Received: 29 December 2018 | Revised: 28 March 2019 | Accepted: 7 June 2019
DOI: 10.1111/vsu.13277

ORIGINAL ARTICLE – CLINICAL

WILEY

Extended long-term radiographic and functional comparison of tibial plateau leveling osteotomy vs tibial tuberosity advancement for cranial cruciate ligament rupture in the dog

Elisabeth V. Moore DVM[1] | Robert Weeren DVM, MS, DACVS[1] | Matthew Paek VMD, MS, DACVR[2]

[1]Surgery Department, Chesapeake Veterinary Surgical Specialists, Towson, Maryland

[2]Radiology Department, Synergy Veterinary Imaging Partners, Columbia, Maryland

Correspondence
Elisabeth Moore, Chesapeake Veterinary Surgical Specialists, 808 Bestgate Rd, Annapolis, MD 21401.
Email: elisabeth@cvssvets.com

Abstract

Objective: To report extended long-term outcomes of dogs with cranial cruciate ligament rupture treated by tibial plateau leveling osteotomy (TPLO) or tibial tuberosity advancement (TTA).

Study design: Retrospective clinical cohort study.

Animals: Client-owned dogs with ≥3 years follow-up (118 dogs, 166 stifles).

Methods: Records from June 2012 to May 2015 were reviewed. Follow-up examination and radiography were performed in dogs meeting the inclusion criteria. Measures of outcomes included a radiographic osteoarthritis score (preoperative, 8 weeks postoperative, and ≥3 years postoperative), the Canine Brief Pain Inventory, and the Canine Orthopedic Index.

Results: Ninety-four dogs treated with TPLO (133 stifles) and 24 dogs treated with TTA (33 stifles) met the inclusion criteria. All dogs underwent meniscal release or partial medial meniscectomy. Osteoarthritis score progressed more after TTA ($P = .003$) and in dogs with bilateral surgery ($P = .022$). Long-term outcomes that were better after TPLO compared with TTA included average pain in the last 7 days ($P = .007$), interference with walking ($P = .010$), morning stiffness ($P = .004$), jumping ($P = .003$) and climbing ($P = .040$), limping during mild activities ($P = .001$), and overall quality of life ($P = .045$).

Conclusion: Osteoarthritis progressed more after TTA and in dogs with bilateral stifle surgery. Dogs treated with TPLO subjectively seemed to have less pain and fewer mobility issues.

Clinical significance: Tibial plateau leveling osteotomy provides a better long-term radiographic and functional outcome than TTA.

1 | INTRODUCTION

Canine osteoarthritis (OA) is one of the most common sources of chronic pain, affecting approximately 20% of adult dogs and up to 80% of geriatric dogs.[1] In 2014 alone, more than 38 000 claims were filed with Nationwide pet insurance for canine OA, accounting for more than $4.6 million in claim amounts.[2] The increasing life expectancy of dogs requires that we understand the long-term outcomes associated with this disease process. Cranial cruciate ligament rupture (CCLR) is the leading

Results of this study were presented at the 2019 Veterinary Orthopedic Society Conference; February 9-16, 2019; Breckenridge, Colorado.

cause of OA in the canine stifle. Rupture of the ligament results in stifle instability, joint effusion, inflammation, pain, and progressive OA.[3-7] These changes lead to chronic stiffness, intermittent lameness, decreased range of motion, limited function, and chronic pain.[8]

Cranial cruciate ligament rupture is followed by an initial compensatory phase lasting approximately 3 years.[4,7] With continued instability, these compensatory responses fail, leading to thinning, fibrillation, and ulceration of the articular cartilage.[4,7,9,10] Stabilization of the stifle immediately after CCLR has been found to prevent this initial osteophyte formation and articular cartilage hypertrophy.[11] Therefore, surgical stabilization of the stifle is recommended as soon as CCLR is diagnosed.[3,4,6,10] Intracapsular, extracapsular, and osteotomy techniques have been described to stabilize the cruciate deficient stifle joint, and radiographic progression of OA seems reduced after osteotomy techniques.[3,5,6,8,12-16] Two of the most commonly performed osteotomies are tibial plateau leveling osteotomy (TPLO) and tibial tuberosity advancement (TTA).[17,18] Both procedures seek to stabilize the stifle during weight bearing by neutralizing cranial tibial thrust (CTT).[15,19] Tibial plateau leveling osteotomy neutralizes CTT by rotating the tibial plateau so that during the stance phase the tibial plateau is ~90° to the patellar tendon.[15] Tibial tuberosity advancement attempts to neutralize the CTT by advancement of the tibial tuberosity and patellar ligament to ~90° to the tibial plateau.[14,19] Osteotomies reduce OA progression compared with extracapsular techniques[3,8,9,20-24]; 40% to 76% of dogs have progressive OA after TPLO,[3,9,23] and 55% to 67% have progressive OA after TTA.[20,25] Studies cannot be directly compared because of variations in study design, patient populations, surgical techniques, radiographic OA scoring systems, and follow up time.

To the best of the authors' knowledge, there are no extended long-term reports evaluating the radiographic progression of OA or long-term outcomes post-TPLO or post-TTA. Our objective was to evaluate extended long-term (≥3 year) outcomes of dogs after TPLO or TTA by evaluating radiographic OA scores and client assessment scores with the Canine Brief Pain Inventory (CBPI) and the Canine Orthopedic Index (COI). Based on published evidence, our hypothesis was that OA would continue to progress over time after both procedures and that no differences in outcomes would be detected ≥3 years after TTA or TPLO.

2 | MATERIALS AND METHODS

2.1 | Case selection

Medical records from June 2012 to May 2015 were reviewed for dogs with CCLR treated by TPLO or TTA. Cases were included when dogs had been treated ≥3 years ago and when orthogonal preoperative, postoperative, and long-term follow-up radiographs and signed client consent were available. Cases were excluded when dogs weighed <15 kg (33 pounds), had a limited arthrotomy or arthroscopy performed at surgery, had a subsequent or previous stifle procedure, had a history of patella luxation, or had a TPLO with an inappropriate rotation (tibial plateau angle [TPA] <3° or >10°) or TTA with inappropriate advancement (<85° or >95°). All postoperative radiographs were evaluated by a board-certified surgeon for inclusion.

2.2 | Data collection

Data collected included age; breed; sex; reproductive status; body weight; body condition score (BCS; scale ranging from 1 = emaciated, 5 = ideal, to 9 = morbidly obese)[13]; affected limb; procedure performed; postoperative TPLO TPA, or TTA; meniscus status and treatment; surgeon or resident who performed the procedure; and any other relevant data.

2.3 | Surgical procedures

Surgical procedures were selected according to surgeon or client preference. All surgeries were performed by a board-certified veterinary surgeon or surgical resident under the direct supervision of a veterinary surgeon as previous described.[15,19] All stifles were approached by a standard craniomedial parapatellar arthrotomy, followed by cranial cruciate ligament debridement and meniscal release or partial meniscectomy according to meniscal evaluation (intact or torn). No joints were injected with local anesthetic.

2.4 | Radiographic OA

Mediolateral and craniocaudal radiographic projections of affected stifle joints were obtained prior to surgery, at 8 weeks postoperatively, and at final examination (≥3 years postoperatively). Three-view radiographs were obtained at final recheck for all dogs (90°/90° lateral, standing angle [~135°] lateral, and craniocaudal view). All radiographs were scored by a board-certified radiologist (M.P.) who randomly reviewed the radiographs and was blinded to patient identity, history, and follow-up results.

A combination of previously used scoring systems was used.[5,12] Our CCLR OA scoring system is based on a 0 to 5 grading scale (Figure 1, Table 1).

2.5 | Final follow-up and client questionnaires

Each client was contacted by phone and/or email regarding participation in the study. Participation included complementary recheck examination and radiographs of the stifle(s) that had been treated. Clients who participated filled out four

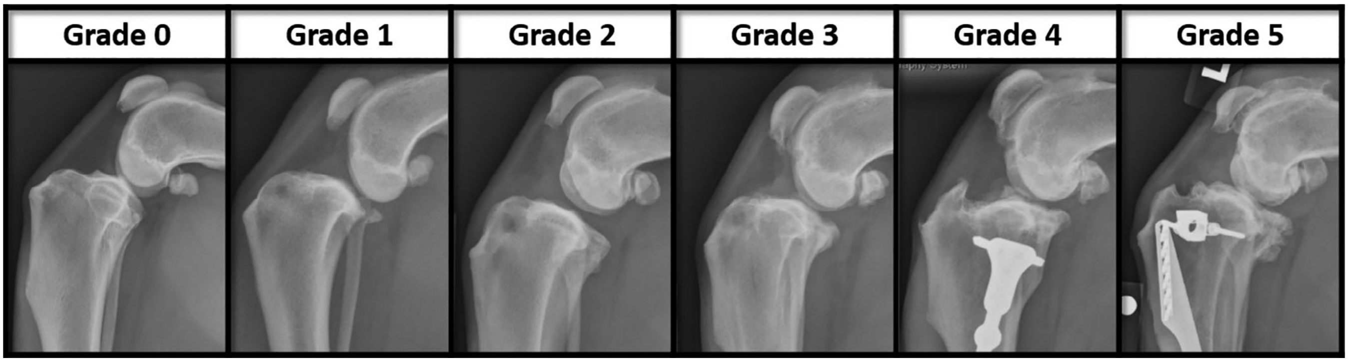

FIGURE 1 Grades of radiographic osteoarthritis. See Table 1 for interpretation of scores

TABLE 1 Radiographic scoring system to grade OA secondary to CCLR[a]

Grade	Degree	Description
0	Normal/no OA	No effusion or osteophytes
1	Early OA	Stifle effusion only; no osteophytes present
2	Mild OA	Osteophytes on patella and femoral trochlea ridges only
3	Moderate OA	Small osteophytes on patella, femoral trochlea ridges, femoral condyles, fabellae, periarticular margins of the tibial plateau, and fibular head only
4	Moderate to severe OA	Medium to large osteophytes on patella, femoral trochlea ridges, femoral condyles, fabellae, periarticular margins of the tibial plateau, and fibular head only; mild to moderate subchondral sclerosis
5	Severe OA	Osteophytes on patella, femoral trochlear ridges, femoral condyles, fabellae, periarticular margins of the tibial plateau, fibular head, and within the intercondylar notch; marked calcification and subchondral sclerosis

Abbreviations: CCLR, cranial cruciate ligament rupture; OA, osteoarthritis.
[a]See Figure 1 for radiographic appearance.

forms: (1) informed consent; (2) additional medical history, orthopedic history, and current medications; (3) CBPI (http://www.vet.upenn.edu/research/clinical-trials/vcic/pennchart/cbpi-tool); and (4) COI (http://www.vet.upenn.edu/research/clinical-trials/vcic/pennchart/canine-orthopedic-index). One set of forms was filled out for each dog prior to or during their final recheck examination. No costs were incurred by the clients for participation in the study.

2.6 | Statistical analysis

Osteoarthritis score was initially analyzed by means of a split-plot analysis of variance (ANOVA) with one grouping factor (TTA/TPLO) and two repeat factors (right/left [R/L] side and time). There was no evidence of any difference between the R/L sides ($P = .68$), so sides were considered repetitions within dog. Osteoarthritis score was then analyzed by means of a split-plot ANOVA with two grouping factors (TTA/TPLO and bilateral/unilateral), with dogs nested within the four groups, and one repeat factor (time). Normality was assessed by means of histogram and normal probability plot; errors were normally distributed. Kruskal-Wallis (KW) test was used to compare the OA scores between surgeons.

Descriptive data were recorded for all dogs and compared between procedures by χ^2 (categorical data) and unpaired *t* test or Wilcoxon rank-sum test (depending on normality, for continuous data). Data are reported as mean ± SD.

Client questionnaires were grouped by procedure, assessed by the Wilcoxon rank-sum test, and are reported as median and 50% interquartile range (25th and 75th quartiles). Analyses were performed in SAS 9.3 (PROC MIXED, PROC TTEST, PROC NPAR1WAY, PROC FREQ, and PROC UNIVARIATE; SAS Institute, Cary, North Carolina). *P* values are reported.

3 | RESULTS

3.1 | Case identification

Five hundred ninety-one dogs were identified (441 received TPLO, 150 received TTA, and one dog received TPLO on one stifle and TTA on the other stifle). The one dog with TPLO on one stifle and TTA on the other stifle was removed from analysis. Among the TPLO cases identified, 94 (21.3%) were included in the study, 118 (26.6%) were deceased, 187 (42.4%) were lost to follow up, and 42 (9.5%) did not meet the inclusion criteria. Among the TTA cases identified, 24 (16.0%) were included in the study, 54 (36.0%) were deceased, 57 (38.0%) were lost to follow up, and 15 (10.0%) did not meet the inclusion criteria.

3.2 | Signalment and descriptive statistics

One hundred eighteen dogs met the inclusion criteria. A summary of the data is presented in Table 2. For the TPLO group, 94 dogs met the inclusion criteria, and 39 dogs had bilateral TPLO (41.5%) performed during the study time frame, for a total of 133 stifles. None of the bilateral procedures were performed during the same anesthetic event. Breeds represented were Labrador retriever (23); mixed breed (16); golden retriever (8); Rottweiler (6); Labrador mix (5); three each of pit bull mix, German shepherd, Chesapeake Bay retriever, Newfoundland, labradoodle, and Doberman pinscher; two each of pitbull terrier, mastiff, goldendoodle; and one each of boxer, Entlebucher Mountain dog, terrier mix, English bulldog, border collie mix, Norwegian elkhound, boerboel, Australian shepherd, Rhodesian ridgeback, husky mix, corgi mix, and Bouvier des Flandres. There were 59 (62.8%) spayed females, one (0.01%) intact male, and 34 (36.2%) castrated males.

TABLE 2 Descriptive statistics for dogs undergoing TPLO or TTA

Variables	TPLO	TTA	*P* Value
Dogs/stifles, n	94/133	24/33	.89
Age preoperative, mean (±SD), y	4.5 (±2.0)	5.1 (±2.6)	.23
Follow-up time, mean (±SD), y	4.59 (±1.05)	4.87 (±1.54)	.41
Weight preoperative, mean (±SD), kg	37.4 (±10.7)	31.4 (±10.0)	.18
BCS, 1–9, mean (±SD)	5.8 (±0.8)	6.5 (±1.2)	.01*
OA score preoperative, 0–5, mean (±SD)	2.1 (±0.7)	1.9 (±0.4)	.17
Meniscal tears, %	59.3	60.6	.99
Postoperative TPA, mean (±SD), °	6.22 (±1.48)	n/a	n/a
Postoperative TTA, mean (±SD), °	n/a	89.8 (±2.66)	n/a

Abbreviations: BCS, body condition score; n/a, not applicable; OA, osteoarthritis; TPA, tibial plateau angle; TPLO, tibial plateau leveling osteotomy; TTA, tibial tuberosity advancement.
*$P < .05$.

Twenty-four dogs met the criteria for inclusion in the TTA group, and nine (37.5%) dogs had bilateral TTA during the study time, for a total of 33 stifles. None of these bilateral procedures were performed during the same anesthetic event. Breeds represented were mixed breed (9); Labrador retriever (4); golden retriever (3); and one each of boxer, Rottweiler, English pointer, Akita, pit bull mix, Australian shepherd, Bernese Mountain dog, and German shepherd. There were 14 (58.3%) spayed females and 10 (41.7%) neutered males.

There were no differences in the percentages of dogs with bilateral procedures ($P = .89$), sex ($P = .69$), preoperative weight ($P = .18$), preoperative age ($P = .23$), or follow up time ($P = .41$) between the TPLO and TTA groups. There was a difference in preoperative BCS ($P = .01$).

3.3 | Surgical procedures

One hundred thirty-three stifles were treated with TPLO; surgeon No. 1 performed 66 (49.6%) TPLO, surgeon No. 2 performed 42 (31.6%) TPLO, surgeon No. 3 performed 10 (0.08%) TPLO, and residents performed 15 (11.3%) TPLO. The meniscus was intact/released in 66 (49.6%) stifles and torn/resected in 67 (51.3%) stifles. The mean postoperative TPA was 6.22 (±1.48). Among the 33 stifles treated with TTA, surgeon No. 1 performed five (15.2%) TTA, surgeon No. 2 performed 0 TTA, surgeon No. 3 performed 26 (78.8%) TTA, and residents performed two (0.06%) TTA. The meniscus was intact/released in 13 (39.4%) stifles and torn/resected in 11 (60.6%) stifles. Mean postoperative advancement was 89.8 (±2.66). The status of the meniscus did not differ between groups ($P = .99$). Surgeon's distribution varied between groups ($P < .001$).

3.4 | Radiographic analysis

There was no difference in mean preoperative OA score ($P = .17$, Table 3) or mean follow-up OA score ($P = .48$) between the groups. The OA score increased over time ($P < .001$) after both procedures. When each procedure was evaluated over time, OA score increased more after TTA ($P = .0026$) and when the dog had bilateral surgery ($P = .0217$). There was no difference in preoperative ($P = .54$, KW), 8-week postoperative ($P = .42$, KW), or final examination ($P = .73$, KW) OA score between surgeons. Body condition score ($P = .17$) and meniscus status ($P = .2562$) were evaluated as covariates and found to be insignificant.

3.5 | Client questionnaires

Owners' assessments of outcome with the CBPI to rate the severity of their dog's pain and the degree to which that pain

TABLE 3 OA scores for dogs over time

Procedure	Unilateral or bilateral surgery (No. of stifles)	Time	OA score, mean (±SD)
TPLO	Unilateral (55)	Preoperative	2.11 (±0.74)
		8 weeks	2.46 (±0.69)*
		Final examination	3.05 (±0.69)*
	Bilateral (78)	Preoperative	2.01 (±0.69)
		8 weeks	2.52 (±0.58)*
		Final examination	3.06 (±0.41)*
TTA	Unilateral (15)	Preoperative	2.07 (±0.27)
		8 weeks	2.31 (±0.48)
		Final examination	3.13 (±0.64)*
	Bilateral (18)	Preoperative	1.67 (±0.49)
		8 weeks	2.25 (±0.58)*
		Final examination	3.28 (±0.46)*

Abbreviations: OA, osteoarthritis; TPLO, tibial plateau leveling osteotomy; TTA, tibial tuberosity advancement.
*$P < .05$.

TABLE 4 CBPI client assessment scores[a]

CBPI question	TPLO	TTA	*P* Value
1. Pain: worst in last 7 days	1.0 (0.0, 4.0)	3.8 (0.0, 5.3)	.016*
2. Pain: least in last 7 days	0.0 (0.0, 1.0)	0.8 (0.0, 4.3)	.009*
3. Pain: average pain in last 7 days	0.0 (0.0, 2.0)	2.0 (0.8, 5.0)	.007*
4. Pain: right now	0.0 (0.0, 1.0)	2.0 (0.0, 4.5)	.003*
5. Pain interference with general activity	0.0 (0.0, 2.0)	1.0 (0.0, 4.0)	.060
6. Pain interference with enjoyment of life	0.0 (0.0, 1.0)	0.0 (0.0, 4.0)	.230
7. Pain interference with ability to rise to standing	1.0 (0.0, 4.0)	2.5 (0.0, 5.0)	.230
8. Pain interference with ability to walk	0.0 (0.0, 1.0)	1.0 (0.0, 3.3)	.010*
9. Pain interference with ability to run	0.0 (0.0, 2.8)	2.0 (0.0, 6.5)	.040*
10. Pain interference with ability to climb	0.0 (0.0, 2.8)	2.5 (0.0, 7.0)	.070
11. Overall impression	3.0 (3.0, 4.0)	3.0 (2.0, 4.0)	.100

Abbreviations: CBPI, Canine Brief Pain Inventory; TPLO, tibial plateau leveling osteotomy; TTA, tibial tuberosity advancement.
[a]Data are median and 50% interquartile range (25th and 75th quartiles). Scoring system for questions 1–4: 0 = no pain, 10 = extreme pain. Scoring system for questions 5–10: 0 = does not interfere, 10 = completely interferes. Scoring system for question 11: 0 = poor, 1 = fair, 2 = good, 3 = very good, 4 = excellent.
*$P < .05$.

interfered with function indicated a better outcome for dogs that had a TPLO (Table 4). Owners assessing the outcome with the COI to rate their dog's degree of joint stiffness, function, gait, and overall quality of life indicated a better outcome for dogs treated with TPLO (Table 5).

4 | DISCUSSION

To the best of our knowledge, this is the first study directly to evaluate and compare extended long-term (≥3 years) outcomes after TPLO and TTA. Osteoarthritis progressed more after TTA, and owners noted less pain and mobility issues long-term after TPLO. These findings provide sufficient evidence to confirm our hypothesis that OA would progress over time after both procedures. The hypothesis that there would be no significant differences in outcomes between TPLO and TTA was rejected.

Outcomes after stifle stabilization include radiographic progression of OA[3,5,9,16,22,24,25] as well as evaluation of limb use and functional outcome (range of motion, ground reaction forces, lameness score, and client questionnaires).[5,8,10,17,24,25] Current recommendations for evaluating orthopedic outcomes include assessment of both objective and subjective measures.[26] For objective outcomes, we chose to evaluate radiographs because they are noninvasive and were available at multiple time points. For subjective outcomes, we chose to use validated client questionnaires (CBPI and the COI) as tools for evaluating chronic pain associated with OA.[27]

After reviewing the literature, we selected a combination of radiographic scoring systems that could monitor changes known to occur after CCLR. Radiography has been the standard for diagnosis, assessment, and monitoring joint disease in vivo.[3] Radiographic changes associated with CCLR have been reported without treatment[4,6,7,28,30] and after surgical stabilization[3,5,8,9,12,16,20-24] and have been found to correlate with disease severity.[31] Changes include effusion, osteophytes, enthesophytes, intra-articular mineralization, subchondral sclerosis, subchondral cyst formation, thickening and fibrosis of the periarticular tissues, and joint space narrowing.[3,12,21,28-30] Effusion is the first radiographically identifiable change present in the early stages and can precede clinical lameness and palpable instability.[6,12,28,30,31] During the following 3 weeks, osteophytes form along the femoral trochlea and at the proximal and distal aspects of the patella.[28,30,31] As the disease process continues, osteophyte formation progresses around the femoral trochlea and proximal and distal aspects of the patella and can be seen along the cranial and caudal aspect of the proximal tibia in association with the fabella.[28] Subchondral sclerosis and calcification of the menisci and ligaments can occur late in the disease process.[28,30] A recent review identified 22 different scoring systems that have been used to evaluate stifle OA post-CCLR.[32] Global scoring systems[3,8,12,21,25,31-33] and semiquantitative scoring

TABLE 5 COI client assessment scores[a]

COI question	TPLO	TTA	*P* Value
1. Stiffness: in the morning	1.0 (0.0, 2.0)	2.0 (1.0, 2.3)	.004*
2. Stiffness: later in the day	1.0 (0.0, 2.0)	1.0 (1.0, 2.0)	.110
3. Problems rising/standing after lying down for at least 15 min	1.0 (0.0, 1.0)	1.0 (0.0, 2.0)	.100
4. Difficulty with joints over the past 7 days	1.0 (0.0, 1.4)	1.0 (0.8, 2.0)	.040*
5. Function: jumping up	1.0 (0.0, 2.0)	2.0 (1.0, 3.0)	.003*
6. Function: jumping down	0.0 (0.0, 1.0)	1.0 (0.0, 2.3)	.030*
7. Function: climbing up	0.0 (0.0, 1.0)	2.0 (0.0, 2.0)	.040*
8. Function: climbing down	0.0 (0.0, 1.0)	1.0 (0.0, 3.0)	.020*
9. Gait: how severe is limping during mild activities?	0.0 (0.0, 1.0)	1.0 (0.0, 2.3)	.001*
10. Gait: how severe is limping during moderate activities?	0.0 (0.0, 1.0)	2.0 (1.0, 3.0)	.001*
11. How often does your dog limp the day after moderate activities?	1.0 (0.0, 2.0)	2.0 (1.0, 3.0)	.010*
12. How often are you aware of your dog's joint problems?	2.0 (1.0, 3.0)	3.0 (1.8, 3.1)	.040*
13. How often does your dog "pay for" overactivity with pain or stiffness the following day?	1.0 (0.0, 2.0)	2.0 (1.0, 3.0)	.040*
14. QOL: what is your level of concern that your dog's joint problems will shorten their life?	0.0 (0.0, 1.0)	1.0 (0.0, 2.3)	.020*
15. QOL: what is your level of concern that your dog is generally slowing down?	0.8 (0.0, 2.0)	2.0 (0.0, 2.3)	.040*
16. QOL: overall, how would you rate your dog's quality of life?	3.0 (3.0, 4.0)	3.0 (2.0, 4.0)	.045*

Abbreviations: COI, Canine Orthopedic Index; QOL, quality of life; TPLO, tibial plateau leveling osteotomy; TTA, tibial tuberosity advancement.
[a]Data are median and 50% interquartile range (25th and 75th quartiles). Scoring system for questions 1–10, 14, 15: 0 = none, 1 = mild, 2 = moderate, 3 = severe, 4 = extreme. Scoring for questions 11–13: 0 = never, 1 = rarely, 2 = occasionally, 3 = frequently, 4 = constantly. Scoring system for question 16: 4 = excellent, 3 = very good, 2 = good, 1 = fair, 0 = poor.
*$P < .05$.

systems have been described.[6,9,16,22,24,30,32] Semiquantitative scoring systems have the benefit of evaluating changes at specific locations but may not be practical for clinical use. Global scoring systems are more general, but do not account for location, which can correlate with disease progression. Osteophyte formation and effusion are two of the most reliable and repeatable markers when scoring OA and have been found to increase over time.[8,12,33] We combined the Innes et al[12] global scoring system and the Moore et al[5] semiquantitative OA scoring system and found that they were able to identify a progression in OA over time.

Osteoarthritis progressed after both surgeries but more so after TTA than TPLO in our study. Our findings are consistent with previous studies.[3,4,7,9,21,30] Dogs with continued instability after stifle stabilization surgery may have increased progression in OA compared with dogs with stable stifles.[5] Krotscheck et al[17] found that 57% of TTA stifles maintained some instability. Krotschek's study did not look at the development of radiographic OA: This persistent instability found after the TTA supports our findings that long-term there is an increased progression of radiographic OA after this procedure. The radiographic OA score also increased more in dogs with bilateral surgeries. Contralateral CCLR has been reported in 40% to 60% of dogs.[5,31] Innes et al[12] described changes in effusion, global OA score, and osteophyte score in 40% of contralateral limbs of dogs with unilateral CCLR. In another study,[31] all contralateral stable stifle joints with evidence of radiographic OA had evidence of synovitis, and 75% of them had evidence of CCL fiber rupture. While the exact cause for bilateral cruciate disease has not been identified, it is attributed to underlying genetic factors. These factors may result in microtearing of the CCL, resulting in synovitis and microinstability prior to overt clinical lameness or palpable instability.[31] Our findings provide evidence that dogs with bilateral CCLR may be at increased risk for OA long term. Prospective extended long-term studies are required to evaluate the effect of early stifle stabilization surgery on long-term OA progression in dogs with bilateral cruciate disease.

Surgical factors that have been evaluated by previous studies for their effect on OA included surgical approach, meniscal treatment, and cruciate ligament debridement.[3,16,21,34] All dogs in our study underwent craniomedial parapatellar arthrotomy for stifle evaluation. Lineberger et al[21] found this approach to be associated with increased OA compared with caudomedial arthrotomy. The menisci are important stabilizers of the stifle. In our study, all dogs received a meniscal release or a partial medial meniscectomy, which may have contributed in stifle instability. We found no difference in the progression of OA between these procedures, which is in line with the findings of Rayward et al,[3] Lazar et al,[16] and Morgan et al,[20] who found no association between meniscus status and treatment and progression in OA scores postoperatively. However, Luther et al[34] found that meniscal release alone resulted in signs of radiographic OA. The cranial cruciate ligament prevents cranial displacement of the tibia on the femur, limits internal rotation of the tibia, and prevents hyperextension of the stifle joint. All remaining cruciate ligament was debrided at the time of surgery in our study. Removal of intact ligament may contribute to stifle instability and, therefore, the progression of OA. Each of these factors may have affected the progression of OA found in our study. However, these factors were consistent between treatment groups and therefore not likely to affect the difference in outcomes between procedures identified.

Animal factors that have been evaluated by previous studies associated with OA included BCS, food intake, weight, and sex.[5,28,35] Kealy et al[35] found that OA was less severe in dogs who received 25% less food compared with control dogs. Assessing quantity and quality of food intake was beyond the scope of our study, but BCS was assessed. A difference between groups was identified, and, when BCS was reevaluated as a covariate, it was found to be insignificant. Our study found no association between weight and radiographic OA. These findings may have been altered by our exclusion of smaller dogs (<15 kg) because larger dogs have developed OA more rapidly in previous studies.[3,28] Sex has intermittently been found to be associated with OA, with females being at higher risk than males.[5,28] We found no correlation between OA score, sex, and/or neuter status in our study.

Human studies indicate that radiographic OA score correlates directly with knee pain.[36] Veterinary studies are less conclusive, with no direct correlation found between radiographic OA and clinical lameness in many studies.[12,31,37] This may be an accurate finding, or it may be due to limitations in how we evaluate lameness in dogs. While the correlations between radiographic OA and clinical outcome are not clear, it is clear that OA is a pathologic process resulting in progressive changes to the bone and soft tissues that may result in altered and/or decreased function. Therefore, every effort to understand the process and prevent the progression should be made.

Responses on the CBPI and the COI provided evidence that owners believed that their dogs did better after the TPLO. Client questionnaires have been shown to be a reliable way to compare outcomes between treatments.[27] The CBPI was developed as an owner-completed questionnaire designed to quantitate owners' assessments of the severity and impact of chronic pain in their dogs with OA.[27] The CBPI is a validated and reliable tool to assess pain in dogs with OA and has been used to compare outcomes between groups.[27] The COI is a validated outcome assessment instrument that reliably measures owners' assessment of outcome in dogs with orthopedic disease. Comparison of outcomes between TPLO to TTA has been performed in previous studies.[17,38] Krotscheck et al[17] used gait analysis to evaluate TTA and TPLO during the first year after surgery. They used force plate analysis to show that dogs who had TPLO achieved normal function at the walk earlier than dogs with TTA, and only dogs that had a TPLO were able to have a normal gait at the trot. Using client questionnaires, Christopher et al[38] evaluated dogs >1 year old after surgery and found that dogs were more likely to reach full function after TPLO and that 61.1% of dogs 1-year post-TTA were judged by their owners to have some degree of long-term pain. Our findings that long-term outcomes are superior for TPLO over TTA are in line with these previous studies.

Our study has several limitations. Because of the retrospective nature of the study, case selection could not be randomized, a large number of dogs had died or were lost to follow-up, and the number of TTA cases was limited. Many variables were also out of our control: animal history, signalment, duration of disease, comorbidities, diet, and medications. We assumed that these variables were randomly distributed among the groups. A prospective study would ideally be performed with a control group that was the same age and weight as our cohorts but without cruciate ruptures.

We limited our objective data to radiographic analysis because dogs were not excluded for concurrent orthopedic and/or neurologic changes identified at follow-up examination and because of the subjective nature of other variables (eg, lameness score, range of motion, muscle atrophy). Force plate analysis is considered the gold standard for evaluating lameness associated with orthopedic disease.[8] We did not perform force plate in our study because there are many factors that can affect ground reaction forces that could not be controlled in our animal population (eg, BCS, concurrent orthopedic and/or neurologic disease, body conformation, limb length).[17] Kinematic gait analysis would have been more appropriate for our animal population to evaluate limb function; however, this is not available at our practice. Additional imaging and diagnostic modalities used for OA evaluation (computed tomography, MRI, arthroscopy)[28-31] would have been ideal; however, dogs' ages prohibited us from recommending procedures that would have required sedation and/or anesthesia solely for diagnostic purposes. Bleedhorn et al[31] showed that, while arthroscopy is more sensitive for detecting synovial changes, the degree of arthroscopic synovitis correlated well with the severity of radiographic OA.

Client questionnaires were used to determine long-term functional outcome. Brown et al[27] found that vertical forces and the CBPI are both appropriate tools for evaluating dogs with OA. However, they noted that results cannot be directly compared because they are quantitating different things. Other possible limitations to consider when using client assessments include caregiver placebo and owners' ability to detect lameness (especially in dogs with bilateral disease).[6]

There was a significant difference between surgeons in each group. There were three surgeons and residents included in the TPLO procedures and only two surgeons and residents included in the TTA procedures. We tried to control for this potential variable by evaluating all preoperative and postoperative radiographs for appropriate rotation or advancement. We also found that there was no difference in radiographic OA score between surgeons at any time point.

Radiographic scoring was performed by a single radiologist. Validating our OA scoring system was beyond the scope of this study; however, portions of our scoring system are based on the Innes et al[12] OA scoring system, which has been validated. Our scoring system should ideally be validated by determining interobserver and intraobserver reliability.

In conclusion, radiographic OA was found to progress more after TTA and when bilateral surgery was performed. Client assessments of outcomes with the CBPI and the COI indicated that dogs had better mobility, decreased pain, and improved quality of life long-term after TPLO. There were many limitations due to the retrospective nature of our study. A prospective, blinded, case-controlled, long-term study with objective measures such as force plate gait analysis could ideally be performed to further evaluate the long-term outcomes of these procedures.

ACKNOWLEDGMENTS

The authors are grateful to the owners and animals who participated in the study as well as to the staff at Chesapeake Veterinary Surgical Specialists who helped with all the final recheck examinations. We also thank Joe Hauptman DVM, MS, DACVS for his assistance with the statistical analysis.

CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this report.

REFERENCES

1. Johnston SA. Osteoarthritis: joint anatomy, physiology, and pathobiology. *Vet Clin North Am Small Anim Pract.* 1997;27(4):699-723.
2. Veterinary Pet Insurance (VPI). Pet osteoarthritis. https://www.petinsurance.com/healthzone/pet-articles/pet-health/Pet-Osteoarthritis.aspx?extcmp=smd-ebiz-BL0002. Accessed June 18, 2019.
3. Rayward R, Thomson D, Davies J, Innes J, Whitelock R. Progression of osteoarthritis following TPLO surgery: a prospective radiographic study of 40 dogs. *J Small Anim Pract.* 2004;45(2):92-97.
4. Brandt K, Myers S, Burr D, Albrecht M. Osteoarthritic changes in canine articular cartilage, subchondral bone, and synovium fifty-four months after transection of the anterior cruciate ligament. *Arthritis Rheum.* 1991;34(12):1560-1570.
5. Moore KW, Read RA. Cranial cruciate ligament rupture in the dog—a retrospective study comparing surgical techniques. *Aust Vet J.* 1995;72(8):281-285.
6. Bennett D, Tennant B, Lewis D, Baughan J, May C, Carter S. A reappraisal of anterior cruciate ligament disease in the dog. *J Small Anim Pract.* 1988;29(5):275-297.
7. Dedrick DK, Goldstein SA, Brandt KD, O'Connor BL, Goulet RW, Albrecht M. A longitudinal study of subchondral plate and trabecular bone in cruciate-deficient dogs with osteoarthritis followed up for 54 months. *Arthritis Rheum.* 1993;36(10):1460-1467.
8. Mölsä S, Hyytiäinen H, Hielm-Björkman A, Laitinen-Vapaavuori O. Long-term functional outcome after surgical repair of cranial cruciate ligament disease in dogs. *BMC Vet Res.* 2014;10(1):1-11.
9. DeLuke AM, Allen DA, Wilson ER, et al. Comparison of radiographic osteoarthritis scores in dogs less than 24 months or greater than 24 months following tibial plateau leveling osteotomy. *Can Vet J.* 2012;53(10):1095-1099.
10. Innes JF, Bacon D, Lynch C, Pollard A. Long-term outcome of surgery for dogs with cranial cruciate ligament deficiency. *Vet Rec.* 2000;147:325-328.
11. Palmoski MJ, Brandt KD. Immobilization of the knee prevents osteoarthritis after anterior cruciate ligament transection. *Arthritis Rheum.* 1982;25(10):1201-1210.
12. Innes J, Costello M, Barr F, Rudorf H, Barr A. Radiographic progression of osteoarthritis of the canine stifle joint: a prospective study. *Vet Radiol Ultrasound.* 2004;45(2):143-148.
13. Gordon-Evans WJ, Griffon DJ, Bubb C, Knap KM, Sullivan M, Evans RB. Comparison of lateral fabellar suture and tibial plateau leveling osteotomy techniques for treatment of dogs with cranial cruciate ligament disease. *J Am Vet Med Assoc.* 2013;243(5):675-680.
14. Tepic S, Damur D, Montavon PM. Biomechanics of the stifle joint. In: Proceedings from the 1st World Orthopedic Veterinary Congress; September 5-8, 2002; Munich, Germany. 2002;189-190.
15. Slocum B, Slocum TD. Tibial plateau leveling osteotomy for repair of the cranial cruciate ligament rupture in the canine. *Vet Clin North Am Small Anim Pract.* 1993;23:777-795.
16. Lazar T, Berry C, Dehaan J, Peck J, Correa M. Long-term radiographic comparison of tibial plateau leveling osteotomy versus extracapsular stabilization for cranial cruciate ligament rupture in the dog. *Vet Surg.* 2005;34(2):133-141.
17. Krotscheck U, Nelson S, Todhunter R, Stone M, Zhang Z. Long term functional outcome of tibial tuberosity advancement vs tibial plateau leveling osteotomy and extracapsular repair in a heterogeneous population of dogs. *Vet Surg.* 2016;45(2):261-268.
18. Duerr FM, Martin KW, Rishniw M, Palmer RH, Selmic LE. Treatment of canine cruciate ligament disease—a survey of ACVS diplomates and primary care veterinarians. *Vet Comp Orthop Traumatol.* 2014;27:478-483.
19. Montavon PM, Damur DM, Tepic S. Advancement of the tibial tuberosity for the treatment of cranial cruciate deficient stifle. In: Proceedings from the 1st World Orthopedic Veterinary Congress; September 5-8, 2002; Munich, Germany. 2002:152.
20. Morgan J, Voss K, Damur D, Guerrero T, Haessig M, Montavon P. Correlation of radiographic changes after tibial tuberosity advancement

in dogs with cranial cruciate-deficient stifles with functional outcome. *Vet Surg*. 2010;39(4):425-432.

21. Lineberger JA, Allen DA, Wilson ER, et al. Comparison of radiographic arthritic changes associated with two variations of tibial plateau leveling osteotomy. *Vet Comp Orthop Traumatol*. 2005; 18(1):13-17.
22. Hurley CR, Hammer DL, Shott S. Progression of radiographic evidence of osteoarthritis following tibial plateau leveling osteotomy in dogs with cranial cruciate ligament rupture: 295 cases (2001-2005). *J Am Vet Med Assoc*. 2007;230(11):1674-1679.
23. Boyd DJ, Miller CW, Etue SM, Monteith G. Radiographic and functional evaluation of dogs at least 1 year after tibial plateau leveling osteotomy. *Can Vet J*. 2007;48(4):392-396.
24. Au KK, Gordon-Evans WJ, Dunning D, et al. Comparison of short- and long-term function and radiographic osteoarthrosis in dogs after postoperative physical rehabilitation and tibial plateau leveling osteotomy or lateral fabellar suture stabilization. *Vet Surg*. 2010;39(2):173-180.
25. Hoffmann DE, Miller JM, Ober CP, Lanz OI, Martin RA, Shires PK. Tibial tuberosity advancement in 65 canine stifles. *Vet Comp Orthop Traumatol*. 2006;19(4):219-227.
26. Belshaw Z, Asher L, Dean R. Systematic review of outcome measures reported in clinical canine osteoarthritis research. *Vet Surg*. 2016;45(4):480-487.
27. Brown DC, Boston RC, Farrar JT. Comparison of force plate gait analysis and owner assessment of pain using the canine brief pain inventory in dogs with osteoarthritis. *J Vet Intern Med*. 2013;27:22-30.
28. Ramírez-Flores G, Angel-Caraza J, Quijano-Hernández I, Hulse D, Beale B, Victoria-Mora J. Correlation between osteoarthritic changes in the stifle joint in dogs and the results of orthopedic, radiographic, ultrasonographic and arthroscopic examinations. *Vet Res Commun*. 2017;41(2):129-137.
29. Sample S, Racette M, Hans E, et al. Radiographic and magnetic resonance imaging predicts severity of cruciate ligament fiber damage and synovitis in dogs with cranial cruciate ligament rupture. *PLoS One*. 2017;12(6):e0178086.
30. Widmer WR, Buckwalter KA, Braunstein EM, Hill MA, O'Connor BL, Visco DE. Radiographic and magnetic resonance imaging of the stifle joint in experimental osteoarthritis of dogs. *Vet Radiol Ultrasound*. 1994;35(5):371-383.
31. Bleedorn J, Greuel E, Manley P, et al. Synovitis in dogs with stable stifle joints and incipient cranial cruciate ligament rupture: a cross-sectional study. *Vet Surg*. 2011;40(5):531-543.
32. Wessely M, Brühschwein A, Schnabl-Feichter E. Evaluation of intra- and inter-observer measurement variability of a radiographic stifle osteoarthritis scoring system in dogs. *Vet Comp Orthop Traumatol*. 2017;30(6):377-384.
33. De Rooster H, van Bree H. Use of compression stress radiography for the detection of partial tears of the canine cranial cruciate ligament. *J Small Anim Pract*. 1999;40(12):573-576.
34. Luther JK, Cook CR, Cook JL. Meniscal release in cranial cruciate ligament intact stifles causes lameness and medial compartment cartilage pathology in dogs 12 weeks postoperatively. *Vet Surg*. 2009;38:520-529.
35. Kealy RD, Lawler DF, Ballam JM, et al. Evaluation of the effect of limited food consumption on radiographic evidence of osteoarthritis in dogs. *J Am Vet Med Assoc*. 2000;217(11):1678-1680.
36. Petersson IF, Boegård T, Saxne T, Silman AJ. Radiographic osteoarthritis of the knee classified by the Ahlbäck and Kellgren & Lawrence systems for the tibiofemoral joint in people aged 35-54 years with chronic knee pain. *Ann Rheum Dis*. 1997;56:493-496.
37. Gordon W, Conzemius M, Riedesel E, et al. The relationship between limb function and radiographic osteoarthrosis in dogs with stifle osteoarthrosis. *Vet Surg*. 2003;32(5):451-454.
38. Christopher SA, Beetem J, Cook JL. Comparison of long-term outcomes associated with three surgical techniques for treatment of cranial cruciate ligament disease. *Vet Surg*. 2013;42: 329-334.

How to cite this article: Moore EV, Weeren R, Paek M. Extended long-term radiographic and functional comparison of tibial plateau leveling osteotomy vs tibial tuberosity advancement for cranial cruciate ligament rupture in the dog. *Veterinary Surgery*. 2020;49:146–154. https://doi.org/10.1111/vsu.13277