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Treatment Outcome and Radiographic Appearance of Healed Tibial Tuberosity Avulsion Fractures in Skeletally Mature Dogs: 21 Cases (2016–2023)

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Abstract

Objective The aim of this study was to evaluate the function and radiographic appearance of healed tibial tuberosity avulsion fractures (TTAF) in dogs after they achieve skeletal maturity.

Study Design This was a retrospective, single-centre cohort study. The medical records of skeletally mature dogs with previously treated TTAF were reviewed.

Bilateral mediolateral stifle radiographs were obtained. Radiographic measurements of tibial plateau angle, patellar position (PP) and axial and transverse tibial tuberosity position were statistically evaluated. Treatment outcome was assessed via direct examination and owner evaluation.

Results Twenty-one dogs were included. Treatment groups were open reduction and internal fixation with pins only ($n = 9$), open reduction and internal fixation with pins and tension band ($n = 6$) and non-surgical management with a cast ($n = 6$). In surgically managed cases, the tibial plateau angle and transverse tibial tuberosity position of TTAF stifles decreased while PP and axial tibial tuberosity position increased. Changes were not observed in the non-surgically managed group. The outcome of surgically managed cases was excellent. The outcome of non-surgically managed cases was reported by owners as good to excellent, although medial patellar luxation was observed in two dogs.

Conclusion Surgically managed TTAF result in altered tibial tuberosity and PP but lead to excellent outcomes despite morphologic changes at skeletal maturity. Non-surgically managed TTAF do not significantly alter tibial tuberosity and PP and result in good to excellent outcomes but may increase the risk of patellar luxation.

Keywords
- tibial tuberosity avulsion fracture
- radiographs
- skeletal maturity
- dog

Introduction

Tibial tuberosity avulsion fractures (TTAF) occur commonly in immature dogs 3 to 8 months old, when the tibial tuberosity is in the apophyseal stage of development.[1–7] The aetiology is associated with low-impact trauma resulting in fracture through the physis due to the weakness of cartilaginous growth plates relative to bone.[3,4] Cranio-proximal displacement of the tibial tuberosity results from the pull of the quadriceps femoris muscle through the patellar ligament.[5,6]

Traditional treatment of TTAF is open reduction and internal fixation (ORIF) with pin and tension band placement; however, numerous other treatments have been described. Alternative surgical fixation methods include ORIF with pins only, fluoroscopic-guided percutaneous pinning and placement of a hybrid external skeletal fixator.[1,7–11] Non-surgical treatment methods, such as cage rest with or

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without external coaptation, are an option for dogs with minimally displaced fragments.[5,6] The prognosis for return to function following TTAF, regardless of the treatment method, has been reported as good to excellent.[1,2,5–9,11]

The juvenile proximal tibia is composed of the tibial tuberosity apophysis, proximal tibial epiphysis, and proximal tibial metaphysis, which are interconnected by three distinct physes. Closure of these growth plates is variable depending on breed but generally occurs between 6 and 12 months of age.[4] Premature closure of a growth plate may occur secondary to the inciting trauma that caused the fracture or due to trauma from surgical implants placed across the physis.[12,13] Although the tibial tuberosity apophysis does not contribute substantially to the longitudinal growth of the bone, premature epiphysiodesis may lead to distal migration of the tibial tuberosity and proximal tibial angular malalignment in the sagittal plane as the diaphysis continues to grow, leading to angular deformities such as procurvatum or recurvatum.[1,5,7,12,13]

To the authors' knowledge, there are no reports evaluating the effect of surgical implants placed across the tibial tuberosity apophysis on proximal tibial morphology and function. This study aims to assess the impact of TTAF on tibial morphology and patellar position (PP) in dogs at skeletal maturity, comparing outcomes between surgically and non-surgically treated fractures. We hypothesized that surgically treated TTAF would result in a more distal position of the tibial tuberosity and patella compared with non-surgically managed fractures while yielding comparable treatment outcomes.

Materials and Methods

The medical records of dogs diagnosed with TTAF and treated either surgically (ORIF with pins only or with pin and tension band) or non-surgically (cage rest with or without external coaptation) at Ocean State Veterinary Specialists from January 2016 to December 2023 were reviewed. Cases with complete medical records and a radiographic diagnosis of TTAF, confirmed by a board-certified radiologist on pretreatment radiographs, were included. Dogs with concurrent orthopaedic injuries that could affect the growth of the tibia (i.e., proximal tibial physeal fractures) or bilateral TTAF and cases with incomplete medical records were excluded. The dog's signalment, including sex, neuter status, breed, age at the time of fracture diagnosis and method of treatment, were recorded.

Owners of dogs meeting the inclusion criteria were contacted via telephone, and those who gave informed consent for participation in the study were scheduled for follow-up radiographs. At the time of follow-up radiographs, a full orthopaedic and lameness examination was performed by a surgical resident. A subjective lameness score (►**Table 1**), the presence or absence of stifle instability, and the presence or absence and grade of patellar luxation were recorded.[7] Owners reported their dog's clinical outcome using a subjective scale of excellent, good or poor (►**Table 2**), and their responses were recorded.[7] All dogs were sedated with butorphanol (Torphadine®: Dechra, Overland Park, KS) 0.2 mg/kg IV and dexmedetomidine (DexmedVet™: Chronus Pharma, East Brunswick, NJ) 2 to 5 µg/kg IV. Bilateral mediolateral stifle radiographs (RAD-74: Varex Imaging, Salt Lake City, UT) were obtained with the stifle and hock flexed 90 degrees, including a radiographic marker in the field of view.

Table 1 Lameness scoring system

Grade	Definition
0	Normal limb function; no lameness at all.
1	Normal weight-bearing at rest but favouring of limb when walking.
2	Toe-touching and weight-bearing at rest and when walking.
3	Toe-touching and weight-bearing at rest and non-weight-bearing when walking.
4	Non-weight-bearing at rest and when walking.

(Adapted from von Pfeil et al.[7])

Table 2 Outcome scoring system

Outcome	Definition
Excellent	Lameness had completely resolved at the final follow-up.
Good	There was significant improvement, but there was occasional lameness that was controlled using medical therapy.
Poor	The lameness never resolved, chronic medical therapy was necessary, or additional surgery was needed.

(Adapted from von Pfeil et al.[7])

Radiographic measurements were obtained by a single surgical resident (primary author) (Medixant, RadiAnt DICOM Viewer, Version 2024.1). Four parameters were measured for each radiograph: tibial plateau angle (TPA), PP and axial (TTP-A) and transverse tibial tuberosity position (TTP-T). The mechanical long axis of the tibia was drawn as a line from the intercondylar eminence to the centre of the talus.[14] The TPA was measured as the angle between a line perpendicular to the tibial long axis and the tibial plateau slope.[14] The PP was measured as the distance from the proximal aspect of the femoral trochlear groove to the proximal pole of the patella.[15] The TTP-A was measured as the distance between the intercondylar eminence and the axial position of the tibial tuberosity along the long axis of the tibia. The TTP-T was measured as the distance between the cranial extent of the tibial tuberosity and the long axis of the tibia, along a line perpendicular to the long axis of the bone (►**Fig. 1**). Dogs were categorized based on the method of treatment for statistical analysis, which included ORIF with pins only (group P), ORIF with pins and tension band (group TB) and non-surgical management with a cast (group C).

Statistical Analysis

The response variables were weight, TPA, PP, TTP-A and TTP-T. The association between weight and group (P, TB, C) was by

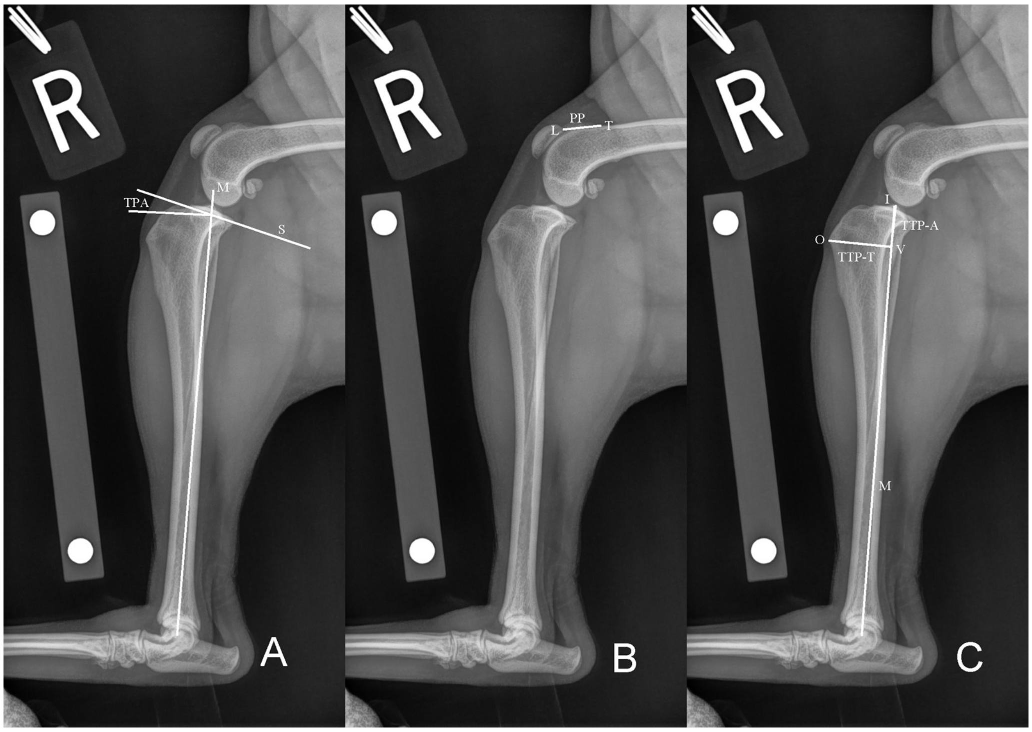

Fig. 1 Radiographs of a normal stifle at skeletal maturity in a dog unaffected by tibial tuberosity avulsion fracture. (**A**) Measurement of tibial plateau angle. (**B**) Measurement of patellar position. (**C**) Measurement of axial and transverse tibial tuberosity position. I, intercondylar eminence; L, proximal pole of the patella; M, mechanical long axis of the tibia; O, tibial tuberosity; PP, patellar position; S, tibial plateau slope; T, proximal aspect of the femoral trochlear groove; TPA, tibial plateau angle; TTP-A, axial tibial tuberosity position; TTP-T, transverse tibial tuberosity position; V, axial tibial tuberosity position along the long axis of the tibia.

means of a one-way analysis of variance. The other response variables could be affected by group (P, TB, C) and side (Normal, TTAF). The analysis was by means of a split-plot analysis of variance with one grouping factor (group) and one repeat factor (side). The normality of the errors was assessed by means of a histogram and normal probability plot. Data were described as mean, standard deviation, and standard error of the mean. p-Values were reported, and $p < 0.05$ was considered significant. All calculations were performed using NCSS 2023 (Kaysville, UT).

Results

Seventy-seven cases were identified. Ten cases were excluded due to a concurrent proximal tibial physeal fracture ($n = 6$), bilateral TTAF ($n = 3$) or because the patient was deceased at the time of data collection ($n = 1$). Among the remaining 67 cases, informed owner consent was obtained in 21 cases (►**Supplementary Table S1** [available in the online version only]).

Signalment

The median age at initial fracture management was 4 months (range: 3–6 months). The median age at follow-up radiographic evaluation was 3 years (range: 1–8 years). At initial presentation, the 21 dogs included 6 entire females, 3 spayed females, 7 entire males, and 5 castrated males. Breeds included were mixed breed dog ($n = 8$), French Bulldog ($n = 2$), Pitbull ($n = 2$), Labrador Retriever, Bernese Mountain Dog, Catahoula Leopard Dog, Yorkshire Terrier, Miniature Poodle, English Bulldog, Miniature American Shepherd, Golden Retriever and Pomeranian ($n = 1$ each). The right stifle was fractured in 11 dogs, and the left in 10 dogs.

There were nine dogs in group P, six dogs in group TB, and six dogs in group C. At the time of follow-up radiographic evaluation, the median weight was 18.6 ± 10.6 kg for group P, 26.2 ± 8.5 kg for group TB and 14.0 ± 6.8 kg for group C. There was no significant difference in weight between treatment groups ($p = 0.09$).

Radiographic Measurements

Radiographs of select case examples are shown in ►**Figs. 2** to **4**.

The TPA measurements are listed in ►**Supplementary Table S2** (available in the online version only). The mean TPA of normal stifles was 23.96 ± 3.15 degrees in group P, 26.08 ± 3.5 degrees in group TB and 21.32 ± 4.47 degrees in group C. The mean TPA of normal stifles was not different between any treatment group ($p = 1$). The mean TPA of TTAF stifles was 4.50 ± 9.85 degrees in group P, 10.60 ± 15.24 degrees in group TB, and 18.18 ± 9.42 degrees in group C. The mean change in TPA of TTAF stifles was -19.46 degrees in group P, -15.28 degrees in group TB and -3.13 degrees in group C. The TPA of TTAF stifles was significantly decreased from normal stifles in group P ($p < 0.001$) and TB ($p = 0.004$), but not in group C ($p = 0.533$). A significant difference in the change in TPA of TTAF stifles was found between surgically managed (P and TB) and non-surgically managed (C) groups ($p = 0.01$).

Fig. 2 Radiograph of a 2-year-old male mixed breed dog (Case 6). (**A**) Normal stifle. (**B**) Tibial tuberosity avulsion fracture stifle treated surgically with pins only (group P).

Fig. 4 Radiograph of a 1-year-old male French bulldog (Case 19). (**A**) Normal stifle. (**B**) Tibial tuberosity avulsion fracture stifle treated non-surgically with a cast (group C).

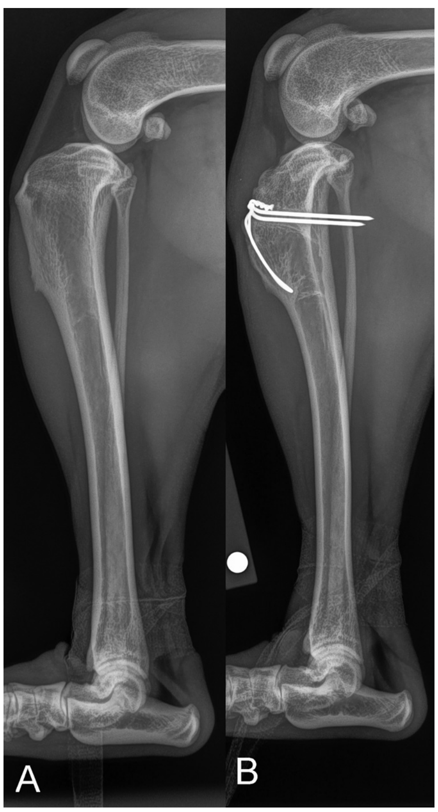

Fig. 3 Radiograph of a 1-year-old female mixed breed dog (Case 14). (**A**) Normal stifle. (**B**) Tibial tuberosity avulsion fracture stifle treated surgically with pin and tension band (group TB).

The PP measurements are listed in ►**Supplementary Table S3** (available in the online version only). The mean PP of normal stifles was 1.54 ± 0.64 cm in group P, 1.73 ± 0.22 cm in group TB and 1.3 ± 0.28 cm in group C. The mean PP of normal stifles was not different between any treatment group ($p = 0.121$). The mean PP of TTAF stifles was 1.77 ± 0.73 cm in group P, 1.77 ± 0.49 cm in group TB and 1.04 ± 0.51 cm in group C. The mean PP of TTAF stifles increased by 0.23 cm in group P and 0.04 cm in group TB and decreased by 0.26 cm in group C. The change in PP of TTAF stifles approached significance in group P ($p = 0.053$), but not TB ($p = 0.086$) or C ($p = 0.136$). A significant difference in the change in PP of TTAF stifles was found between surgically managed (P and TB) and non-surgically managed (C) groups ($p = 0.009$).

The TTP-A measurements are listed in ►**Supplementary Table S4** (available in the online version only). The mean TTP-A of normal stifles was 1.22 ± 0.44 cm in group P, 1.38 ± 0.35 cm in group TB and 1.18 ± 0.27 cm in group C. The mean TTP-A of normal stifles was not different between any treatment group ($p = 0.19$). The mean TTP-A of TTAF stifles was 1.82 ± 0.72 cm in group P, 1.67 ± 1.10 cm in group TB and 0.88 ± 0.38 cm in group C. The mean TTP-A of TTAF stifles increased by 0.60 cm in group P and 0.29 cm in group TB, and decreased by 0.29 cm in group C. The change in TTP-A of TTAF stifles was significant in group P ($p = 0.007$), but not TB ($p = 0.24$) or C ($p = 0.242$). A significant difference in the change in TTP-A of TTAF stifles was found between surgically managed (P and TB) and non-surgically managed (C) groups ($p = 0.005$).

The TTP-T measurements are listed in ►**Supplementary Table S5** (available in the online version only). The mean TTP-T of normal stifles was 2.42 ± 0.57 cm in group P, 2.92 ± 0.53 cm in group TB, and 2.16 ± 0.47 cm in group C. The mean TTP-T of normal stifles was not different between any treatment group ($p = 0.086$). The mean TTP-T of TTAF stifles was 2.14 ± 0.65 cm in group P, 2.66 ± 0.24 cm in group TB and 2.15 ± 0.49 cm in group C. The mean TTP-T of TTAF stifles was decreased by 0.28 cm in group P, 0.26 cm in group TB and 0.01 cm in group C. The change in TTP-T of TTAF stifles was significant in group P ($p = 0.02$), approached significance in group TB ($p = 0.068$), and was not significant in group C ($p = 0.99$). A significant difference in the change in TTP-T of TTAF stifles was found between surgically managed (P and TB) and non-surgically managed (C) groups ($p = 0.023$).

Outcome

All surgically managed patients (P and TB) had a lameness score of 0, with no stifle instability or patellar luxation, and the clinical outcome was graded as excellent by their owners in all cases. In group C, four out of six dogs had a lameness score of 0, with no stifle instability or patellar luxation, and their outcomes were graded as excellent by their owners. The remaining two dogs had a lameness score of 1, accompanied by grade III/IV medial patellar luxation, and their outcomes were graded as good by their owners.

Discussion

In this study, the mean TPA of surgically repaired TTAF stifles was significantly lower than that of contralateral normal stifles, regardless of the method of ORIF. The TPA plays an important role in force distribution during walking and has a relationship with the amount of cranial or caudal tibial thrust produced during axial loading.[16–18] A high TPA (>25 degrees) is expected to increase strain on the cranial cruciate ligament, leading to an increased risk of rupture, whereas a low TPA (<5 degrees) has been shown to increase strain on the caudal cruciate ligament.[14,16,18–20] However, the pathophysiology of cruciate ligament disease in dogs and the role of TPA in disease development is not completely understood.[18,19,21] The TPA of dogs unaffected by cranial cruciate ligament disease has been reported to be influenced by size, breed, age, and neuter status, and there is currently no consensus on the causal relationship between increased TPA and cranial cruciate ligament disease.[17,19,22,23] While increased TPA is a biomechanical factor associated with cranial cruciate ligament disease, it is likely one of several contributing factors rather than a direct cause.[24–26] A recent case report described a partial rupture of the caudal cruciate ligament in a dog with a proximal diaphyseal tibial deformity and negative TPA.[27] Surgical repair of TTAF resulting in a decreased or negative TPA therefore may be protective for the development of cranial cruciate ligament disease in dogs and may increase caudal cruciate ligament strain leading to possible ligament deficiency, although no dog in the present study showed evidence of stifle instability or cruciate ligament disease in any limb. Additional large-scale studies are needed to further evaluate this relationship.

Several biochemical models of stifle joint kinematics have been proposed in the literature. The active model proposes that the total joint force is parallel to the functional axis of the tibia.[28] The Tepic model suggests that the total joint force is instead parallel to the patellar ligament.[29] Both theoretical *ex vivo* models oversimplify the complex stifle joint function by assuming full muscle recruitment and do not consider rotational stability of the stifle joint.[30] Regardless, it is reasonable to assume that anatomical changes to the proximal tibia leading to altered tibial tuberosity and PP would result in changes in stifle joint biomechanics. In this study, PP, TTP-A and TTP-T were significantly different from the contralateral normal stifle in dogs with surgically managed TTAF, but not in non-surgically managed cases. The magnitude to which these changes alter stifle joint biomechanics was beyond the scope of this study; however, kinematic studies evaluating joint function in surgically managed TTAF could be considered to further quantify these changes.

The quadriceps extensor mechanism of the stifle originates from the proximal femur and pelvis and converges on the patella, continues as the patellar ligament and attaches to the tibial tuberosity. Accordingly, contraction of the quadriceps muscle group extends the tibia cranially, resulting in stifle joint extension.[30,31] The axis of rotation of the stifle is the femorotibial contact point, and the lever arm is the perpendicular distance from the femorotibial contact point to the attachment of the patellar ligament on the tibial tuberosity. The patella acts to increase the magnitude of quadriceps extensor mechanism force by increasing the lever arm length.[31] Consequently, an altered patellofemoral contact point with patella alta or baja and an altered tibial tuberosity position would be expected to influence the magnitude of force generated by the quadriceps.[31,32] Although dogs with surgically managed TTAF in this study displayed altered patellar and tibial tuberosity positions, the extent of these changes on the quadriceps extensor mechanism was beyond the scope of this study. Additional studies using advanced imaging and kinetic gait analysis to measure quadriceps muscle force could be considered to further quantify these changes.

Interestingly, the only dogs in this study that presented with medial patellar luxation at skeletal maturity were in the non-surgical group, in which tibial tuberosity and PP were expected to remain constant. The pathogenesis of medial patellar luxation in dogs is complex and incompletely understood, so the exact mechanism of patellar luxation development in these dogs was unable to be determined and is beyond the scope of the study.[33] It is possible that these dogs had undiagnosed patellar luxations previous to their TTAF. It is possible that placing them in a cast at this young age influenced the quadriceps axis through tibial position or effects on tibial and femoral growth plates. Although there are conflicting results in the literature as to the relationship between patellar alta or baja and patellar luxation, it is possible that an altered proximodistal PP contributed to the development of patellar luxation in these dogs.[34,35] It is also possible that the avulsion altered the mediolateral position of the tuberosity, resulting in a medial shift of the distal quadriceps axis. Both proximodistal and mediolateral alignment of the tibial tuberosity fragment is achievable with ORIF of TTAF, but no such alignment can be guaranteed with non-surgically managed cases. In this study, only mediolateral views were obtained to evaluate TTP-A and TTP-T, which do not take into account the mediolateral alignment of the tibial tuberosity. Furthermore, it is difficult to conclude the significance of this finding since only two dogs developed medial patellar luxation, possibly resulting in a type I error. Additional large-scale studies in which dogs are clinically evaluated for patellar luxation and craniocaudal stifle radiographs are evaluated for mediolateral translation of the tibial tuberosity in non-surgically managed TTAF could be considered to further evaluate the risk of patellar luxation in this population of dogs.

There are several limitations to this study. The small number of cases may not be representative of a larger population. Among dogs meeting the inclusion criteria, only about a third of their owners gave informed consent for study participation. A small proportion of owners declined participation due to reasons including scheduling conflicts and proximity to the hospital, however, the large majority of cases not included were due to the inability to contact owners despite three attempts. Due to the retrospective nature of the study, surgical procedures and case management were not standardized, which may have affected the outcome. It seems likely that there was case selection bias, with a tendency to manage most minimally displaced fractures non-surgically and to surgically manage most cases with more displacement. Only two dogs within the non-surgically managed group displayed moderate to marked displacement of the tibial tuberosity on pretreatment radiographs. In both cases, surgical fixation was recommended, but declined by the owners due to financial limitations. Although the contralateral normal stifle was used as a control in each dog, case–control matching between groups may have resulted in more meaningful conclusions regarding the changes in radiographic measurements between groups. Another limitation is the irregular bony profile of TTAF stifles, making radiographic measurements more difficult because the observer must estimate the true anatomical landmarks. Lastly, radiographic measurements were obtained by a single observer who was not blinded to the group each radiograph belonged to. A larger number of observers may have increased measurement accuracy, although it would not be possible to truly blind observers when measuring TTAF stifles due to the presence of implants on radiographs of surgically treated cases.

The hypothesis that surgically treated TTAF would lead to a more distal position of the tibial tuberosity and patella was accepted, with TTP-A and PP significantly increased in surgical treatment groups. Despite the change in proximal tibial morphology at skeletal maturity, all dogs with surgically treated TTAF in this study had excellent outcomes, and surgical repair of TTAF may still be considered a gold standard. To mitigate the risk of premature epiphysiodesis, previous reports have advocated for the removal of surgical implants following radiographic healing, but there are currently no data in the literature to confirm this recommendation.[1,5] In this study population, surgical implants were left *in situ* in all but one case. Additional studies evaluating the tibial morphology of surgically managed TTAF with planned implant removal are warranted. Despite two dogs in the non-surgical group developing medial patellar luxation, both owners were satisfied with the clinical outcome. It is unknown if the patellar luxations were caused by the avulsion fracture and non-surgical management or were coincidental, and a larger case series may address this more definitively. Although all non-surgically managed cases were externally coapted to minimize the risk of further tibial tuberosity displacement, the effectiveness of casting in this population remains uncertain. Activity restriction without coaptation may be equally effective in managing these cases while also eliminating the risk of bandage-related complications. However, treatment outcomes of all non-surgically managed dogs in this study were good to excellent, which is similar to previous reports of prognosis for return to function following TTAF.[1,2,5–9,11] Therefore, non-surgical management of TTAF may be considered a feasible treatment option in cases where surgical management cannot be pursued, especially in cases of non- or minimally displaced fragments. Owners electing non-surgical management of TTAF should be counselled on the risk of possible patellar luxation, as well as risks of further displacement of the tibial tuberosity.

Authors' Contribution

J.N.Z. contributed to study design, data collection, data analysis, interpretation of results, and manuscript writing. S.C.R. contributed to study conception, study design, interpretation of results, and manuscript revision. All authors approved the final manuscript.

Conflict of Interest

None declared.

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