Cranial cruciate ligament disease is one of the most common stifle joint disorders diagnosed in dogs.¹ The CrCL functions to limit cranial translation of the tibia in relation to the femur, internal rotation of the tibia, and hyperextension of the stifle joint.² Therefore, rupture of this ligament results in stifle joint instability and secondary pathological changes, including inflammation, synovitis, osteoarthritis, and meniscal injury.³ Several surgical techniques exist to stabilize CrCL-deficient stifle joints and minimize progression of secondary changes. Regardless of the technique used, the goal is to stabilize the stifle joint while the affected dog is weight bearing and neutralize the tibiofemoral shear forces, also referred to as cranial tibial thrust. Tibial plateau leveling osteotomy and TTA are 2 of the more commonly performed procedures for CrCL rupture in medium- to large-breed dogs.²,₄,a,b

The TPLO technique involves radial osteotomy of the proximal aspect of the tibia, followed by rotation of the proximal segment to reduce the TPA.² Reported complications of TPLO include tibial tuberosity fracture or avulsion, fracture of the proximal aspect of the fibula, hemorrhage secondary to laceration of the popliteal vessels, implant loosening or failure, patellar luxation, intraarticular placement of proximal

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**OBJECTIVE**
To radiographically evaluate and compare changes in the patellar ligament of dogs following tibial plateau leveling osteotomy (TPLO) and tibial tuberosity advancement (TTA).

**DESIGN**
Retrospective case series.

**ANIMALS**
106 dogs that underwent TPLO (n = 59) or TTA (n = 47) for unilateral rupture of the cranial cruciate ligament at a private veterinary hospital from August 2009 through September 2012.

**PROCEDURES**
Medical records were reviewed to collect information on dog signalment, surgical procedure, whether arthrotomy had been performed, pre- and postoperative measurements of patellar ligament angle (PLA) and tibial plateau angle (TPA), and preoperative and follow-up measurements of patellar ligament thickness.

**RESULTS**
For dogs that underwent TTA, thickening of the distal portion of the patellar ligament was identified radiographically in 43 (92%) dogs at the first follow-up examination and 36 (77%) at the second follow-up examination. For dogs that underwent TPLO, these numbers were 57 (97%) and 54 (92%), respectively. A significant decrease in patellar ligament thickness was identified between the first and second follow-up examinations for TTA but not TPLO. Mean ± SD PLA following TTA was 89.46 ± 5.54°, representing a mean difference from the preoperative PLA of 11.86 ± 5.3°; following TPLO, mean TPA was 12.61 ± 4.03°, representing a mean difference from the preoperative TPA of 16.74 ± 7.13°.

**CONCLUSIONS AND CLINICAL RELEVANCE**
Patellar ligament thickening occurred following TPLO and TTA in dogs. The clinical relevance of this thickening remains unknown. (J Am Vet Med Assoc 2017;250:68–74)
screws, pivot shift, tibial plateau collapse, articular or periarticular infection, patellar ligament thickening, and patellar ligament rupture.5-10

The TTA technique involves dorsal plane osteotomy of the tibial crest to modify the position of the patellar ligament so that the ligament is aligned perpendicular to the tibial plateau.5,6,11-13 Reported complications of this procedure include infection, implant failure, tibial tuberosity fracture, tibial diaphyseal fracture, medial patellar luxation, meniscal injury, caudal cruciate ligament injury as a result of excessive advancement, and patellar ligament thickening.5,5,9

Patellar ligament thickening has been identified both radiographically and ultrasonographically in dogs following TPLO and, more recently, TTA.7,11-13 The patellar ligament thickening that follows TPLO is proposed to be a result of the stress placed on the patellar ligament when the tibial plateau is rotated.12 In a review article,12 this theory is illustrated by means of a lever arm.

The lever arm is the distance from the femorotibial contact point to the attachment of the patellar ligament on the tibial tuberosity. Although not statistically evaluated, the lever arm is presumed to be able to shorten by as much as 10% following TPLO and lengthen by as much as 10% following TTA. A shorter lever arm requires more force, or quadriceps muscle pull, to extend the stifle joint, and a longer lever arm requires less force to extend the stifle joint. Hence, on the basis of this notion, it was initially suspected that the TTA procedure would not result in patellar ligament thickening. However, patellar desmopathy was recently identified as a common postoperative sequela to TTA.11,13

Ultrasonography of the patellar ligament following TPLO reveals hypoechoic to anechoic central lesions and loss of the typical longitudinal fiber pattern.9 Additional ultrasonographic studies are needed to determine whether structural changes to the patellar ligament following TTA are similar. To the authors’ knowledge, no studies have been reported in which the similarities in patellar ligament thickening were evaluated between TPLO and TTA. Following TPLO, patellar ligament thickening can lead to desmitis, discomfort, and lameness. If there is less patellar ligament thickening and structural damage following TTA, then perhaps the short-term outcome of that procedure would be better and the risk of complications associated with desmitis lower than with TPLO.

The purpose of the study reported here was to radiographically evaluate and compare changes in the patellar ligament following TPLO and TTA in dogs with unilateral CrCL rupture. Our hypothesis was that there would be a difference between procedures in the degree of patellar ligament thickening, with a greater degree of thickening following TPLO.

Materials and Methods

Case selection
Medical records of Affiliated Veterinary Specialists-Maitland were reviewed to identify dogs that had complete rupture of the CrCL and TPLO or TTA performed by a board-certified surgeon from August 2009 through September 2012. Surgical procedure had been chosen on the basis of 1 or more of the following characteristics: preoperative TPA, stifle joint anatomic characteristics (ie, genu varum and prominence of the tibial crest), and surgeon preference. The TTA and TPLO procedures were performed as described elsewhere.2,4,14 When the TPA of the affected hind limb was ≥ 32°, the dog was deemed to have genu varum or to have lacked a prominent tibial crest, then TPLO was performed.

To be included in the study, dogs were required to have had a diagnosis of CrCL rupture in 1 hind limb only, no other suspected or diagnosed concurrent orthopedic problems (eg, contralateral CrCL rupture, patella luxation, or hip dysplasia), no previous CrCL repair, and no intra- or postoperative complications associated with TPLO or TTA. Complete sets of radiographs were also required to have been obtained, including images obtained before surgery and at 2 follow-up evaluations (approx 3 and 6 weeks after TPLO or approx 4 and 8 weeks after TTA).

Medical records review
Data extracted from the medical records of each dog included signalment at the time of surgery (breed, age, sex, and body weight), surgical procedure (TTA or TPLO), approach for stifle joint exploration (parapatellar approach, caudal arthrotomy, or no arthrotomy), pre- and postoperative PLA or TPA data, and preoperative and follow-up measurements of patellar thickness.

Mediolateral and caudocranial digital radiographic views of the affected stifle joint were also obtained for each of the 4 predefined assessment points. All pre- and postoperative digital radiographic examinations had been performed with dogs anesthetized, whereas all follow-up radiographic examinations were performed with dogs sedated. Mediolateral radiographic views of the stifle joint had been obtained with the stifle joint in 135° of flexion for dogs that underwent TTA and 90° of flexion for dogs that underwent TPLO. To account for digital magnification, the same radiographic ball marker had been included at the level of the stifle joint in all images.

The PLA was measured digitally on the mediolateral TTA radiographic views by use of the conventional method. All measurements were performed by the primary author (DMD) at the time of the study. The cranial and caudal landmarks of the medial tibial condyle were identified on the images, and a line was drawn connecting these 2 landmarks. This line, defined as the tibial plateau slope, was extended to the patellar ligament. A second line was drawn from the cranial margin of the patella to the tibial tuberosity. The angle of intersection of these 2 lines was digitally measured and recorded as the PLA. For measurement of the TPA on the mediolateral TPLO radiographic views, a line was drawn connecting the cranial and
caudal landmarks of the medial tibial condyle. A second line, referred to as the tibial long axis, was drawn starting at a point dividing the intercondylar tubercles of the tibia and the center of rotation of the talus. The angle at which these 2 lines intersected was digitally measured and recorded as the TPA.

Patellar ligament length was measured on the mediolateral radiographic views by the primary author at the time of the study. The length of the ligament extended from its point of origin on the distal aspect of the patella to its insertion on the proximal aspect of the tibial tuberosity.

Digital radiographs were reviewed by the primary author, who was not blinded to the procedure performed. The mediolateral views were used for evaluation of the patellar ligament at each assessment point (Figures 1 and 2). When deemed necessary, the contrast level was adjusted digitally to improve visibility of the borders of the patellar ligament. Sites for thickness measurements of the proximal and distal portions of the patellar ligament were determined as described elsewhere. Thickness of the proximal portion was measured 1 cm distal to the caudal origin of the patellar ligament on the distal aspect of the patella. Thickness of the distal portion was measured 1 cm proximal to its caudal insertion at the proximal aspect of the tibial crest. Three consecutive digital measurements, to account for intraobserver measurement variability, were obtained for both the proximal and distal portions of the patellar ligament with the aid of imaging software. The mean of each set of measurements was calculated and used for statistical analysis.

**Statistical analysis**

All statistical analyses were performed by use of statistical software. Repeated-measures ANCOVA was used to test for differences in mean patellar ligament thickness between the 2 surgical procedures at the first and second follow-up examinations. Two ANCOVA models were created: one in which thickness of the proximal portion of the patellar ligament was used as the response variable and another in which thickness of the distal portion was used instead. For each model, preoperative ligament thickness was used as a covariate, and assessment point (first or second follow-up examination) was used as the within-subject factor. Procedure (TTA or TPLO) was used as the between-subjects factor. Age, body weight, and sex were also considered as possible covariates; however, none of these variables met the threshold for significance ($P < 0.05$) and so they were excluded from the models. A between-subjects factor was also included to control for dogs that had a parapatellar approach versus those that did not.

For descriptive purposes, the differences in mean ligament thickness among assessment points were calculated separately for both surgical procedures. The ANCOVA method was used to test for correlations between change in PLA or TPA and change in ligament thickness for each procedure. The changes were all calculated as postoperative vs preoperative values because no data were available for PLA or TPA at the first follow-up examination.

**Results**

**Animals**

Of the dogs undergoing surgery for CrCL rupture during the study period, 106 dogs met the inclusion criteria. Forty seven (44%) of the included dogs underwent TTA, and 59 (56%) underwent TPLO.

Of dogs that underwent TTA, 28 (60%) were spayed females and 19 (40%) were neutered males. Mean ± SD age of dogs in this group at the time of surgery was 5.6 ± 2.6 years (range, 1 to 12 years), and mean body weight was 33.0 ± 7.8 kg (72.6 ± 17.2 lb; range, 12.0 to 48.6 kg.
Breeds included Labrador Retriever (n = 10 [21%]), German Shepherd Dog (3 [6%]), Golden Retriever (2 [4%]), Boxer (2 [4%]), Doberman Pincher (2 [4%]), American Pitbull Terrier (2 [4%]), Cocker Spaniel (2 [4%]), and 7 other breeds represented by 1 (2%) dog each; 17 (36%) dogs were mixed breeds. Rupture of the left CrCL was diagnosed in 21 (45%) dogs, and rupture of the right CrCL was diagnosed in 26 (55%) dogs. Caudal arthrotomy was performed in 28 (60%) dogs, parapatellar arthrotomy in 14 (30%) dogs, and no arthrotomy in 2 (4%) dogs; arthrotomy was not documented for 3 (6%) dogs. All arthrotomies involved closure with polydioxanone suture (suture size based on dog size) in a simple continuous pattern.

Of dogs that underwent TPLO, 33 (56%) were spayed females, 24 (41%) were neutered males, 1 (2%) was a sexually intact female, and 1 (2%) was a sexually intact male. Mean ± SD age of dogs in this group at the time of surgery was 4.4 ± 2.3 years (range, 1 to 9 years), and mean body weight was 33.1 ± 10.9 kg (72.8 ± 24.0 lb; range, 7.3 to 66.8 kg [16.1 to 147.0 lb]). Breeds included Labrador Retriever (8 [14%]), Golden Retriever (6 [10%]), Boxer (5 [8%]), Doberman Pinscher (2 [3%]), and 16 other breeds represented by 1 (2%) dog each; 22 (37%) dogs were mixed breeds. Rupture of the left CrCL was diagnosed in 36 (61%) dogs, and rupture of the right CrCL was diagnosed in 23 (39%) dogs. Caudal arthrotomy was performed in 43 (73%) dogs, parapatellar arthrotomy in 13 (22%) dogs, and no arthrotomy in 1 (2%) dog; arthrotomy was not documented for 2 (3%) dogs.

Dogs that underwent TPLO received a first follow-up examination 23 to 41 days after the procedure (mean, 29 days; median, 28 days) and a second follow-up examination 48 to 76 days after the procedure (mean, 59 days; median, 58 days). For dogs that underwent TTA, the first follow-up examination was 23 to 68 days after the procedure (mean, 41 days; median, 42 days) and the second follow-up examination was 48 to 76 days after the procedure (mean, 59 days; median, 58 days). For dogs that underwent TTA, the first follow-up examination was 23 to 68 days after the procedure (mean, 41 days; median, 42 days) and the second follow-up examination was 60 to 130 days after the procedure (mean, 72 days; median, 70 days).

**Stifle joint measurements**

The mean ± SD preoperative PLA in dogs undergoing TTA was 101.31 ± 5.03° (range, 90.1° to 109.9°). Following surgery, the mean PLA for dogs in that group was 89.46 ± 5.54° (range, 71.2° to 102.9°), representing a mean change in PLA of 11.86 ± 5.39° (range, 2.4° to 25.8°). The mean preoperative TPA in dogs undergoing TPLO was 29.35 ± 6.33° (range, 16.0° to 50.0°). Following surgery, the mean TPA for dogs in that group was 12.61 ± 4.03° (range, 0.0° to 20.0°), representing a mean change in TPA of 16.74 ± 7.13° (range, 1.0° to 35.0°).

The ANCOVA models for estimated thickness of the distal and proximal portions of the patellar ligament revealed no significant (P = 0.23 and 0.19, respectively) main effect of procedure type but a significant (P = 0.03 and 0.009, respectively) interaction between procedure type and assessment point. For thickness of the distal portion, a significant decrease from the first to second follow-up examination was identified for TTA (95% CI, −0.99 to −0.20) but not for TPLO (95% CI, −0.34 to 0.40). For thickness of the proximal portion, a significant decrease from the first to second follow-up examination was also identified for TTA (95% CI, −0.50 to −0.10) but not for TPLO (95% CI, −0.11 to 0.25).

The amount of thickening in the distal portion of the patellar ligament was significantly (P = 0.01) negatively correlated (r = −0.5) with postoperative TPA for dogs in the TPLO group. However, for dogs in the TTA group, no significant correlation was identified between the amount of thickening of the distal portion of the patellar ligament and the amount of change between pre- and postoperative PLA measurements. The parapatellar approach to surgery was significantly (P = 0.03) associated with greater thickening of the proximal portion but not the distal portion of the patellar ligament.

Thickening of the distal portion of the patellar ligament was evident radiographically at first and second follow-up examinations in 43 (91%) and 36 (77%) dogs in the TTA group, respectively, and 57 (97%) and 54 (92%) of dogs in the TPLO group, respectively. Measurements were summarized by assessment point (Table 1; Figure 3). Mean differences in thickness, in both the proximal and distal portions of the patellar ligament, from before surgery to first and second follow-up examinations, were significant for both TPLO and TTA (Table 2).

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Preoperative</th>
<th>First follow-up</th>
<th>Second follow-up</th>
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<tbody>
<tr>
<td><strong>Proximal</strong></td>
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<td></td>
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<tr>
<td>TPLO</td>
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<td>3.49 ± 1.29</td>
<td>3.54 ± 1.62</td>
</tr>
<tr>
<td>TTA</td>
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<td>3.48 ± 0.74</td>
<td>3.20 ± 0.64</td>
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<tr>
<td><strong>Distal</strong></td>
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<tr>
<td>TPLO</td>
<td>2.57 ± 0.55</td>
<td>5.46 ± 2.54</td>
<td>5.48 ± 2.75</td>
</tr>
<tr>
<td>TTA</td>
<td>2.78 ± 0.49</td>
<td>5.33 ± 2.21</td>
<td>4.73 ± 2.14</td>
</tr>
</tbody>
</table>

Dogs that underwent TPLO received a first follow-up examination 23 to 41 days after the procedure (mean, 29 days; median, 28 days) and a second follow-up examination 48 to 76 days after the procedure (mean, 59 days; median, 58 days). For dogs that underwent TTA, the first follow-up examination was 23 to 68 days after the procedure (mean, 41 days; median, 42 days) and the second follow-up examination was 60 to 130 days after the procedure (mean, 72 days; median, 70 days).
Results of the present study indicated that, after controlling for other factors, a significant reduction occurred in thickness of the patellar ligament in the affected limb of dogs with CrCL rupture from first to second follow-up examination after TTA but not after TPLO. However, this finding may have been due to the differences in the timing of the follow-up examinations. For TTA, the median number of days from surgery until first follow-up examination was 42, and the median number of days from surgery until second follow-up examination was 70. For TPLO, these numbers were 28 days and 58 days, respectively. It may have been that the reduction in ligament thickness was greater between days 42 and 70 for either procedure than it was between days 28 and 58; however, no data were collected to assess this possibility. As expected, a significant increase was identified in thickness of the patellar ligament from the preoperative examination to first and second follow-up examinations for both TPLO and TTA.

Digital radiographs were used for measurements in the present study, allowing for additional magnification of images and thus improved accuracy of measurements. Measurements of patellar ligament thickness...
ness, however, were based on the evaluator’s radiographic interpretation of the ligament margins and therefore could have been subject to error. Furthermore, the surgical method of stifle joint exploration could have affected the ease with which patellar ligament margins could be distinguished. In the author’s experience, parapatellar arthrotomy and closure has the potential to result in tissue reaction in the region of the ligament that could be construed as thickening on the radiographs. A prospective study including ultrasonographic evaluation of the ligament is needed to better differentiate between penilignamentous tissues and the patellar ligament and allow for more accurate measurement of ligament thickness.

Although mediolateral radiographic views of the stifle joint were to be obtained in the present study with the joint in 135° of flexion for TTA and 90° degrees of flexion for TPLO, variation was noted in angles actually obtained. However, in another study involving dogs with CrCL rupture, no significant difference in patellar ligament thickness following TTA was identified when the stifle joint was positioned in flexion versus extension.

No correlation was identified between the amount of change in the PLA and degree of patellar ligament thickening in dogs in the present study. Nevertheless, reduction in the TPA was correlated with an increase in thickness of the distal portion of the patellar ligament for dogs in the TPLO group. This finding contradicted the lever-arm theory, by which a longer lever arm requires less force to extend the stifle joint and thus would not result in patellar ligament thickening. Overrotation of the proximal tibial segment following TPLO could influence the strain placed on the patellar ligament caused by translation of the tibia in relation to the femur; thus, overrotation may also influence the degree of patellar ligament thickening. However, comparison of preoperative and postoperative TPA measurements in the present study revealed a significant correlation between underrotation (< 7°) of the proximal tibial segment and an increase in the degree of patellar ligament thickening. Additional information obtained via biplanar fluoroscopic kinematography would be helpful to determine the degree of translation and thus instability and strain on the patellar ligament, both before and after surgery.

In the study reported here, the patellar ligament was measured 1 cm distal to its caudal origin on the proximal aspect of the tibial crest. Variation in patient size may alter these results. In future studies, measurements could be standardized for patient size by measuring the total length of the patellar ligament, from the apex of the patella to its attachment at the proximal aspect of the tibial crest, dividing that into 4 equal segments, and then measuring at the junction of each segment.

Owners of dogs included in the study reported here had been provided with written activity restrictions for their dog after hospital discharge. All activity restrictions were the same for each dog, regardless of procedure performed, but the duration of the activity restriction varied among dogs on the basis of the times required to heal and gradually return to their regular amount of activity. At the follow-up examinations, owners had reported that their dogs’ activity was being appropriately restricted at home. Although the degree of activity restriction likely varied from one dog to another, such variation might be expected in clinical settings. Activity in excess of that recommended or any trauma during the recovery period could have caused or exacerbated patellar ligament thickening. Owner completion of a questionnaire with specific questions regarding activity restriction would be appropriate for future prospective studies.

A weakness of the present study was that the effects of pre- and postoperative medications on patellar ligament thickening were not accounted for in the present study. It remains unknown whether administration of NSAIDs or other medications may have affected the results. Moreover, we did not assess the correlation between patellar ligament thickening and clinical performance after surgery. Following TPLO, patellar ligament thickening can lead to structural damage, desmitis, discomfort, and lameness. Because patellar ligament thickening was evident with TTA also, then perhaps TTA is no more clinically beneficial than TPLO.

Additional study limitations include its retrospective nature and the variability in the timing of follow-up evaluations both between TTA and TPLO procedures as well as among dogs undergoing each procedure. The recommended timing of radiographic recheck examinations at the authors’ hospital was derived from the hospital’s standard protocol, which was established on the basis of the documented healing time for the TPLO versus TTA osteotomy site. Despite the aforementioned limitations, the study reported here revealed important information about radiographic outcomes in dogs following TPLO and TTA. Ultrasonographic evaluation of the patellar ligament, biomechanical analyses following TTA versus TPLO, and correlation of patellar ligament thickening with clinical lameness should be considered in the design of future studies to help determine the clinical importance of patellar ligament thickening in dogs during recovery from TTA or TPLO procedures. Long-term radiographic follow-up could also be beneficial to determine the period required for resolution of patellar ligament thickening.

**Footnotes**


c. PACS4VETS, CoActiv Medical Business Solutions, Ridgefield, Conn.

d. R statistical software, Revolution Analytics, Palo Alto, Calif.
References

From this month’s AJVR

Effects of diurnal variation and anesthetic agents on intraocular pressure in Syrian hamsters (Mesocricetus auratus)
Seyed Mehdi Rajaei et al

OBJECTIVE
To determine effects of diurnal variation and anesthetic agents on intraocular pressure (IOP) in Syrian hamsters (Mesocricetus auratus).

ANIMALS
90 healthy adult Syrian hamsters (45 males and 45 females).

PROCEDURES
IOP was measured with a rebound tonometer. In phase 1, IOP was measured in all hamsters 3 times during a 24-hour period (7 AM, 3 PM, and 11 PM). In phase 2, hamsters were assigned to 5 groups (18 animals [9 males and 9 females]/group). Each group received an anesthetic agent or combination of anesthetic agents (ketamine hydrochloride, xylazine hydrochloride, diazepam, ketamine-diazepam [KD], or ketamine-xylazine [KX] groups) administered via the IP route. The IOP was measured before (time 0 [baseline]) and 10, 30, 60, 90, 120, and 150 minutes after administration of drugs.

RESULTS
Mean ± SD IOP values were 2.58 ± 0.87 mm Hg, 4.46 ± 1.58 mm Hg, and 5.96 ± 1.23 mm Hg at 7 AM, 3 PM, and 11 PM, respectively. Mean baseline IOP was 6.25 ± 0.28 mm Hg, 6.12 ± 0.23 mm Hg, 5.75 ± 0.64 mm Hg, 5.12 ± 1.40 mm Hg, and 4.50 ± 1.30 mm Hg for the ketamine, xylazine, diazepam, KD, and KX groups, respectively. A significant decrease in IOP, compared with baseline IOP, was detected in only the KX group at 30, 60, and 90 minutes after drug administration.

CONCLUSIONS AND CLINICAL RELEVANCE
Maximum IOP in Syrian hamsters was detected at night. The KX anesthetic combination significantly decreased IOP in Syrian hamsters. (Am J Vet Res 2017;78:85–89)