Received: 25 June 2020 | Revised: 10 March 2021 | Accepted: 24 March 2021

DOI: 10.1111/vsu.13634

ORIGINAL ARTICLE - RESEARCH

WILEY

Timing of and risk factors for deep surgical site infection requiring implant removal following canine tibial plateau leveling osteotomy

Renee A. McDougall DVM, MPH[1] | Daniel I. Spector DVM, DACVS-SA[1] | Robert C. Hart DVM, DACVS[1] | David L. Dycus DVM, MS, CCRP, DACVS-SA[2] | Hollis N. Erb DVM, MS, PhD[3]

[1]Department of Surgery, The Animal Medical Center, New York, New York, USA

[2]Department of Surgery, Veterinary Orthopedics and Sports Medicine Group, Annapolis Junction, Maryland, USA

[3]College of Veterinary Medicine, Cornell University, Ithaca, New York, USA

Correspondence
Renee A. McDougall, Department of Surgery, The Animal Medical Center, 510 E 62nd Street, New York, NY 10065, USA.
Email: randrea.mcdougall@gmail.com

Abstract

Objective: To identify demographic risk factors for deep surgical site infection (SSI) requiring tibial plateau leveling osteotomy (TPLO) implant removal and time to implant removal.

Animals: Four hundred and thirty-three dogs that underwent a TPLO (144 that developed a deep SSI and required implant removal, 289 that did not).

Study Design: Retrospective case–control study.

Methods: Records of dogs undergoing implant removal due to a deep SSI after TPLO between 2006 and 2018 at two referral centers were reviewed. These records were frequency-matched by date to dogs undergoing TPLO that did not require implant removal. Multivariable analyses tested associations between demographics and implant removal as well as timing of implant removal.

Results: Deep SSI and implant removal occurred in 144 of 4813 (3.0%; 95% CI: 2.5, 3.5) dogs treated with TPLO. Implant removal was performed at a median of 279 days (range 49–2394 days) postoperatively. Male dogs (OR 1.8; 95% CI: 1.2, 2.7) and German Shepherd dogs (GSDs) (OR 7.4; 95% CI: 2.6, 20.5) were associated with plate removal. Earlier TPLO plate removal was associated with GSDs only (HR 2.4; 95% CI: 1.4, 4.1).

Conclusion: Implant removal due to SSI after TPLO was uncommon, although male dogs and GSDs seemed predisposed to this complication.

Significance: These demographic risk factors can be used to educate owners regarding perioperative management.

1 | INTRODUCTION

Pathology of the cranial cruciate ligament (CCL) is one of the most common causes of lameness in dogs.[1] Though several treatments exist, the tibial plateau leveling osteotomy (TPLO), proposed by Slocum and Devine, is one of the most commonly performed.[2,3] Among dogs undergoing the TPLO, development of a surgical site infection (SSI) has been reported in up to 3%–15.8% of dogs.[4-14] Though the impact of SSI can vary, consequences may include increased costs, discomfort, poor long-term outcome, and additional patient morbidity associated with a second anesthetic event.[13,15,16]

Risk factors identified for the development of an SSI associated with the TPLO include the German Shepard

Results were presented at 2019 VOS Conference, Sun Valley, Idaho.

breed (GSD), intact male dog status, increased body weight, preoperative colonization with methicillin-resistant *Staphylococcus pseudintermedius* (MRSP), anesthesia time, certain types of implants, performance of a meniscectomy, lower experience of the attending surgeon, and lack of postoperative antibiotics.[8,11,12,16-19] These studies have helped shape client education and perioperative patient care, though they cast a wide net for investigation. Most, for example, recognize a difference between superficial incisional and deep incisional SSIs as defined by the Centers for Disease Control (CDC), but do not evaluate differences between these populations.[20] In human medicine, a distinction between risk factors associated with superficial and deep/organ space infections is well established.[21-23] For example, in studies evaluating patients undergoing colectomy and pancreatectomy procedures, increased BMI has been linked to the development of deep/organ space SSI versus superficial SSI.[21,22] Investigation into subtype-specific SSI risk factors in dogs undergoing a TPLO might reveal similar disparities. For example, though weight has commonly been identified as a risk factor for SSI following the TPLO,[8,19,24] a recent study by Stine et al evaluating only dogs with deep SSI undergoing implant removal identified no such trend.[25]

Few studies evaluating dogs developing a deep SSI and requiring implant removal have been published. All share a focus on surgical risk factors including implant type, and protocol changes to reduce implant-associated infection.[12,16,25] An evaluation of demographic risk factors was only performed in a single study and revealed that among age, sex, and weight, none were associated with an increased risk of implant removal.[25] Corroboration of demographic risk factors for dogs undergoing implant removal following a TPLO may help guide client education and patient care. The objective of the current study was to describe the population of dogs with deep SSI undergoing TPLO implant removal—including age, sex, breed, and weight— and identify demographic risk factors for implant removal following a TPLO. Our two-sided null hypotheses were that the age, male sex, breed, and heavier body weight would not be associated with increased risk of implant removal or time to implant removal following a TPLO.

2 | MATERIALS AND METHODS

2.1 | Definitions

In the current study, superficial, deep, and organ/space SSI are defined according to the criteria established by the CDC with two modifications (Table 1). First, to increase the objectivity of diagnosis, implant removal was used to confirm involvement of deep soft tissues for dogs diagnosed with a deep SSI. Second, according to historical precedent, time to diagnosis of a deep SSI was not restricted to 90 days.[12,16,25]

2.1.1 | Explant group selection

Inclusion criteria

Electronic medical records of dogs that underwent TPLO plate removal between October 2006 and April 2018 at two referral centers—Veterinary Orthopedics and Sports Medicine group (VOSM) and the Animal Medical Center (AMC)—were reviewed for clinical signs of a deep SSI (Table 1). Dogs with a negative culture were included. For all dogs undergoing staged bilateral TPLO implant removals, the first procedure was selected for inclusion. Dogs were excluded if at the time of the initial TPLO medical records were incomplete, additional procedures requiring metal implantation were performed, removal of any previously implanted material was noted, or re-evaluation was not performed by a veterinarian at least 30 days following surgery. Similarly, dogs were excluded if evidence of postliminary meniscal pathology was noted at the time of implant removal.

Data collection

Demographic data collected included age (year), sex, breed, and weight (kg) as recorded at the time of the TPLO. Non-orthopedic comorbidities were recorded. When postoperative oral or subcutaneous antimicrobial therapy was administered, the type, dose, route, and duration were recorded. Postoperative variables recorded included the number of days between the TPLO and plate removal and the presence of a positive or negative culture. Culture and susceptibility patterns following TPLO plate removal have been reported elsewhere and were not reported here.[12,13,25]

2.1.2 | Reference group selection

Inclusion criteria

Due to the rarity of the outcome of interest (deep SSI and implant removal), a 2:1 ratio of reference to explant dogs was considered sufficient. Cases were frequency matched by facility and date of initial TPLO. This meant that the dog undergoing TPLO without subsequent plate removal immediately preceding and following the TPLO for each explant dog was selected for inclusion in the reference group. This selection method was used to minimize the impact of external factors, such as season, surgeon, and

TABLE 1 Criteria for defining a surgical site infection[20]

	Superficial incisional SSI	Deep incisional SSI	Organ/space SSI
Timing	Within 30 days of surgery	Within 30 or 90 days of surgery	Within 30 or 90 days of surgery
Location	Only skin or subcutaneous tissues of the incision	Deep soft tissues (i.e., fascial and muscle layers) of the incision	Any area other than the incision which was opened or manipulated during surgery
Clinical aspects (one or more of the following must be present)	• Purulent discharge • Organisms isolated from an aseptically collected sample of fluid or tissue • One or more of pain or tenderness, localized swelling, redness, or heat, and incision is deliberately opened by surgeon unless culture negative	• Purulent drainage from the deep incision but not organ/space • Deep incision spontaneously dehisces or is deliberately opened when patient has one or more of fever, localized pain or tenderness unless culture negative • Abscess or other evidence of infection on direct exam, during re-operation or by histopathology or radiology	• Purulent drainage from drain that is placed into the organ/space • Organisms isolated from aseptically collected sample from the organ/space • Abscess or other evidence of infection on direct exam, during re-operation or by histopathology or radiology • Diagnosis of organ/space SSI by attending clinician

additional staff, on outcomes. Dogs were excluded if at the time of the initial TPLO medical records were incomplete, additional procedures requiring metal implantation were performed, removal of any previously implanted material was noted, or re-evaluation was not performed by a veterinarian at least 30 days following surgery.

Data collection

Demographic variables abstracted for the reference group were the same as those for the explant group. Postoperative variables included date of final follow-up only.

2.1.3 | Treatments

Surgical technique

TPLO surgical procedures were performed by a Diplomate of the American College of Veterinary Surgeons or an experienced, residency-trained veterinarian with the assistance of one or two surgical interns or residents. Surgery was performed according to the technique of Slocum and Devine.[2] All dogs underwent either a craniomedial or caudomedial arthrotomy with the assistance of a probe to evaluate the medial meniscus. If the medial meniscus appeared grossly healthy upon examination, caudal pole medial meniscal release was performed according to surgeon preference. A jig was used at the discretion of the surgeon. The osteotomy was stabilized using a TPLO plate according to surgeon preference. At both facilities, cefazolin (22 mg/kg IV) was administered between the time of induction and surgery, every 90 min intraoperatively, and every 8 h postoperatively for the evening following the procedure. Warming water blankets were routinely used at both facilities intraoperatively to reduce the risk of hypothermia.

Postoperative care and follow-up

Dogs were typically discharged 24–48 h postoperatively and returned for incisional evaluation 10–14 days postoperatively. An Elizabethan collar was dispensed with all dogs and use was recommended until incisional evaluation. Routine evaluations at VOSM consisted of a physical examination and radiographs at 4, 8, and 12 weeks postoperatively. At AMC, evaluation consisted similarly of a physical examination and radiographs at 6–8 weeks postoperatively. At both facilities, owners were encouraged to gradually increase leash walks after incisional healing, but eliminate or minimize running, jumping, and playing until the 6–8 weeks postoperative evaluation. At that time, given appropriate radiographic healing, owners were provided with instruction on gradual return to normal activity over 3–4 weeks.

Implant removal and diagnosis

Removal of a TPLO implant was performed following adequate radiographic healing of the osteotomy. Prior to closure, a plate screw and sample of soft tissue surrounding the plate was submitted for aerobic and anaerobic culture and sensitivity.

2.2 | Statistical analysis

Most statistical analysis was performed using Statistix© (Statistix© 10, Analytical Software, Tallahassee, FL). Some sample-size justification was performed using

MedCalc® (MedCalc® 19.5.1, Software, Ostend, Belgium). Demographic and surgical variables were described using frequencies (%) or median (quartiles 1 and 3, Q1, Q3) for categorical and non-normally distributed continuous data, respectively. All continuous variables had $p \leq .0001$ in the Shapiro-Wilks test for goodness-of-fit to the Gaussian distribution; tests were run separately for the explant and reference groups.

For risk factor analysis, continuous variables were categorized because they were considered unlikely to meet linearity assumptions in the regression analyses. Weight was divided into dogs 3.7 to ≤20 kg, >20 to ≤50 kg, and > 50 to 92 kg based both on previous literature and clinical relevance (e.g., dogs ≤20 kg were likely to receive a 2.7 mm TPLO plate or smaller, dogs >50 kg were likely to receive a 3.5 mm broad or larger TPLO plate) (Table A1).[26,27] Age was divided into quartiles (Table A1). Breed was categorized into Five categories, including the four most common breeds in the data set and all other breeds. A chi-squared test of independence was performed to assess proposed demographic variables for association with implant removal. Associations between proposed risk factors and time to implant removal were assessed using the log-rank test. Factors identified in the univariable analyses as significant were considered for inclusion in the relevant multivariable regression model. Weight was offered to each multivariable model on a priori grounds (because it was the risk factor of primary interest). Additional risk factors were assessed using a Bonferroni-adjusted *p*-value of $p < .017$ ($p = .05/3 = .017$, two-sided).

Prior to multivariable modeling, polychotomous risk factors eligible for either regression were transformed into sets of dichotomous variables. This included dichotomous categories for weight: 3.7 to ≤20 kg (yes/no) and >50 to 92 kg (yes/no). Age became three dichotomous variables, including one for each of the three lowest age quartiles. Breed became four dichotomous variables for GSD, Golden Retriever, Labrador Retriever, and American Pit Bull Terrier breeds. For each dichotomous variable, the reference group was all other dogs. Dichotomous variables were created because the risk factors could not be modeled in continuous or polychotomous forms. Both logistic and proportional-hazards regressions assume that all 1-unit increases between adjacent pairs of values (of the independent variable in an ordered data set) have the same odds ratio (OR) or hazards ratio (HR). The "proportional-odds" and "proportional-hazards" assumptions are unlikely to be met even for data with intrinsic ordering. In contrast, a dichotomous variable is associated with only one such increase; therefore, the proportionality assumption is met by default.

A logistic regression model was used to identify relationships between risk factors and TPLO plate removal. A proportional hazards regression model was used to identify relationships between variables and time to TPLO plate removal. For both models, a *p*-value of <.05 (two-sided) was considered significant for the primary risk factor of interest: weight. A Bonferroni-adjusted *p*-value of ≤.017 (two-sided) was considered significant for age, sex, and breed to account for multiplicity. For the final models, significant OR and HR were reported with a 95% CI. Significant results for days to implant removal were displayed using Kaplan–Meier graphs. A post-hoc analysis of detectable odds ratios for weight (the primary risk factor of interest) was performed given an alpha of 5%. This suggested that the current study had 90% power to detect whether dogs >50 kg had an increased odds of implant removal greater than ≥1.9 when compared with other weight groups. Chi-square tests of association were used to detect associations between risk factors retained in the final models and weight.

3 | RESULTS

Of 4813 dogs that underwent TPLO (4507/4813, 93.6% performed at VOSM and 306/4813, 6.4% performed at AMC) performed during the study period, 346 dogs underwent removal of the TPLO implants. There were 202 dogs that did not meet the inclusion/exclusion criteria. For 135 of the 202 dogs, removal or placement of additional implants was noted at the time of initial TPLO. An additional 67 dogs were excluded because the TPLO implant was removed for a reason other than suspected implant-associated infection, including postliminary meniscal injury. In total, 144 (3.0%; 95% CI: 2.5, 3.5) dogs were included in the explant group. Two hundred and eighty-nine reference dogs were selected. In no case was a reference dog selected for inclusion more than once. In total, 433 dogs were included in the study.

3.1 | Demographic variables

Median age of explant dogs was 4.0 years (2.5, 6.6 years). Median age of reference dogs was 5.3 years (3.0, 8.0 years) (Table 2). There were 53% males and 47% females within the explant group. In the reference group, there were 38% males and 62% females (Table 2). The most common breeds were the same among both groups and included GSD 12%, Labrador retrievers 11%, American Pit Bull Terriers 6%, and Golden retrievers 3% in the explant group. Among reference dogs, this included Labrador retrievers 17%, American Pit Bull Terriers 4%,

TABLE 2 Frequency distributions (%) of selected demographic variables for 433 dogs that underwent the tibial plateau leveling osteotomy (TPLO) at one of two referral hospitals between 2006 and 2018

		Explant group		Time to TPLO plate removal	Reference group		Risk of TPLO plate removal
Variable	Category of variable	Total dogs	% in this category	*p*-value	Total dogs	% in this category	*p*-value
Age (years)		144		.97	289		.022
Sex	Male	144	53	.011[a]	289	38	.004[b]
	Female		47			62	
Breed	Labrador Retriever	144	11	.001[a]	289	17	.0001[b]
	German Shepherd		12			2	
	American Pit Bull Terrier		6			4	
	Golden Retriever		3			4	
	Other		69			74	
Weight (kg)	3.7 to ≤20	144	9	.13[a]	289	15	.05[b]
	>20 to ≤50		76			76	
	>50 to 92		15			9	

Note: Risk factors considered for inclusion in multivariable regression models. *p*-values associated with univariable analysis evaluating whether demographic variables were associated with risk of TPLO plate removal or time to TPLO plate removal are included.
[a]Considered for inclusion in the proportional hazards regression.
[b]Considered for inclusion in the logistic regression model. A *p*-value of <.05 was considered significant for weight because it was considered the primary outcome of interest. A *p*-value of <.017 was considered significant for all other variables to address multiplicity.

Golden retrievers 4%, and GSD 2% (Table 2). Median weight among explant dogs was 35.0 kg (28.2, 43.6 kg). Median weight among reference dogs was 32.0 kg (25.0, 39.5 kg) (Table 2). Comorbidities were present in 20 (13.9%) of 144 explant dogs, including a history of pyoderma in one (0.7%), mange one (0.7%), environmental allergies nine (6.3%), ear infections one (0.7%), urinary tract infections (UTI) one (0/7%), and testing positive for *Borrelia burgdorferi* four (2.8%), *Anaplasma phagocytophilum* one (0.7%), or *Erhlichia* two (1.4%) antibodies. Comorbidities were present in 29 (10.0%) of 289 reference dogs, including a history of MRSP in one (0.3%), pyoderma one (0.3%), ear infections three (1.0%), environmental allergies eight (2.8%), UTIs one (0.3%), urinary incontinence three (1.0%), hypothyroidism one (0.3%), inflammatory bowel disease two (0.6%), a heart murmur three (1.0%), and testing positive for *Borrelia burgdorferi* antibodies six (2.1%).

3.2 | Postoperative variables

Postoperative antimicrobials were used in all dogs (100%) and included cefpodoxime (5–10 mg/kg orally once daily) in 363 (83.8%) of 433 dogs, cephalexin (22–30 mg/kg orally twice daily) in 59 (13.6%) of 433 dogs, amoxicillin/clavulanic acid (13.75 mg/kg orally twice daily) in four (0.9%) of 433 dogs, enrofloxacin (10 mg/kg orally once daily) in three (0.7%) of 433 dogs, doxycycline (5–10 mg/kg orally twice daily) in two (0.5%) of 433 dogs, cefovecin (8 mg/kg subcutaneously once) in one (0.2%) of 433 dogs, and clindamycin (10–15 mg/kg orally twice daily) in one (0.2%) of 433 dogs. Antimicrobials were dispensed for a median of 7 days in both groups (Q1, Q3: 7, 7 days). Implant removal was performed at a median of 279 days for dogs in the explant group (Q1, Q3: 159, 557). A positive culture was present in 100 (69%) explant cases, negative culture in 24 (17%) cases, and no record in the remaining 20 (14%). Median follow-up time was 318 days (Q1, Q3: 170, 650 days) for the explant group and 106 days (Q1, Q3: 84, 410 days) for the reference group.

3.3 | Univariable assessment

Risk factors for TPLO plate removal offered to the final model included sex (p = .0040), breed (p = .0001), and

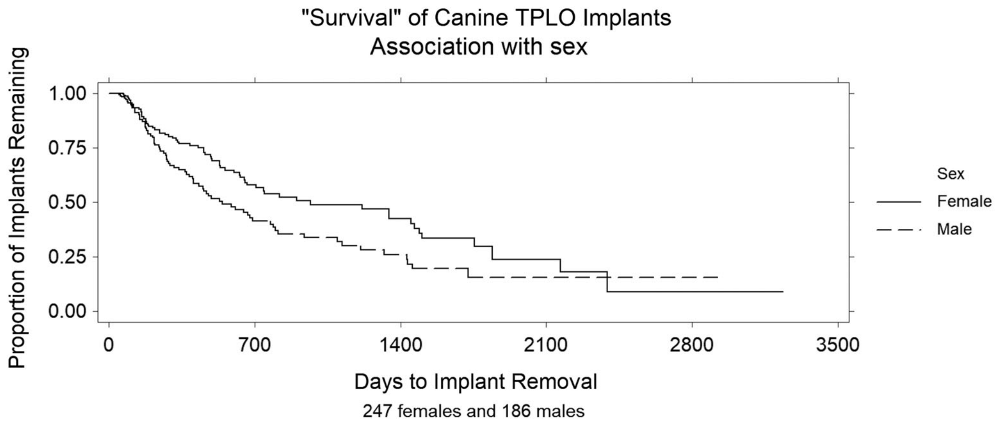

FIGURE 1 Kaplan–Meier graph displaying time until implant removal for female dogs (solid line) and male dogs (dashed line) from 2006 to 2018. TPLO, tibial plateau leveling osteotomy

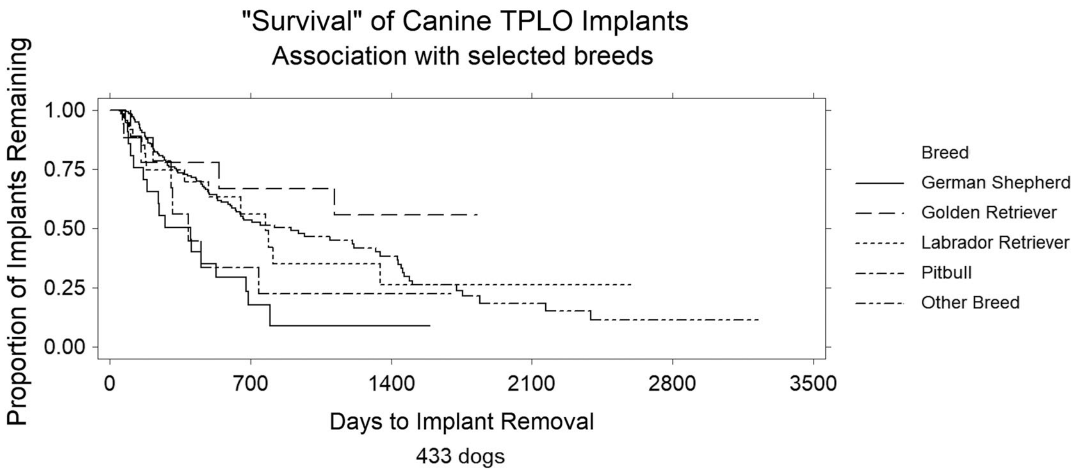

FIGURE 2 Kaplan–Meier graph displaying time until implant removal for German Shepard dogs (GSDs) (solid line), Golden Retrievers (dashed line), Labrador Retrievers (dotted line), American Pit Bull Terriers (dash-dot-dash line), and all other breeds (dash-dot-dot-dash line) from 2006 to 2018. TPLO, tibial plateau leveling osteotomy

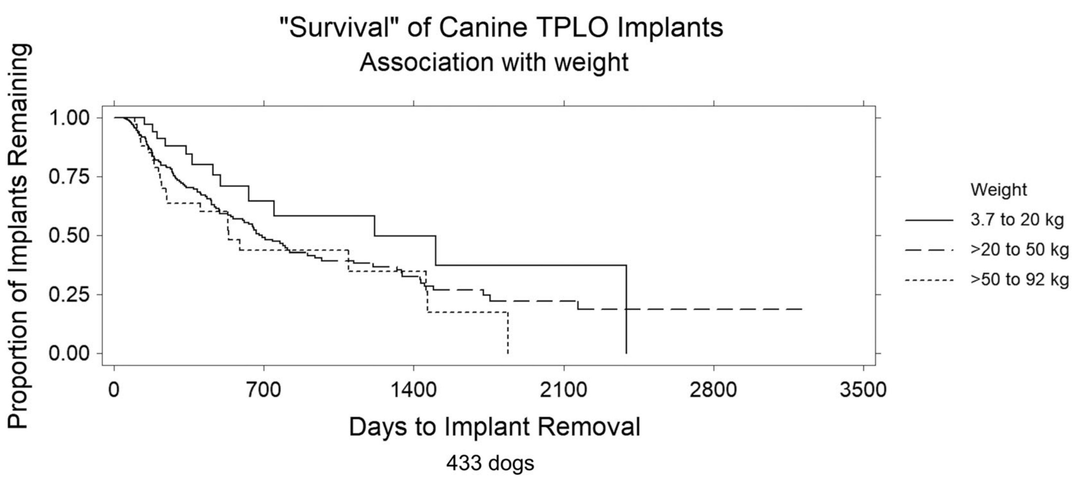

FIGURE 3 Kaplan–Meier graph displaying time until implant removal for dogs 3.7 to ≤20 kg (solid line), 20 to ≤50kg (dashed line), and >50 to 92 kg (dotted line) between 2006 and 2018. Data points represent the proportion of implants remaining relative to time after tibial plateau leveling osteotomy (TPLO) surgery. Median time to TPLO plate removal was 1205 days for dogs 3.7 to ≤20 kg, 676 days for dogs >20 to ≤50 kg, and 534 days for dogs >50 to 92 kg

TABLE 3 Final multivariable model results

Variable	OR	HR	95% CI	*p*-value
Logistic regression				
Male (vs. female)	1.8	N/A	1.2, 2.7	.0064
German Shepherd dogs (vs. all other breeds)	7.4	N/A	2.6, 20.5	.0001
Proportional hazards regression				
German Shepherd dogs (vs. all other breeds)	N/A	2.4	1.4, 4.1	.0006

Note: Separate models were tested for factors associated with tibial plateau leveling osteotomy (TPLO) plate removal (odds ratio; OR) and factors associated with time to TPLO plate removal (hazards ratio; HR) in 433 dogs that underwent a TPLO.

body weight ($p = .05$) (Table 2). Demographic risk factors for time to TPLO plate removal offered to the final model included sex ($p = .0111$), breed ($p = .0011$), and weight ($p = .13$). Kaplan–Meier survival analysis for sex revealed median time to implant removal to be 538 days for male dogs (Q3, Q1: 241, 1371) and 940 days for female dogs (Q3, Q1: 427, 1839) (Figure 1). A Kaplan–Meier survival analysis was also created for breed (Figure 2). Median estimated days to implant removal for GSD was 286 days (Q3, Q1: 124, 640 days), for American Pit Bull Terriers 355 days (Q3, Q1: 298, 674 days), Labrador Retrievers, 761 days (Q3, Q1: 182, not reached), and all other breeds 889 days (Q3, Q1: 330, 1687) (Figure 2). The median was not reached for Golden Retrievers. Median estimated time to implant removal was 1205 days (Q3, Q1: 472, 1863 days) for dogs 3.7 to ≤20 kg, 676 days (Q3, Q1: 282, 1720 days) for dogs >20 to ≤50 kg, and 534 days (Q3, Q1: 212, 1458 days) for dogs >50 to 92 kg (Figure 3).

3.4 | Multivariable analyses

The final logistic regression model for TPLO plate removal showed higher odds of removal for the male dogs (OR 1.8; 95% CI: 1.2, 2.7) and GSD breed (OR 7.4; 95% CI: 2.6, 20.5) (Table 3). The final proportional hazards regression model for time to TPLO plate removal retained only GSD breed (HR 2.4; 95% CI: 1.4, 4.1) (Table 3).

4 | DISCUSSION

In the current study, male dogs were at increased odds of developing a deep SSI requiring TPLO implant removal. Additionally, GSD were at both increased odds of implant removal and experienced decreased time to implant removal. Though weight was significant in a univariable analysis, it was ultimately not identified as a risk factor for TPLO implant removal or time to implant removal in a multivariable analysis. Age was similarly not identified as a risk factor for TPLO implant removal or time to implant removal. Given these results, our null hypothesis regarding age and weight was accepted.

Overall, development of a deep SSI and implant removal was uncommon in the current study and was required in only 3.0% of dogs undergoing a TPLO. This is similar to previously published rates of deep SSI and implant removal following the TPLO, which range from 3.5% to 7.4%.[12,13,16,17] Though uncommon, deep SSI and implant removal are associated with unique consequences, including aggressive or long-term antibiotic use.[12] Treatment with antimicrobials, however, is often unsuccessful in the face of deep soft tissue involvement, and implant removal is required in up to 88.9% of these cases.[12] Treatment failures and antimicrobial stewardship suggest a prophylactic approach should be strongly considered, rather than a focus on therapeutic antimicrobial treatment. To this end, a better demographic understanding of this population is valuable.

Among demographic risk factors evaluated, male dogs were identified in a univariable and multivariable analyses as requiring TPLO plate removal more commonly than female dogs (OR 1.8). Sex differences in risk may be related to androgen-related differences in skin physiology. Specifically, testosterone has been previously demonstrated in a mouse model to impair wound healing and enhance the inflammatory response.[28] Evidence of this endocrine-mediated difference in wound healing has been previously demonstrated in dogs, humans, and rodents.[29,30] Given the high rate of neutered dogs likely to be present in the current population, the influence of androgens on wound healing is uncertain, leaving the cause for this sex difference largely unknown.

In addition to male dogs, GSDs had a 7.4-fold increased odds of deep SSI requiring TPLO implant removal in both the univariable and multivariable analyses, compared with all other breeds. Previous studies have similarly identified GSD as a breed at increased risk of complications including SSI following the TPLO.[17,24] Lopez et al has proposed that GSD may be genetically predisposed to SSI, regardless of other pre-existing conditions at the time of TPLO.[17] The apparent increased odds of TPLO plate removal in GSD suggests that heightened level of awareness of SSI risk is indicated for this breed. Understanding the increased risk of TPLO implant removal in GSD may increase perioperative vigilance, which may, in turn, result in earlier recognition and treatment of an SSI. Early diagnosis of SSI has been demonstrated to reduce the risk of implant removal following TPLO.[31]

Unlike sex and breed, neither age nor weight was identified as a risk factor for TPLO plate removal in the multivariable analyses. Though age has never been identified as a risk factor for SSI or deep SSI following TPLO, weight has been identified in several previous studies.[8,26,27] The underlying cause of this relationship is unknown; however, authors have suggested that contributing factors include increasing micromotion at the level of the osteotomy in large and giant-breed dogs resulting in a favorable local environment for infection.[26,27] It is possible that the current study was underpowered to identify a relationship between weight and implant removal. This is considered particularly unlikely given that we had 90% power to identify an OR $\geq$ 1.9 and that weight was similarly dismissed as a potential risk factor in a previous study evaluating dogs with deep SSI undergoing implant removal ($p = .13$).[25] Alternatively, it is possible that weight is simply a reflection of the breeds at increased risk of implant removal. In the current study, for example, all 22 GSD were >20 kg.

To the authors' knowledge, this study represents the first evaluation of risk factors for time to TPLO implant removal. Among age, sex, breed, and weight, the only factor associated with a decreased time to implant removal was the GSD breed, for which estimated median time to implant removal was 286 days. In contrast, the median time to implant removal for all other breeds (not including the Golden Retriever, Labrador Retriever, and American Pit Bull Terrier) was 889 days. It is possible that purulent drainage was more common in GSDs than other breeds, making early recognition of a deep SSI more likely. Alternatively, it is possible that a portion of the GSD in our population were working dogs and frequently evaluated by veterinarians, similarly increasing the likelihood of an early diagnosis. Ultimately, regardless of cause, this information should play a role in client education.

Breeds other than the GSD underwent implant removal significantly later than 285 days, including two groups with a median time to implant removal more than 2 years following initial TPLO (median time to implant removal was 761 days for Labrador Retrievers and 888 days for all other breeds). In a strict interpretation of the criteria defining a deep SSI (Table 1), in which a diagnosis of deep SSI must be made within 90 days, many of these dogs would have been excluded from the study population. However, previous studies evaluating dogs undergoing TPLO implant removal have similarly identified dogs undergoing implant removal well beyond 1 year postoperatively.[12,16,25] In fact, in one study performed by Thompson et al, mean time to TPLO implant removal was 16 months.[16] This commonality does not negate the importance of the CDC criteria, particularly in achieving sensible active surveillance and improving comparability of veterinary data. Instead, it suggests that when investigating TPLO SSI, the criteria for a deep SSI might require a less strict timeline.

4.1 | Limitations

The major limitation to this study was the retrospective nature, and reliance on the completeness of medical records. Data such as length of anesthesia, hypotension, and hypothermia that are known risk factors previously linked to SSI in general were not consistently reported, preventing further assessment. Additionally, potential surgical risk factors, including meniscal treatment, type of material used to close the skin, TPLO plate type, and skin carriage of MRSP were deliberately omitted from this analysis. Type of meniscal treatment and type of material used to close the skin at the time of initial surgery could not be consistently ascertained. The TPLO implant was selected according to surgeon preference; however, the locking versus non-locking nature of the plate was not consistently recorded. Due to the time frame associated with study inclusion (October 2006 and April 2018), it is possible that some non-locking plates were used. This would be of particular interest in dogs >50 kg, where the use of non-locking implants has recently been associated with an increased risk of SSI following the TPLO procedure.[26] To avoid undue bias, assessment of plate type was not performed. Lastly, while skin carriage of MRSP has been identified as a risk factor for SSI following the TPLO, culture of the skin prior to surgery was not a routine practice at either facility.

All of the dogs in the current study received postoperative antimicrobials; however, the impact of antimicrobial administration on the risk of deep SSI is unclear. Despite several studies identifying postoperative antimicrobials as protective against SSI following TPLO,[8,11,13,26] other studies have refuted this finding.[19,32] For example, use of postoperative cefpodoxime did not impact the risk of SSI following TPLO according to a prospective study performed by Spencer et al.[19] Similarly, the use of antimicrobials did not alter the risk of either superficial or deep SSI following TPLO in a more recent study.[32] Ultimately, given the variable surgical and postoperative protocols used, as well as the aggregation of dogs diagnosed with superficial and deep SSI in previous studies, further evaluation is needed to better understand the impact of antimicrobials following the TPLO.

5 | CONCLUSION

To the authors' knowledge, this is the first study to evaluate demographic risk factors for both implant removal and time to implant removal following TPLO. Male dogs had an increased odds of implant removal. Additionally, GSD had an increased odds of implant removal and decreased time to implant removal, with a median time to implant removal of 286 days.

While the cause for these at-risk groups is not known, owner education may play a role in increasing postoperative vigilance as well as early recognition and treatment of SSI reducing the need for implant removal. Additionally, time to implant removal in the current study extended well beyond a year for some groups, suggesting that future studies on deep SSI following TPLO should consider adopting long-term follow-up.

ACKNOWLEDGMENTS

RAM—Corresponding author with substantial contributions to study conception and design, data acquisition and interpretation, manuscript drafting, and final approval of the version to be published. DIS, RCH, and DLD—Provided substantial contribution to the study design, data interpretation, critical manuscript revision, and final approval of the version to be published. HNE—Provided substantial contribution to the study design, data analysis, interpretation, critical manuscript revision, and final approval of the version to be published; all authors agree to be accountable for all aspects of the work as described by the ICMJE.

CONFLICT OF INTEREST

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

REFERENCES

1. Hayashi K, Manley PA, Muir P. Cranial cruciate ligament pathophysiology in dogs with cruciate disease: a review. *J Am Anim Hosp Assoc*. 2004;40:385-390.
2. Slocum B, Devine-Slocum T. Tibial plateau leveling osteotomy for cranial cruciate ligament rupture. In: Bojrab MJ, ed. *Current Techniques in Small Animal Surgery*. Baltimore, MD: Williams & Wilkins; 1998:1209-1215.
3. Kim SE, Pozzi A, Kowaleski MP, Lewis DD. Tibial osteotomies for cranial cruciate ligament insufficiency in dogs. *Vet Surg*. 2008;37:111-125.
4. Pacchiana PD, Morris E, Gillings SL, Jessen CR, Lipowitz AJ. Surgical and postoperative complications associated with tibial plateau leveling osteotomy in dogs with cranial cruciate ligament rupture: 397 cases (1998-2001). *J Am Vet Med Assoc*. 2003;222:184-193.
5. Priddy NH, Tomlinson JL, Dodam JR, Hornbostel JE. Complications with and owner assessment of the outcome of tibial plateau leveling osteotomy for treatment of cranial cruciate ligament rupture in dogs: 193 cases (1997-2001). *J Am Vet Med Assoc*. 2003;222:1726-1732.
6. Stauffer KD, Turtle TA, Elkins AD, Wehrenberg AP, Character BJ. Complications associated with 696 tibial plateau leveling osteotomies (2001-2003). *J Am Anim Hosp Assoc*. 2006;42:44-50.
7. Kowaleski MP, Boudrieau RJ, Beale BS, Piras A, Hulse D, Johnson KA. Radiographic outcome and complications of tibial plateau leveling osteotomy stabilized with an anatomically contoured locking bone plate. *Vet Surg*. 2013;42:847-852.
8. Fitzpatrick N, Solano M. Predictive variables for complications after tibial plateau leveling osteotomy with stifle inspection by arthrotomy in 1000 consecutive dogs. *Vet Surg*. 2010;39:460-474.
9. Vasseur PB, Levy J, Dowd E, Eliot J. Surgical wound infection rates in dogs and cats: data from a teaching hospital. *Vet Surg*. 1988;17:60-64.
10. Etter SW, Ragetly GR, Bennet RA, Schaeffer DJ. Effect of using triclosan-impregnated suture for incisional closure on surgical site infection and inflammation following tibial plateau leveling osteotomy in dogs. *J Am Vet Med Assoc*. 2013;242:355-358.
11. Nazarali A, Singh A, Weese JS. Perioperative administration of antimicrobials during tibial plateau leveling osteotomy. *Vet Surg*. 2014;43:966-971.
12. Savicky R, Beale B, Murtaugh R, Swiderski-Hazlett J, Unis M. Outcome following removal of TPLO implants with surgical site infection. *Vet Comp Orthop Traumatol*. 2013;26:260-265.
13. Gallagher AD, Mertens WD. Implant removal rate from infection after tibial plateau leveling osteotomy in dogs. *Vet Surg*. 2012;41:705-711.
14. Christopher S, Beetem J, Cook J. Comparison of long-term outcomes associated with three surgical techniques for treatment of cranial cruciate ligament disease in dogs. *Vet Surg*. 2013;42:329-334.
15. Nicoll C, Singh A, Weese JS. Economic impact of tibial plateau leveling osteotomy surgical site infections in dogs. *Vet Surg*. 2014;43:899-902.
16. Thompson AM, Bergh MS, Wang C, Wells K. Tibial plateau leveling osteotomy implant removal: a retrospective analysis of 129 cases. *Vet Comp Orthop Traumatol*. 2011;24:450-456.
17. Lopez DL, VanDeventer GM, Azyazand Y, et al. Retrospective study of factors associated with surgical site infection in dogs following tibial plateau leveling osteotomy. *J Am Vet Med Assoc*. 2018;253:315-321.
18. Nazarali A, Singh A, Moens N, et al. Association between methicillin-resistant *Staphylococcus pseudintermedius* carriage and the development of surgical site infections following tibial plateau leveling osteotomy in dogs. *J Am Vet Med Assoc*. 2014;247:909-916.
19. Spencer DD, Daye RM. A prospective, randomized, double-blinded, placebo-controlled clinical study on postoperative antibiotherapy in 150 arthroscopy-assisted tibial plateau leveling osteotomies in dogs. *Vet Surg*. 2018;47:E79-E87.
20. National Healthcare Safety Network patient safety component manual: chapter 9: surgical site infection (SSI) event. Centers for Disease Control and Prevention Web site. https://www.cdc.

gov/nhsn/PDFs/pscManual/9pscSSIcurrent.pdf. Accessed March 10, 2021.
21. Lawson EH, Hall BL, Ko CY. Risk factors for superficial vs deep/organ-space surgical site infections: implications for quality improvement initiatives. *JAMA Surg*. 2013;148:849-858.
22. Fadayomi AB, Kasumova GG, Tabatabaie O, et al. Unique predictors and economic burden of superficial and deep/organ space surgical site infections following pancreatectomy. *HPB (Oxford)*. 2018;20:658-668.
23. Herruzo R, Diez-Sebastian J, Mora E, Garcia-Caballero J. Trends in the incidence of superficial versus deep-organ/space surgical site infection in a tertiary hospital. *J Surg Res*. 2013; 184:1085-1091.
24. Coletti TJ, Anderson M, Gorse MJ, Madsen R. Complications associated with tibial plateau leveling osteotomy: a retrospective of 1519 procedures. *Can Vet J*. 2014;55:249-254.
25. Stine SL, Odum SM, Mertens WD. Protocol changes to reduce implant-associated infection rate after tibial plateau leveling osteotomy: 703 dogs, 811 TPLO (2006-2014). *Vet Surg*. 2018;47: 481-489.
26. Solano MA, Danielski A, Kovach K, Fitzpatrick N, Farrell M. Locking plate and screw fixation after tibial plateau leveling osteotomy reduces postoperative infection rate in dogs over 50 kg. *Vet Surg*. 2015;44:59-64.
27. Hans EC, Barnhart MD, Kennedy SC, Naber SJ. Comparison of complications following tibial tuberosity advancement and tibial plateau levelling osteotomy in very large and giant dogs 50 kg or more in body weight. *Vet Comp Orthop Traumatol*. 2017;30:229-305.
28. Ashcroft GS, Mills SJ. Androgen receptor-mediated inhibition of cutaneous wound healing. *J Clin Invest*. 2002;110:615-624.
29. Dao H Jr, Kazin RA. Gender differences in skin: a review of the literature. *Gend Med*. 2007;4:308-328.
30. Kurach LM, Stanley BJ, Gazzola KM, et al. The effect of low-level laser therapy on the healing of open wounds in dogs. *Vet Surg*. 2015;44:988-996.
31. Brown G, Maddox T, Baglietto Siles MM. Client-assessed long-term outcome in dogs with surgical site infection following tibial plateau levelling osteotomy. *Vet Rec*. 2016;179:409.
32. Clark AC, Greco JJ, Bergman PJ. Influence of administration of antimicrobial medications after tibial plateau leveling osteotomy on surgical site infections: a retrospective study of 308 dogs. *Vet Surg*. 2020;49:106-113.

How to cite this article: McDougall RA, Spector DI, Hart RC, Dycus DL, Erb HN. Timing of and risk factors for deep surgical site infection requiring implant removal following canine tibial plateau leveling osteotomy. *Veterinary Surgery*. 2021;50:999–1008. https://doi.org/10.1111/vsu.13634

APPENDIX A.

TABLE A1 Appendix to Table 2

		Explant group			Reference group		
Variable	**Category of variable**	**Minimum**	**Median**	**Maximum**	**Minimum**	**Median**	**Maximum**
Age (years)	Overall	0.9	4.0	12.0	0.9	5.3	13.1
	0.94 to ≤2.8	0.9	2.0	2.8	0.9	2.0	2.8
	>2.8 to ≤5.0	2.8	3.6	5.0	2.9	4.0	5.0
	>5.0 to ≤7.3	5.0	6.2	7.2	5.0	6.2	7.2
	>7.3 to 13.1	7.3	8.9	12.0	7.3	8.9	13.1
Weight (kg)	Overall	6.8	35.0	92.3	3.7	32.0	73.6
	3.7 to ≤20	6.8	15.8	19.1	3.7	11.5	20.0
	>20 to ≤50	20.3	34.4	50.0	20.1	33.0	50.0
	>50 to ≤92	50.3	60.9	92.3	50.5	59.0	73.6

Note: Among risk factors assessed, the non-normal variables of age and weight are more completely described by minimum, median, and maximum values, in addition to those listed in Table 2.