar notch during tibial translation. The clinical importance of these tears is unknown, and treatment is seldom performed.

Diagnosis

Meniscal damage should be suspected if a meniscal “click” is identified during physical examination. Friction between the femur and meniscus during tibial subluxation, generated as the meniscus moves back and forth under the femoral condyle, can manifest as an audible and palpable click when cycling the stifle through a range of motion during physical examination; this click can sometimes be heard while the patient is walking.⁴³ Although this finding suggests the mechanism by which meniscal injury is presumed to occur, more extensive imaging is needed to evaluate the joint because severely damaged menisci may remain silent even as they are repeatedly crushed under the femoral condyle. Only 28% of dogs with meniscal pathology identified by arthroscopy in one study had an audible or palpable meniscal click.⁵

FIGURE 4



Hohmann retractor (bottom) and Wallace stifle retractor (top). These instruments are used to assist with arthrotomy and exploration of the stifle joint.

Traditionally, the caudal pole of the medial meniscus has been assessed through a medial or lateral arthrotomy. A Hohmann retractor or curved hemostat is placed caudal to the tibia and used to lever the bone cranial into the cranial drawer position (FIGURES 4 and 5).³⁰ Alternatively, a Wallace stifle retractor can be placed adjacent to the origin of the caudal cruciate ligament, taking care not to impinge on the ligament, and in the tibial plateau just cranial to the articular surface and the insertion of the CrCL (FIGURES 4 and 6). A smaller “miniarthrotomy” made just caudal to the medial collateral ligament has also been advocated as an alternative approach that may minimize morbidity while enabling evaluation and release of the caudal pole of the medial meniscus.⁴⁴ The meniscus should always be probed, as experimental studies demonstrate that probing increases sensitivity for detecting meniscal tears.³⁶ Multiple studies have demonstrated significantly higher complication rates or more rapid progression of osteoarthritis (OA) after tibial plateau leveling osteotomy (TPLO) with a standard medial arthrotomy versus either a mini caudomedial arthrotomy or no arthrotomy.^{25,27,45} However, complicating factors in these studies, such as differences between the type of meniscal release performed and biased selection of animals that underwent exploratory arthrotomy, dictate that conclusions from these reports be interpreted with caution.

Arthroscopy, long used in human orthopedics, is gaining popularity for joint evaluation in dogs. Its use has been demonstrated to maximize identification of meniscal tears compared with arthrotomy, potentially because the joint is distended with fluid and visualization is magnified.^{36,46} An angled probe should be used on the meniscal surface to enhance identification of pathology during either arthroscopy or arthrotomy.³⁶ Arthroscopy probably has an advantage over arthrotomy in terms of decreased perioperative morbidity and earlier return to function. This presumption has been supported by a randomized, prospective study using force-plate analysis to compare arthroscopy with arthrotomy for treatment of CrCL rupture in dogs.⁴⁷

Ultrasonography, CT, and MRI have also been used to

FIGURE 5



Use of the Hohmann retractor. The retractor is placed caudal to the tibial plateau and used to lever the tibia cranial so that the caudal pole of the medial meniscus (arrow) can be adequately evaluated.

evaluate the meniscus in veterinary patients.^{42,48–53} MRI is frequently used for preoperative evaluation in human medicine, but it is rarely used in veterinary medicine because of expense, limited availability, and the need for extended periods of general anesthesia. CT is likely less effective than MRI because the latter provides better soft-tissue detail. However, use of contrast CT arthrography has recently been demonstrated to be fairly sensitive for detecting surgically created folded caudal pole injuries.⁵³ Ultrasonography may also be a feasible noninvasive alternative. Early studies report difficulty in evaluating the meniscus, whereas more recent studies report 82% to 90% sensitivity and 93% specificity of ultrasonography compared with arthroscopy and arthrotomy.^{42,48,52,54} User skill and expertise, coupled with advances in the quality of ultrasound equipment, may explain the improved sensitivity.

During initial surgery to stabilize a CrCL-deficient stifle, we advise full evaluation of the joint to confirm a diagnosis of a ruptured CrCL and evaluate the menisci. Use of arthroscopy by a skilled arthroscopist is ideal for evaluation, but arthrotomy is the current standard of care. Alternative diagnostic modalities, such as ultrasonography, CT, and MRI, are best reserved for cases in which lameness persists or recurs weeks to months after surgery has been performed to stabilize a CrCL-deficient stifle. In such cases, use of a noninvasive or minimally invasive method is preferable to determine whether meniscal pathology is the cause of persistent lameness before arthrotomy and joint exploration.

Compared with arthroscopy, low-field MRI has low sensitivity for detecting meniscal pathology and high-field MRI is costly and relatively inaccessible; therefore, we do not consider MRI a routine method of diagnosing meniscal pathol-

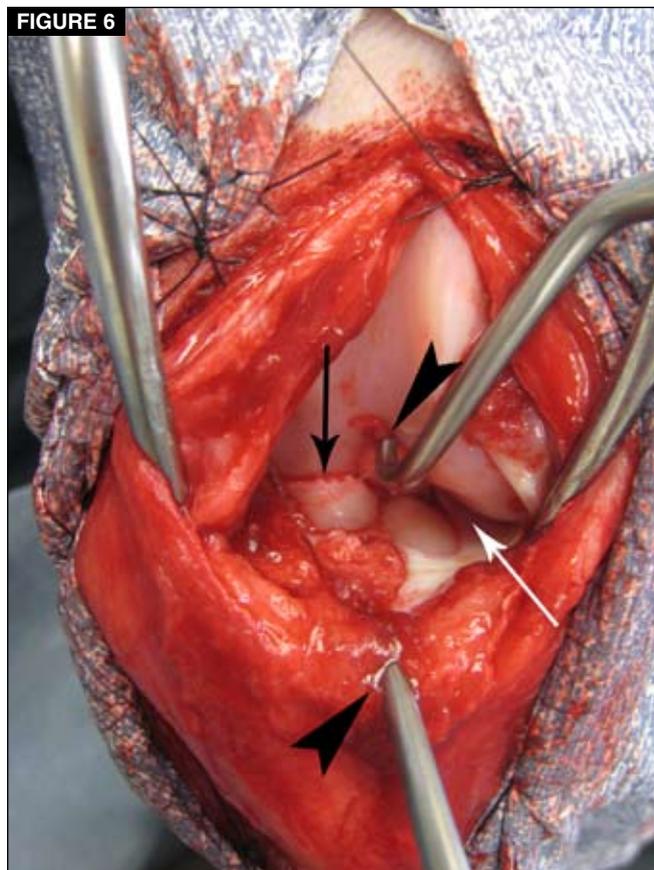
ogy.⁵⁵ CT arthrography may be a more available alternative, but it has only been shown to detect folded caudal pole injuries; its ability to reveal other pathology remains unknown. Similarly, ultrasonography can allow visualization of a folded caudal pole and complex transverse tears, but its ability to identify more subtle pathology is uncertain.

Arthroscopy has sensitivity equal to or greater than that of ultrasonography and CT for diagnosing meniscal injuries, and it can be used therapeutically to debride remnants of the CrCL and repair or remove damaged menisci. Therefore, we believe arthroscopy is the best choice for practitioners investing in new equipment to assist evaluation and treatment of the menisci. The limitations of arthroscopy are primarily the availability of the equipment and the time required to develop adequate dexterity.

Treatment

Because the abaxial 25% of the meniscus is vascular, tears in this portion of the meniscus or peripheral detachments of the meniscus from the joint capsule have the potential to heal and can be repaired. In a recent *ex vivo* study, repair of bucket handle tears in the abaxial 25% of the meniscus restored normal contact mechanics while partial meniscectomy of the bucket handle tear significantly decreased the contact area between the tibia and femur and significantly increased peak contact pressure compared with unaffected controls.⁵⁶ Prior *in vivo* experimental studies have demonstrated the feasibility of such repairs, and good results of primary repair of abaxial longitudinal tears or peripheral detachment have been described in 92 clinical cases.⁵⁷⁻⁵⁹ Despite these promising results and the potential long-term benefits of retaining an intact functional meniscus, primary repairs are rarely performed in dogs because few tears are perceived as repairable.⁵⁹ However, the benefits of preserving meniscal function may warrant attempted repair in appropriately selected cases.

The current standard of care for treatment of meniscal tears in any part of the canine medial meniscus, regardless of vascularity, is either partial meniscectomy or hemimeniscectomy to remove the damaged tissue (FIGURE 3). However, meniscectomy precipitates the onset of OA, as evidenced in controlled experimental studies in dogs with no other pathology.⁶⁰ Complete meniscectomy precipitates more severe OA than partial meniscectomy.⁶⁰ Likewise, the severity of OA has been shown to correlate directly with the amount of meniscal tissue removed at surgery.⁶¹ Degenerative changes are similar regardless of whether hemimeniscectomy or complete meniscectomy is performed, and mechanical testing has demonstrated that peak contact pressures increase so dramatically with large partial meniscectomy and hemimeniscectomy that these procedures may completely eliminate meniscal load bearing.⁶²⁻⁶⁴ Therefore, current recommendations are to perform partial meniscectomy and to minimize



Courtesy of E. Steinberg, DVM, University of Pennsylvania

FIGURE 6
Use of the Wallace stifle retractor. The retractor is engaged just cranial to the origin of the caudal cruciate ligament and the insertion of the CrCL (arrowheads), taking care not to impinge the ligaments or impale the articular cartilage. Note the folded caudal pole injury of the medial meniscus (black arrow) and the caudal pole of the lateral meniscus lifting proximally due to its attachment to the femur (white arrow).

the amount of meniscus removed at the time of surgery. A caudal pole hemimeniscectomy remains the treatment of choice when the caudal pole is severely crushed, fibrillated, or macerated.

Considering the known negative ramifications of removing meniscal tissue, an important question is whether partial meniscectomy is more detrimental than leaving a damaged meniscus that is not interfering with joint mechanics *in situ*. A recent *ex vivo* study showed that peak contact pressures in the stifle were significantly increased with bucket handle tears and macerated caudal pole injuries compared with intact controls. The authors concluded that the damaged meniscal tissue did not contribute to load distribution and that partial meniscectomy in such case is warranted.⁶⁵ Conversely, an *in vivo* study compared menisci that were incised in the vascular region 2 to 3 mm from the joint capsule and left *in situ* with menisci subjected to a corresponding partial meniscectomy.⁶⁶ The investigators failed to find a difference in the degree of OA progression between these two experimental groups, suggesting that leaving a tear in

Clinical Pearls

- When performing an arthrotomy to assess the caudal pole of the medial meniscus, use either a Hohmann retractor or Wallace stifle retractor to maximize visualization.
- Always probe the superior and inferior surfaces of the medial meniscus using an angled probe such as a nerve root retractor.
- When performing a partial meniscectomy or hemimiscectomy, grasp the damaged portion of tissue with a small hemostat or meniscus forceps, or pass a stay suture to serve as a handle and enable manipulation of the damaged tissue to facilitate its removal.
- Be particularly careful not to damage the articular cartilage or the medial collateral ligament when excising damaged meniscal tissue.

the vascular region in situ is no worse than performing a partial meniscectomy. Further, another study found that OA progression with complete meniscectomy was significantly greater than that with surgically created meniscal tears that did not interfere with joint motion.⁶⁷ It is tempting to conclude that leaving a meniscal tear in place may be preferable to meniscectomy. However, it would be improper to draw such a conclusion from these *in vivo* studies because the menisci in the first study were surgically incised close to the periphery in the vascular region and the CrCL was intact, minimizing the likelihood of the tear propagating to become a bucket handle tear and maximizing the likelihood of the tear healing. Furthermore, the second study involved complete meniscectomy, which is no longer recommended, so corresponding conclusions cannot be drawn about the efficacy of partial meniscectomy.

In the absence of controlled *in vivo* studies comparing outcomes associated with leaving irreparable tears in situ versus performing partial meniscectomy, partial meniscectomy or hemimiscectomy remains the standard of care in dogs, based largely on clinical retrospective reports. Most recently, Case et al⁵ described 26 dogs (29 stifles) that were evaluated for acute onset of lameness weeks to years after stifle stabilization surgery and in which no meniscal pathology was identified at the initial surgery. In all cases, meniscal pathology was identified with second-look arthroscopy or arthrotomy, and partial meniscectomy was performed without augmentation of the previous surgery. Lameness improved or resolved in 97% of cases. Similarly, five dogs that became increasingly lame after stabilization of a CrCL-deficient stifle had resolution of lameness after a second surgery was performed to remove a torn meniscus without

augmentation of the prior stifle stabilization.²² An additional report by the same author⁸ describes 21 stifles in 19 dogs with static or worsening lameness after stifle stabilization that required a second arthrotomy to perform meniscectomy, with 14 stifles presumed to have had a meniscal tear missed at the initial surgery and seven presumed to have sustained bucket handle tears after the first surgery. All 19 dogs improved clinically after meniscectomy. Metelman et al⁴ described 48 cases that had static or worsening lameness after stifle stabilization with no meniscal pathology identified during the first procedure. Subsequent arthrotomy was performed, meniscal pathology identified, and partial meniscectomy and augmentation of the initial stifle stabilization performed. Lameness resolved in 88% of patients. Accordingly, adequate evaluation of the meniscus and removal of damaged tissue at the time of stifle stabilization is presumed imperative to maximizing clinical outcome.

Meniscal Tears After Stifle Stabilization

Meniscal tears occur in up to 50% of dogs after stifle stabilization.^{4,25,28,43,68,69} The rate of poststabilization tears varies with the diagnostic modality used to identify tears during the initial operation. It may also depend on the stabilization procedure used and on whether meniscal release was performed at the initial procedure. Thieman et al⁶⁹ found that meniscal tears were more common after TPLO stabilization when arthrotomy was performed without meniscal release compared with combined arthrotomy and meniscal release or arthroscopy without meniscal release. They hypothesized that joint exploration via arthrotomy may have a higher rate of postsurgical meniscal tears versus arthroscopy because some tears are missed during arthrotomy, a problem that has been noted elsewhere.⁸

Rates of postsurgical meniscal tears may vary depending on the technique used to stabilize the stifle, as fewer tears were identified when a fibular head transposition (FHT) was performed than when either retinacular imbrication or a 4-in-1 technique was used.⁴ This finding contradicts another study that reported a 50% rate of meniscal tears in eight dogs evaluated 10 months after FHT.⁶⁸ Initial reports of surgical complications with TPLO and tibial tuberosity advancement (TTA) specify rates of poststabilization meniscal tears up to 20%, depending on how the at-risk population is defined.^{25,28,69} To date, no published studies have directly compared the rate of meniscal tears after proximal tibial osteotomy (e.g., TPLO, TTA) with lateral suture or FHT techniques. However, a recent study⁷⁰ found a poststabilization tear rate of 8% to 9% for both TPLO and a new static stifle stabilization technique (TightRope CCL) in a prospective comparison. These results suggest that the two techniques are equally efficacious in preventing poststabilization meniscal tears.⁷⁰

Given the negative consequences associated with stifle reexploration and meniscectomy, Slocum and Slocum^{43,44} rec-

ommend either axial or abaxial release of the intact medial meniscus at the time of TPLO to minimize the likelihood of poststabilization tears (**FIGURE 3**). These methods have been modified by others to include performing an abaxial release blindly or with arthroscopic guidance and arthroscopic axial release.^{28,71} Meniscal release techniques have also been used in conjunction with TTA and lateral fabellotibial suture techniques.^{1,28} We are not aware of reports of meniscal release being performed in combination with FHT or intracapsular repairs. Abaxial meniscal release involves severing the midbody of the medial meniscus just caudal to the medial collateral ligament while angling the blade 30° cranio-laterally toward the tubercle of Gerdi. Alternatively, axial release involves severing the caudal meniscotibial ligament of the medial meniscus by cutting straight down along the medial wall of the intracondylar fossa of the femur.

All meniscal release techniques are intended to allow caudal and lateral displacement of the caudal pole so that it is spared crushing by the femoral condyle. Two studies have effectively demonstrated considerable caudolateral displacement of the caudal pole and minimization of meniscofemoral entrapment with both axial and abaxial release.^{20,41} Lateralization was greater with axial release because abaxial release left a remnant of the caudal pole centered under the femur.⁴¹ Rates of successful abaxial release varied (though not significantly) from 56% to 88%, depending on whether the release was done blindly, through a miniarthrotomy approach, or with arthroscopic guidance. The time required for release was significantly longer when arthroscopic guidance was used compared with the blind and miniarthrotomy approaches, but the CrCL was intact in the cadavers used, making arthroscopic visualization of the caudal compartment more difficult.⁷¹

Evidence supporting the benefits of and need for meniscal release is ambiguous. Slocum and Slocum⁴⁴ reported no meniscal tears after combined TPLO and medial meniscal release in 212 stifles evaluated over a 4-year period. Lafaver et al²⁸ identified poststabilization meniscal tears in 10 of their first 46 dogs (21%) treated using TTA without concurrent meniscectomy or meniscal release. When they began performing meniscal release, they identified no post-TTA meniscal tears in the subsequent 22 dogs. In addition, Kennedy et al⁴¹ identified compression of the caudal pole of the medial meniscus between the femoral condyle and tibia with CrCL deficiency that was mitigated by TPLO but was still abnormal compared with a normal stifle. As a result, they speculated that the meniscus could still be at risk for crush injury after TPLO and that release may be indicated.

Contrary to the above studies, Thieman et al⁶⁹ retrospectively compared rates of post-TPLO meniscal tears when the meniscus was and was not released. About 3% of stifles (3 of 90) that were explored arthroscopically and in which no release was performed had poststabilization tears versus

Key Facts

- Medial meniscal injuries frequently occur in conjunction with rupture of the cranial cruciate ligament (CrCL) and can inhibit resolution of lameness after stabilization of a CrCL-deficient stifle.
- Several methods can be used to evaluate the meniscus. Arthroscopy offers maximum sensitivity for detecting meniscal pathology and the ability to treat the damaged meniscus.
- The current standard of care is to remove the damaged meniscal tissue at surgery (partial meniscectomy or hemimiscectomy) while preserving as much normal meniscal tissue as possible.
- Primary repair of damaged menisci is possible in select cases and can maximize stifle function.
- Meniscal release for grossly intact menisci is a controversial topic. A growing body of evidence documents negative consequences of release. There are few reports of release being performed with static stifle stabilization methods such as intracapsular reconstruction, lateral suture imbrication, or fibular head transposition.

5% (4 of 86) of stifles explored via arthrotomy with meniscal release; this difference was not significant. Similarly, a retrospective comparison⁷² of 764 TPLOs, 334 with release and 430 without, failed to find a significant difference between the two groups with respect to poststabilization tears. Another abstract⁷³ details 295 cases of TPLO without meniscal release or meniscectomy, with only six stifles (2%) having a meniscal tear identified up to 12 months after surgery, two of which were presumed to have been missed at the original surgery. Furthermore, an *in vitro* study failed to find that the meniscus contributed at all to cranial-caudal stifle stability after TPLO at a set degree of stifle flexion, suggesting that the meniscus was not wedged against the femur and therefore was not at risk for damage after TPLO.²⁰ However, extrapolation of the results from this experiment to a live dog is questionable.

Numerous complications have been demonstrated with meniscal release. Severing of the CrCL followed by abaxial meniscal release and hemimiscectomy demonstrated that cranial tibial thrust did not increase after hemimiscectomy, suggesting that meniscal release creates just as much joint instability as does hemimiscectomy.²⁰ Moreover, both axial and abaxial release significantly increased the intrameniscal area (i.e., the space encircled by the meniscus between the poles) compared with an intact meniscus. In turn, this corresponded to increased femorotibial contact with articular

cartilage and a greater area of articular cartilage sustaining high pressures from femorotibial contact.^{41,74-76} Furthermore, radiographic evidence of OA progresses more rapidly when an abaxial meniscal release is performed with TPLO than when release is omitted, and radiographic signs of progression are worse with axial release versus abaxial release.^{45,77} Most notably, a recent study⁷⁸ described an experimental study in which dogs with an intact CrCL underwent meniscal release and subsequently developed clinically significant OA and lameness compared with sham-operated controls. Less serious complications of release have included breaking of a #11 blade inside the joint, damage to the tibial articular cartilage and the caudal cruciate ligament, and partial severing of the medial collateral ligament.^{41,71}

Given the negative effects on clinical outcome in dogs with poststabilization meniscal tears, the arguable efficacy of release in mitigating these tears, and the negative consequences associated with meniscal release, there remains a difference of opinion on whether release is indicated for an intact medial meniscus. Our opinion is that meniscal release should not be performed in conjunction with static stifle stabilization procedures (e.g., lateral suture imbrication, FHT, TightRope CCL, intracapsular techniques). In addition, meniscal release seems to result in loss of meniscal function when used in conjunction with proximal tibial osteotomy (e.g., TPLO, TTA). However, we differ as to whether this loss is outweighed by the potential benefit of avoiding poststabilization tears when release is used in conjunction with these procedures. These procedures rely on dynamic constraint from properly timed contraction of healthy surrounding muscle groups. Atrophy of these muscles and disruption of their normal electromyographic activity after CrCL rupture have been clearly established.⁷⁹ As a result, the medial meniscus is at risk for tearing secondary to cranial tibial subluxation in dogs with poor muscle tone and marked instability resulting from acute, complete CrCL rupture. Thus, a meniscal release may be indicated in such instances.

An alternative view is that poststabilization tears are sufficiently rare that more dogs would benefit from leaving the meniscus intact at the initial surgery, preserving meniscal function in dogs that never develop a tear, and that a second surgery to perform partial meniscectomy for a poststabilization tear is still preferable to meniscal release. When the circumferential fibers are severed by a meniscal release, the meniscus can no longer generate hoop stress and thus cannot contribute to load distribution and joint stability. Partial meniscectomy preserves some circumferential fibers that may generate hoop stress and contribute to load distribution.⁸⁰

Future Directions

In an attempt to restore functionality and mitigate the onset of OA, repairable tears in the vascular portion of the human

meniscus are typically treated by apposing the edges of the tears with suture, tacks, staples, or screws.⁸¹ Many of these devices enable an “all inside” repair and obviate the need for passing suture or other materials through the caudal joint capsule. Primary repair using these devices could be used for tears in the vascular portion of the meniscus in dogs, just as the inside-out technique is used. These techniques may also be an option for detachment of the meniscus from the adjacent joint capsule, but they have not been investigated specifically for such use.

Because few meniscal defects in dogs and humans are conducive to primary repair with apposition of torn edges, numerous alternative treatment options have been investigated to augment the regenerative capacity of the meniscus. Placement of synovial pedicle flaps or fibrin clots and creation of vascular access channels have been attempted with limited success.⁸²⁻⁸⁴ More recent investigations have evaluated tissue-engineered implantable materials, either biologic substances or synthetic polymers, that can act as scaffolds for tissue ingrowth and be seeded with cells.⁸⁵ Porcine small intestinal submucosa (SIS) incites regeneration of tissue in surgically created large posterior pole defects in dogs that is more similar histologically and functionally to native meniscus than regenerative tissue present after partial meniscectomy alone.⁸⁶ Similarly, a collagen meniscal implant (CMI; ReGen Biologics, Redwood City, CA) has improved meniscal regeneration and is now approved for use in humans.⁸⁷

Although recent work with implantable biomaterials and scaffolds such as SIS and CMI shows promise, these materials require contact with an intact, vascular peripheral meniscal rim. Tears in the avascular portion of the meniscus, termed the *white/white region*, remain problematic. Efforts to induce ingrowth of blood vessels by creating vascular access channels from the periphery of the meniscus may fail due to premature mechanical collapse of the channel before healing is complete, thus severing the blood supply. A bioabsorbable conduit has been created to maintain the patency of these channels for a longer period of time. Insertion of these conduits has significantly increased the regenerative capacity of the avascular portion of the meniscus in dogs.⁸⁸

Finally, for humans in whom the entire meniscus has been damaged or removed, meniscal allografts have been used clinically for 20 years. Meniscal allografting has now been performed in a dog.^{89,90} However, experience in human medicine indicates there is considerable difficulty associated with graft harvesting, preparation, and sizing; a risk of disease transmission; and debatable efficacy. Therefore, current research is focused on growing meniscal autografts in vitro or producing a synthetic allograft. Future treatments for dogs may include allogeneic grafting, either with natural or synthetic grafts (pending demonstrated efficacy) or use of commercially available implants (such as biodegradable

polymers, SIS, or CMI) given their already proven efficacy in experimental canine models.

Conclusion

The canine menisci are important intraarticular structures that play a vital role in maintaining joint congruency, stability, lubrication, proprioception, and load distribution. The medial meniscus is commonly injured in conjunction with CrCL rupture. Identifying meniscal damage and treating it appropriately is crucial to maximizing recovery and return to function. Studies demonstrate the advantages of newer diagnostic modalities such as arthroscopy and ultrasonography for recognizing and treating meniscal pathology. The current standard of care for meniscal tears in dogs is to remove the affected tissue while preserving as much of the meniscus as possible to retain some meniscal function. Medial meniscal release at the time of stifle stabilization is a controversial topic because its ability to reduce the likelihood of postsurgical meniscal tears is uncertain and because it reduces meniscal function and hastens progression of OA. New treatment modalities for regenerating or repairing damaged menisci have been developed and tested in dogs and humans and illuminate treatment options that could be employed in the future by surgeons seeking to provide optimal patient care.

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3 CE
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1. **In a healthy stifle, the menisci**
 - a. distribute compressive load radially through their ligamentous attachments, generating hoop stress.
 - b. contribute to the cranial–caudal, varus–valgus, and rotational stability of the stifle.
 - c. assist in proprioception and coordination of muscle tone to stabilize the stifle.
 - d. all of the above
2. **After CrCL rupture, which portion of which meniscus is more frequently damaged and a source of clinical lameness?**
 - a. cranial pole, medial meniscus
 - b. caudal pole, medial meniscus
 - c. abaxial edge, lateral meniscus
 - d. caudal pole, lateral meniscus
3. **Which mechanism(s) lead to meniscal damage in dogs with CrCL deficiency?**
 - a. repeated compression during tibial internal rotation
 - b. repeated compression during external rotation
 - c. cyclic crushing during episodes of femorotibial subluxation
 - d. a and c
4. **Which of the following are considered meniscal tears?**
 - a. radial tears
 - b. peripheral tearing from the joint capsule
 - c. fibrillation and maceration of the caudal pole
 - d. all of the above
5. **If a meniscal click is not identified on physical examination, the meniscus**
 - a. is probably not injured.
 - b. does not need to be further evaluated before stifle stabilization.
 - c. may still be damaged.
 - d. is adequately stabilizing the joint.
6. **Which modalities can be used to assist evaluation of the meniscus?**
 - a. arthroscopy and arthrotomy only
 - b. MRI, arthroscopy, and arthrotomy
 - c. arthroscopy, ultrasonography, and arthrotomy
 - d. MRI, CT arthrography, ultrasonography, arthroscopy, and arthrotomy
7. **What technique should be used in conjunction with either arthrotomy or arthroscopy to assist in evaluation of the menisci?**
 - a. probing the meniscus with an angled probe
 - b. incising the meniscus to assess vascularity
 - c. meniscal release
 - d. debridement of the caudal cruciate ligament
8. **What portion of the meniscus is vascular and has regenerative capacity?**
 - a. the axial (inner) 50%
 - b. the abaxial (outer) 25%
 - c. the axial 25%
 - d. the axial 33%
9. **If a longitudinal tear is identified in any part of the medial meniscus, the current standard of care is**
 - a. complete meniscectomy.
 - b. partial meniscectomy.
 - c. primary repair.
 - d. to leave the tear in situ to heal on its own.
10. **Which procedure(s) decrease(s) the load-bearing function of normal menisci in vitro?**
 - a. hemimenisectomy
 - b. complete meniscectomy
 - c. meniscal release
 - d. all of the above