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ORIGINAL ARTICLE

Major complications of tibial tuberosity advancement in 1613 dogs

Mario Costa, BS[1] | Diane Craig, DVM, DACVS[2] | Tony Cambridge, BVMS, DACVS[2] | Peter Sebestyen, DVM, DACVS[2] | Yuhua Su, PhD[3] | Maria A. Fahie, DVM, MS, DACVS[1]

[1] Western University of Health Sciences, College of Veterinary Medicine, Pomona, California
[2] Veterinary Surgical Specialists, Tustin, California
[3] Dr. Su Statistics, Kaunakakai, Hawaii

Correspondence
Maria Fahie, DVM, MS, DACVS, Western University of Health Sciences, College of Veterinary Medicine, 309 E. Second Street, Pomona, CA 91766.
Email: mfahie@westernu.edu

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Abstract

Objectives: To report major postoperative complications in 1613 dogs with tibial tuberosity advancement (TTA).

Study design: Retrospective case series.

Sample population: Dogs (n = 1613) with cranial cruciate ligament deficiency treated with TTA.

Methods: Medical records of TTAs performed between December 2007-2013 were reviewed for age, sex, weight, contralateral stifle surgery, surgical approach, duration of preoperative lameness, presence of meniscal damage, concurrent patellar luxation and simultaneous bilateral TTA. Major postoperative complications were defined as surgical site infection (SSI) (superficial, deep, or organ/space), implant failure, fracture, patellar luxation, and meniscal tear.

Results: Major complications were recorded in 13.4% of cases. Superficial SSI (incisional irritation) was diagnosed in 6.9% cases, requiring only antimicrobial therapy. Other complications included postliminary medial meniscal tear (2% incidence), deep SSI (incisional dehiscence, 1.1%), implant failure (1%), patellar luxation (1.2%), fracture (0.9%), and organ/space SSI (septic arthritis, 0.4%). Dogs with normal menisci were less likely to develop postliminary meniscal tears if the medial meniscus was released at the time of TTA ($P < .0001$). No association was detected between recorded parameters and complications, although dogs >8 years old approached significance ($P = .05$) in terms of predisposition to major complications.

Conclusions: Major complications after TTA are uncommon, even in dogs with concurrent patellar luxation or bilateral simultaneous procedures. In spite of its morbidity, medial meniscal release may prevent postliminary meniscal tears.

1 | INTRODUCTION

Tibial tuberosity advancement (TTA) is designed to align the patellar tendon perpendicularly relative to the tibial plateau, by displacing the tibial tuberosity cranially. This advancement neutralizes tibiofemoral shear forces and allows return to function despite deterioration of the cranial cruciate ligament (CrCL) in the dog stifle.[1-6] TTA is an accepted surgical procedure to manage lameness associated with cruciate ligament disease in dogs.[2,7-15] Postoperative complications associated with the TTA procedure include bone fracture (1-5.1%),[2,10,11,16-18] implant failure (0.8-2%),[2,7-9] patellar luxation (0.8-1%),[2,7,17] postliminary meniscal tear (3.1-25.4%),[2,7-12] and infection (0.5-5.3%).[2,7,10,11,16,17] Predisposing factors to complications include breed,[19] poor implant position, and narrow distal osteotomy width.[16] The impact of body weight remains controversial as conflicting results have been published.[7,16] Simultaneous bilateral TTA procedures and concurrent correction of patellar luxation via tibial tuberosity transposition advancement (TTTA) are other factors that could be expected to increase the risk of postoperative complication. Hirshenson et al found no difference in complication rates after unilateral (11.7%) or single-session bilateral TTA (17.6%).[17] Yeadon et al reported complication in 18% of dogs undergoing TTTA, which is within the range of major complication proportions in previous reports (12-21%).[7-12,16,17,19-21]

The purpose of this study is to report major postoperative complications in a large group of dogs treated with TTA. Based on clinical impression, we hypothesized that prognostic factors for postoperative complications would be identified, and that medial meniscal release would reduce the occurrence of postoperative medial meniscal tears.

2 | MATERIALS AND METHODS

2.1 | Data collection

Medical records from DVMAX (IDEXX/DVMAX Products, Westbrook, Maine) were searched for dogs that underwent TTA procedures performed at Advanced Veterinary Surgical Group, Veterinary Surgical Specialists by ACVS board certified surgeons (DC, TC, PS) from December 2007-2013. One author (MC) reviewed all records in 2014-2015, to include at least 1 year of postoperative follow up. Data recorded included age, sex, weight, contralateral stifle surgery, intra-articular approach (arthrotomy vs arthroscopy), preoperative lameness duration, presence of meniscal damage, concurrent patellar luxation, and simultaneous bilateral TTA.

2.2 | Complications

Major complications were defined as those requiring further surgical or medical treatment.[18,22] A superficial surgical site infection (SSI) occurred within 30 days of surgery, involved skin and/or subcutaneous tissue, and displayed signs of inflammation (heat, redness, pain, swelling).[18] A deep SSI occurred within 1 year of surgery (since an implant was present), affected the superficial and deep soft tissues of the incision without evidence of bone or joint infection on radiographs and cytology.[18] An organ/space SSI occurred within 1 year of surgery (since an implant was present), and involved the bone or synovial space with cytologic confirmation of bacteria present.[18] Dogs with implant failure or fracture that did not cause clinical signs of pain or lameness and did not require surgical management were not included as a major complication.

2.3 | Surgical technique and postoperative care

Dogs were positioned in dorsal recumbency with a standard hanging limb preparation using Hibiclens (Molnlycke Health Care, Norcross, Georgia) scrub soap and 2% chlorhexidine rinse (Vetoquinol, Fort Worth, Texas). Intravenous cefazolin was administered (22 mg/kg) every 2 hours intraoperatively, with dogs receiving only 1 dose since surgery not exceeding that time. A standard medial approach to the stifle joint was performed for open arthrotomy.[23] Arthroscopy was performed with a 1.9 or 2.7 mm Dyonics small joint scope and a Dyonics Powermax shaver (Dyonics, Smith & Nephew, Memphis, Tennessee). Medial meniscal release of the caudal meniscotibial ligament, or meniscectomy of damaged meniscus was performed based on surgeon's preference with a #11 scalpel blade. All CrCL remnants were removed in all cases.

A TTA procedure was performed as initially described,[2] with implants manufactured by Kyon (Kyon Veterinary Surgical Products, Boston, Massachusetts) or Medicatech (Medicatech Vet Veterinary Medical Products, Irvine, California). Cage and plate size were selected based on recommended preoperative radiographic measurements using anatomic overlay, software analysis, and more recently common tangent overlay.[24] No bone grafts were placed at the osteotomy sites. Postoperative coaptation of the stifle consisted of a soft padded bandage for 4-7 days. Oral cephalexin was administered (22 mg/kg PO BID) for 3-14 days depending on dermatologic evaluation by the attending surgeon. Exercise was restricted to short controlled walks for 6-8 weeks postoperatively. Dogs were examined by the attending surgeon at 3-5 days, 10-14 days, then every 6 weeks postoperatively, until return to normal exercise. Radiographs were repeated every 6 weeks postoperatively.

2.4 | Statistical analysis

Data were analyzed with SAS software version 9.4 (SAS Institute, Inc., Cary, North Carolina). Descriptive statistics included means, standard deviations, median, and proportions with 95% CI, as applicable. Wilcoxon rank-sum tests were used to determine significant differences in age and weight between male and female dogs. Kruskal-Wallis test was used to test differences in age and weight among different breeds. When differences were detected, the Dwass, Steel, Critchlow-Fligner post-hoc paired comparison was used to investigate whether 2 breed groups differed in age and weight.[25] Significance level was set at $P < .05$.

The proportional odds model was used to investigate the relationship between complications and the predictors of interest, including age (3 levels: <3 years, 3-8 years, and >8 years), sex (2 levels: male vs female), weight (3 levels: ≤22.9 kg, 23-39.9 kg, and ≥40 kg), contralateral stifle surgery (2 levels: no vs yes), intra-articular approach (2 levels: arthroscopy vs arthrotomy), and duration of lameness (a continuous variable, measured in "days"). For each categorical predictor, age, sex, weight, contralateral stifle surgery, or intra-articular approach, there is a reference category (ref). Confidence intervals that did not contain 1 implied that the effect was significant. Score test was used to determine the

TABLE 1 Factors predisposing dogs to complications after TTA

Predictor	Number of dogs	Number of major complications	% major complications	Odds ratio (95% CI)	*P* (Wald test)
<3 years old	214	27	12.6	0.58 (0.37, 0.91)	.050*
3-8 years old	1136	164	14.4	0.74 (0.54, 1.01)	
>8 years old	263	25	9.5	R	
Female	864	104	12	1.12 (0.85, 1.61)	.448
Male	749	45	9.5	R	
≤22 kg	238	33	13.8	1.18 (0.85, 1.62)	.231
23-39 kg	953	109	11.4	0.88 (0.58, 1.34)	
≥40 kg	353	59	16.7	R	
No contralateral stifle surgery	885	24	2.7	0.80 (0.06, 1.09)	.156
Yes contralateral stifle surgery	728	96	13.1	R	
Arthroscopy	519	76	14.6	0.92 (0.7, 1.2)	.558
Arthrotomy	1094	138	12.6	R	
<30 days versus >30 days duration of lameness				1.0 (0.9, 1.0)	.396

*Significance $P < .05$, CI = confidence interval, R = reference value, % = number of major complications/1613 dogs.

validity of the proportional odds assumption ($P > .05$), indicating the proportional odds assumption was satisfied. The Wald chi-square test was used to determine if an effect was significant. Pearson goodness-of-fit statistic was used to determine model adequacy with insignificance ($P > .05$) indicating appropriate model fit. The odds ratio estimates the strength of the effects and the confidence intervals indicated confidence in this estimate.

Fisher's exact test was done with each pair of variables independently, to further assess medial meniscal release, concurrent patellar luxation and simultaneous bilateral TTA procedures. The influence of meniscal disease was evaluated based on 2 variables: meniscus (2 levels: no release vs release) and tear (2 levels: postliminary tear vs no postliminary tear). For concurrent patellar luxation, the 2 variables consisted of concurrent patellar luxation (2 levels: normal preoperative versus concurrent medial patellar luxation [MPL]) and complication (2 levels: none vs major). For simultaneous bilateral TTA, variables included bilateral TTA (2 levels: yes vs no) and complication (2 levels: none vs major) ($P < .05$)

3 | RESULTS

The fitted proportional odds model was adequate based on the Pearson goodness-of-fit test for model adequacy ($\chi^2 = 1.04$, $P = .1200$) and the score test for proportional odds assumption ($\chi^2 = 13.2996$, $P = .21$, Table 1). The odds ratio for dogs < 3 years was 0.58 with 95% CI (0.37, 0.92). Dogs younger than 3 years approached statistically significant likelihood to have fewer complications than dogs >8 years ($P = .05$). The odds ratio for age 3-8 was 0.74, but the 95% CI (0.53, 1.01) contained 1, indicating the odds ratio was not different from 1. Therefore, we did not further interpret the odds ratio for age 3-8. There were no significant relationships between complication and any of the other predictors. The mean duration of postoperative follow-up without any reported complications was 3.3 years (range, 1-7.2 years). The median duration of postoperative follow-up without any reported complications was 3.2 years.

3.1 | Medial meniscal tear

Torn medial meniscus was identified intraoperatively in 40.5% of dogs and managed with partial meniscectomy. The medial meniscus was reported as normal in 59.4% of dogs, and the medial meniscus was released in 72.4% of these dogs. Only 0.5% of those dogs developed postoperative lameness due to meniscal tear, which was diagnosed and managed with a second surgery (Table 2). The meniscus was not released in 27.6% of dogs. These dogs were more likely to develop postliminary meniscal tear ($P < .0001$), as 10.2%

TABLE 2 Univariate analysis of complications in 1613 dogs

Predictor	Categorization	Number of dogs	Percentage of dogs	95% CI	Significance
Meniscus	Normal-no release-postop tear	27	10.2	6.5, 13.8	$P < .00001$*
	Normal-release-postop tear	4	0.58	02, 1.1	
	Normal-release-no postop tear	690	99.4		
Patellar luxation	Normal preop-MPL/LPL postop	24	1.4	6, 1.6	$P = .30$
	MPL concurrent-normal postop	29	96.7	90.3, 103	
Simultaneous bilateral TTA	Bilateral TTA-major	1	9.1	7.9, 26.1	$P = 1$

*Significance $P < .05$, CI = confidence interval, FET = Fisher's exact test, MPL = medial patellar luxation, LPL = lateral patellar luxation.

developed a postliminary meniscal tear requiring surgical management.

3.2 | Postoperative patellar luxation

Thirty dogs (2%) were concurrently treated for grade 2 MPL and CrCL tear with TTA. Two of these dogs had persistent grade 2 MPL postoperatively, requiring surgical revision. Twenty dogs (1.2%) developed patellar luxation postoperatively: 3 dogs had grade 1 lateral patellar luxation, 8 grade 1 MPL, and 13 grade 2 MPL. Grade 1 luxation required only soft tissue release or imbrication as determined by the surgeon. Grade 2 luxation required trochlear wedge recession or tibial tuberosity lateralization or both in addition to the soft tissue procedures.

3.3 | Surgical site infection

One hundred and twelve dogs (6.9%) developed superficial SSI, based on cardinal signs of inflammation including redness, irritation, and swelling (Table 3). All were successfully managed with oral antibiotherapy with cephalosporin (22 mg/kg PO BID 14-28 days) or enrofloxacin (2.5-5 mg/kg PO BID 14-28 days). Eighteen dogs (1.1%) developed a deep SSI, characterized by at least partial incisional dehiscence, necessitating surgical wound management including soft tissue debridement, lavage, and primary wound closure for resolution.

3.4 | Implant failure and fractures

Surgical revision of failed implants was necessary in 17 (1%) dogs, including 5 broken cage screws, 7 broken TTA forks, and 5 plate removal procedures. One of the 5 cases with a broken cage screw required screw replacement. Implants were replaced in 4 of 7 dogs with a broken TTA fork. All 5 cases requiring plate removal also had deep SSI; the cage was not removed in these cases, and the plate and fork were not replaced. Eleven (0.7%) dogs sustained fractures, including 8 tibial tuberosity fractures and 3 tibial fractures. These cases were successfully managed via implant removal or replacement, as determined by the surgeon.

4 | DISCUSSION

To the authors' knowledge, this is the largest reported sequential case series of TTAs with the longest postoperative follow up. Major complications after TTA were uncommon in our population, and were not influenced by sex, weight,

TABLE 3 Postoperative major complications from 1613 dogs (% = # dogs/1613 [total population of dogs], CI = confidence interval)

Complication	Complication	# Dogs	% Dogs	95% CI
Surgical site infection (SSI)	Superficial SSI-incision inflammation	112	6.9	5.6-8.1
	Deep SSI-incision dehiscence	18	1.1	0.6-1.6
	Organ/space SSI-septic arthritis	8	0.4	0.09-0.71
Implant problem	Broken/loose implant	17	1	0.5-1.5
Fracture	Tibial fracture postop	4	0.2	−0.02-0.42
	Tuberosity fracture postop	12	0.7	0.3-1.1

contralateral stifle surgery, intra-articular approach (arthroscopy vs arthrotomy), duration of lameness, presence of meniscal damage, concurrent patellar luxation or simultaneous bilateral TTA procedures. Dogs older than 8 years approached statistical significance for predisposition to major complications. Meniscal release of normal medial menisci was associated with fewer postliminary meniscal tears.

Releasing the medial meniscus during initial osteotomy in dogs with CrCL disease remains controversial, as conflicting results have been reported.[2,7-12] This procedure has been found to cause osteoarthritis and stifle joint dysfunction when performed in normal joints.[26] Conversely, postliminary meniscal tears have been reported as the most common cause for revision surgery after TTA.[2,7-12] However, the validity of the conclusions proposed in previous study is limited by sample size and overall low incidence of postliminary meniscal tears, ranging from 3.1% to 25.4%.[2,7-12] Wolf et al released 84% of normal menisci in dogs undergoing TTA, and concluded that this procedure lowered the incidence of postliminary meniscal tears from 27% to 2.5%.[8] The incidence of postliminary tears is lower in our study (31 dogs or 1.9%) than prior reports of TTA, and 27 of the 31 dogs who suffered this complication did not undergo medial meniscal release. This finding confirms the preventive effect of medial meniscal release on postliminary meniscal tears after TTAs.

Postoperative SSI is a concern in any orthopedic procedure requiring placement of implants because of the potential biofilm formation and associated bacterial resistance.[27] SSI has been reported in 0.5-5.3% of TTAs.[2,7,10,11,17,18] The highest incidence was reported in a study of 224 TTAs, where prolonged surgery times directly increased the risk of infection, and postoperative antibiotherapy did not prevent SSI.[28] Antibiotherapy and implant removal are often combined in SSI cases to facilitate resolution of the infection. However, TTA implants may be more difficult to remove due to the location of the cage within the osteotomy gap and the design of the pronged fork. TTA implant removal was only necessary in 0-1.3% of cases in previous reports, which is consistent the 1% incidence in our study.[2,7-10,28] Our results provide evidence to suggest that surgeons should anticipate low rates of bone fractures, infections, or implant removals due to complications after TTAs.

Titanium TTA implants are smaller and more flexible compared to implants designed for tibial plateau leveling osteotomy (TPLO), because TTA functions as a tension band and compression repair rather than a buttress plate. Implant failure can be caused by surgical error, damage to the fork during insertion, cycling of the hardware, poor bone quality, or poor owner compliance with postoperative exercise restriction. Since its introduction in small animals, research on postoperative complications, implant biomechanics, and advancement of software technology have led to refinement in preoperative planning and implant selection for TTAs.[6,9,24] The authors now use lateral stifle radiographs with the limb in full extension, rather than at 135 degrees of flexion for preoperative measurements. Similarly, transparent common tangent overlay[24] or software (Orthoplan, Sound-Eklin, Carlsbad, California) are used to select cage and plate size. Nutt et al concluded that bone fractures after TTA resulted from poor plate and cage positioning, and narrow width at the distal level of the osteotomy.[16] Small cage size has been associated with increased postoperative complications, including persistent tibial thrust and meniscal tears.[7,8] To avoid complications in dogs with concurrent MPL, the authors recommend concurrent lateral transposition and advancement of the tibial tuberosity, which can be accomplished by appropriate bending of the plate and lateral placement of the largest cage size possible.

No studies have documented the relation between planned and actual patellar tendon angles after TTA. The surgeons in this study performed TPLO but were prompted to introduce TTAs in their practice because it is less invasive, seemed associated with fewer complications, and eliminated the potential loss of desired tibial plateau angle due to unstable fixation after TPLO. Since the development of TPLO locking plates,[29] the authors have returned to TPLOs, as both procedures may now have similar postoperative complications.[14,30] Systematic literature reviews comparing surgical options to treat CrCL deficiency emphasize the lack of level I and II randomized, controlled, blinded studies to guide the selection of any particular procedure.[31,32] The evidence currently available in the veterinary literature consists mainly of level III and IV retrospective studies and case reports, many of those limited in sample size.[2,7,9-12,16,17,21]

Surgeons with a heavy case load of CrCL disease should be encouraged to report their surgical repair techniques in detail and document postoperative outcomes. While such reports provide a basis for future research and evidence-based surgery, their impact may be affected by limitations related to case selection and measures of outcomes. First, the retrospective nature of our study allows for bias in case selection, surgeon, or clinics. In addition, our study did not assess body condition score, muscle mass, or limb conformation, factors that could have influenced surgical outcomes. Our study most likely underestimates the overall incidence of complications after TTA since minor complications were not included. In addition, complications may have been undiagnosed, treated elsewhere or lost to follow-up. The potential of undiagnosed postliminary meniscal tear is especially relevant, as no reliable tool has been established to diagnose this condition. Menisci were inspected in all cases, but latent meniscal tears may not have been identified at initial surgery. Our study design cannot account for dogs that experienced postoperative lameness but were not returned to the clinic.

In conclusion, TTA was associated with a relatively low incidence of major postoperative complications, all successfully managed in the population of dogs evaluated here. Medial meniscal release is recommended at the time of TTA to avoid postliminary tears in dogs with CrCL deficiency and no apparent meniscal damage.

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