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ORIGINAL ARTICLE

Management of proximal metaphyseal curvilinear tibial fractures in 25 skeletally immature dogs (2009 to 2020)

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Objectives: To describe the occurrence, management and outcome of proximal metaphyseal curvilinear tibial fractures in skeletally immature dogs.

Materials and Methods: A multi-centre retrospective review was conducted, searching for skeletally immature dogs presenting with proximal metaphyseal curvilinear tibial fractures between January 2009 and September 2020. Signalment, fracture description and case management data were retrieved. Outcome was assessed by retrospectively evaluating follow-up radiographs, hospital records and an owner questionnaire.

Results: Twenty-five dogs met the inclusion criteria. All but one fracture was a result of minimal trauma. Twenty fractures were managed with internal fixation, two with external fixation and three conservatively. All 25 fractures healed. Eight major complications occurred in seven of 25 (28%) dogs. Twelve minor complications occurred in 10 of 25 (40%) dogs. Owner questionnaire data were available for 12 of 25 dogs; 11 of 12 were reported as having full function and one of 12 as having acceptable function at the time of questioning (median 34.5 months following presentation). At final follow-up, either by clinical examination or owner questionnaire, full function was achieved in 22 of 25 patients and acceptable function in three of 25.

Clinical Significance: This study reported a series of proximal metaphyseal tibial fractures in skeletally immature dogs. The most common fixation method was internal fixation, which frequently resulted in full limb function at final follow-up. Owners reported outcome as fully functional in all dogs that underwent surgery at first presentation and had owner follow-up available, though positive outcomes may have been affected by participation bias.

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INTRODUCTION

Tibial fractures account for approximately 20% of long bone fractures in dogs (Unger *et al.* 1990, Johnson *et al.* 1994), and mainly occur due to trauma. In the study by Unger *et al.* (1990), 72% of tibial fractures were diaphyseal, 21% affected the distal tibia and 7% affected the proximal tibia. The most common proximal tibial fractures are physeal (Unger *et al.* 1990). Avulsion fractures of the tibial tuberosity, including Salter–Harris types I and II fractures of the proximal tibial physes, have been well documented in immature dogs (Pratt 2001, Clements *et al.* 2003, Gower *et al.* 2008, von Pfeil *et al.* 2012). Recently, a fracture of the proximal tibial metaphysis has been described in skeletally immature dogs, typically affecting small breeds less

than 6 months of age. All fractures were associated with minimal trauma and displayed a characteristic curvilinear pattern (McKee *et al.* 2010, Deahl *et al.* 2017).

Similar proximal metaphyseal fractures occur in children, often as a consequence of trampolining, though these are not typically curvilinear (Boyer *et al.* 1986, Mubarak *et al.* 2009, Bruyeer *et al.* 2012). There are reports of proximal tibial valgus deformity and limb overgrowth associated with proximal metaphyseal tibial fractures in children (Skak 1982, Jordan *et al.* 1987, Ogden *et al.* 1995, Tuten *et al.* 1999, Müller *et al.* 2002). Treatment for these fractures in children commonly consists of a long leg cast for 4 weeks, or in the case of displaced fractures, closed reduction and splinting or open reduction and internal stabilisation under general anaesthetic (Müller *et al.* 2002, Mubarak *et al.* 2009, Yoo *et al.* 2019). Two studies have reported two proximal metaphyseal curvilinear tibial fractures in immature dogs stabilised with crossed pins (Mehmet & Ümit 2004) and external fixation (Cheong *et al.* 2014). The following databases (CAB Abstracts and PubMed) have been searched with the keywords dog* OR canine* OR pupp* OR bitch* AND proximal AND metaphysis OR metaphyseal AND tibia* AND fracture* on May 4, 2021; the following textbooks have been consulted (Johnston & Tobias 2018). No other reports of the management of proximal metaphyseal curvilinear tibial fractures in skeletally immature dogs have been found in this search.

The objective of this study was to retrospectively describe the characteristics of this particular fracture and to describe the management and associated outcome.

FIG 1. Proximal metaphyseal curvilinear tibial fracture. Radiographs demonstrate caudo-medial displacement and caudo-lateral angulation

MATERIALS AND METHODS

Patient records of four referral hospitals in the UK were retrospectively searched by four independent operators for the keywords "dog" and "tibial fracture" between the dates January 2009 and September 2020. Clinical records and radiographs were obtained, and data on signalment, clinical examination findings, degree of trauma, time from fracture to presentation, fracture pattern, surgical management and outcome were recorded. Outcome data were derived from hospital records and radiographs acquired at postoperative re-examination, and a telephone-based owner questionnaire previously used to evaluate longer-term outcome following surgery in a study of tibial tuberosity avulsion fractures in immature dogs (Gower *et al.* 2008). Overall outcome was reported in terms of functional outcome according to Cook *et al.* (2010).

Dogs were included if they had radiographs or CT scans demonstrating the same proximal metaphyseal curvilinear fracture configuration as described by Deahl *et al.* (2017) and McKee *et al.* (2010), open proximal tibial physes (see Fig 1), complete hospital records, postoperative radiographs, follow-up radiographs and/or owner questionnaire response.

Radiographs were analysed in an imaging software (imageJ; National Institutes of Health, Bethesda, Maryland, USA). All radiographs were assessed by a single board-certified orthopaedic specialist. Initial radiographs were assessed for a concurrent fibular fracture, fracture segment displacement and angulation (defined in terms of the abnormal position of the distal segment). Radiographs were also evaluated for the presence of a longitudinal radiolucency from the tibial tuberosity apophysis to the tibial fracture, as described by Deahl *et al.* (2017).

All available radiographs were evaluated for implant positioning and alignment. Follow-up radiographs were also assessed for evidence of healing. Tibial plateau angle (TPA) and medial mechanical proximal tibial angle (mMPTA) measurements were recorded in all fractures with orthogonal radiographic views including the whole tibia (Kowaleski *et al.* 2018). Where radiographs of the contralateral limb were available, TPA and mMPTA measurements were recorded as a control. Proximal tibial valgus was determined if the mMPTA angle was greater than 97°, based on the data range published by Dismukes *et al.* (2007). TPA was deemed excessive if it was greater than 35°, based on the previous evaluation of dogs with excessive TPA (Duerr *et al.* 2007).

Complications were defined as surgical (any complication arising from the beginning of surgery until postoperative radiographs had been taken) or postoperative. Postoperative complication data were gathered from hospital revisit appointments, radiographic analysis and owner telephone follow-up. Postoperative complications were classified according to Cook *et al.* (2010).

Ethical approval for this study was obtained from the University of Bristol.

RESULTS

Signalment

Twenty-nine dogs were identified with proximal metaphyseal curvilinear tibial fractures and 25 dogs met the inclusion criteria. All affected dogs were small breeds. Dogs involved had a median age of 4 (range 2.5 to 8.5) months. The mean weight of all dogs at the first visit was 4.24 (range 1 to 7) kg. Median time from fracture to presentation was 2 (range 0 to 16) days.

A traumatic event resulting in fracture was documented in 20 of 25 dogs, with 19 being a result of minimal trauma, such as a short fall, a slip or playing with another dog. No comorbidities were present in 24 of 25 dogs. One dog had additional fractures to the right second metatarsal, right femoral neck, right displaced acetabular physis and right sacroiliac luxation. Most dogs were non-weight bearing or severely lame at presentation. All dogs sustained unilateral fractures. Signalment data are detailed in Table 1.

Fracture description

Sixteen fractures involved both the tibia and fibula with nine cases fracturing the tibia alone. Twenty tibial fractures were complete with five incomplete. Of the incomplete fractures, four remained intact at the caudal cortex and one remained intact at the cranial cortex. Two fractures incorporated the proximal tibial physis. Fibular fractures were diaphyseal and distal to the tibial fracture in 15 of 16, with the remaining fibular fracture proximal and metaphyseal. Displacement was recorded as no displacement

Table 1. Patient signalment data

Case no.	Breed	Age (months)	Weight (kg)	Sex and neuter status	Comorbidities	Orthopaedic examination findings	Limb fractured	Trauma description	Days to presentation
1	Border terrier	4	4	FE	X	No info	R	Unknown	5
2	French bulldog	4	8	FE	X	NWB	L	Running in garden	5
3	Cairn terrier	6	7	ME	X	NWB, swollen stifle	R	Jumped off bench	1
4	Pomeranian	3	1	FE	X	NWB, supportive dressing	L	Fell from sofa	1
5	JRT	4.5	3	FE	X	NWB, swollen stifle	R	Fell from sofa	0
6	French bulldog	5	6	FE	X	Severe lameness, stifle crepitus	R	Fell from bed	5
7	Border terrier	4	6	FE	X	NWB	L	Fell from bed	2
8	Border terrier	4	5	FE	X	Severe lameness, muscle atrophy	L	Unknown	16
9	Cross-breed	5	3	FE	X	Severe lameness, painful swollen tibia	R	Slipped on floor	7
10	French bulldog	3	5	ME	X	Severe lameness, painful tibia	R	Unknown	4
11	French bulldog	3	3	FE	X	NWB, swollen stifle	R	Fell from arms	2
12	Chihuahua	3	2	FE	X	NWB, swollen stifle, bruising	L	Jumped from car	2
13	Cockapoo	3	3	FE	X	NWB	R	Fell from sofa	4
14	Chihuahua	8.5	2	FN	X	NWB	L	Playing with another dog	0
15	French bulldog	4	5	FE	X	Severe lameness	L	Fell from sofa	3
16	French bulldog	4.5	4	MN	X	NWB	R	Fell from sofa	0
17	Border terrier	4	6	FE	X	NWB	R	Playing with dog	0
18	Chihuahua	4	4	FE	X	NWB	L	Fell from bed	1
19	Cross-breed	2.5	2	FE	X	NWB	L	Fell from arms	1
20	Boston terrier	3	5	FE	X	NWB	L	Unknown	3
21	WHWT	7	7	ME	X	NWB	R	Unknown	3
22	Border terrier	3	5	ME	X	Severe lameness, painful tibia	L	Running in garden	1
23	Border terrier	3	5	ME	X	NWB	R	Fell over	2
24	Yorkshire terrier	4	2	ME	X	Palpable bone callus proximal R tibia, mild lameness	R	Fell over	14
25	JRT	4	3	FE	Additional fractures to R 2nd metatarsal, R Femoral neck, displaced R acetabular physis, R sacroiliac luxation)	NWB, painful unstable stifle	R	RTA	1

FE female entire, MN male neutered, RTA road traffic accident, R right, L left, NWB Non-weight bearing, JRT Jack Russell terrier, WHWT West Highland white terrier

(nine), craniomedial (seven), cranial (four), craniolateral (two), medial (two) and proximomedial (one). Angulation was identified as caudal (17), caudolateral (five) and lateral (three). The presence of a radiolucent line from the tibial tuberosity apophysis to the fracture site was noted in 11 fractures, as previously described by Deahl *et al.* (2017). Ten of these had a "hazy" appearance of the ossification centre where the tuberosity fuses with the metaphysis, with the remaining one presumed to be comminution of the fracture. Full fracture description data can be viewed in Table S1.

Fracture management

Twenty-two fractures were managed surgically; 20 were stabilised with internal fixation (Fig 2) and two were managed with external skeletal fixation. The remaining three fractures were managed conservatively. Surgical approaches to the proximal tibia were medial (21) and *via* a medial and lateral approach (one). All dogs were operated on by a board-certified specialist orthopaedic surgeon or resident under direct specialist supervision. Surgical complications were noted in nine dogs with some dogs experiencing multiple complications. Complications included valgus mal-reduction (four), a screw penetrating the proximal tibial physis (four), one of which was intra-articular, mal-reduction with excessive TPA (two), a mal-positioned interfragmentary wire in the tibial tuberosity physis (one) and proximal screw placement within the fibular head (one). Mal-positioned implants were left in place due to concerns regarding the difficulty of fracture reduction (in instances of late presentation) and due to limited or poor-quality bone stock, leading to concerns that repositioning of implants might result in an increased risk of short-term complications.

All dogs received peri-operative intravenous cefuroxime at standard dose rate (20 mg/kg q 90 minutes). Five dogs received broad-spectrum antibiotics (potentiated amoxicillin n=3, cephalexin n=2) postoperatively for a median of 7 (range 5 to 7) days. All owners were instructed to cage rest their dogs following surgery for 4 to 6 weeks, with short lead walks only during this time. Fracture management data are detailed in Table 2.

Peri-operative outcome

Follow-up radiographs were available for 22 dogs and were taken at a median of 4.5 (range 2 to 9) weeks following surgery. Out of 22 fractures, 20 had healed or were healing and implant failure had occurred before radiographic union in two of 22 fractures. Incidental screw pull-out (n=1) and pin loosening (n=2) were also observed, neither requiring treatment. There were no radiographic changes to the implants in the remaining 14 of 19 fractures, which were surgically managed and had follow-up radiographs available.

Alignment at follow-up was assessed in the cranio-caudal plane (mMPTA) in 21 of 22 fractures and in the medio-lateral plane (TPA) in 20 of 22 fractures. Proximal tibial valgus deformity was present on follow-up radiographs in five of 21 fractures, three of which were due to valgus mal-reduction noted on immediate postoperative radiographs. An excessive TPA was present in five of 20 fractures at radiographic follow-up, two of which had undergone surgery and three of which had been managed conservatively. One of these surgically managed fractures was noted to be mal-reduced on immediate postoperative radiographs. TPA could not be measured in the other surgically managed fracture due to the external skeletal fixator (ESF) obscuring the tibial plateau. The remaining three fractures that were conservatively managed (dogs 2, 8 and 24) developed mal-unions with TPAs of 49°, 44° and 37° (see Fig 3). Dogs 8 and 24 required no further treatment; however, dog 2 required a cranial closing wedge ostectomy due to persistent lameness noted 4 weeks after initial presentation. This went on to heal with a TPA of 23° at 14 weeks after presentation. Alignment was considered normal in the remaining 12 fractures. Full alignment data can be viewed in Table S2.

A clinical assessment by a veterinary surgeon was available in 20 dogs at a median of 5 (range 3 to 46) weeks following surgery. Patients were recorded to be free of lameness (14), with mild lameness (five) and with intermittent lameness (one).

Owner-assessed outcome

The telephone questionnaire was completed by 12 of 25 owners at a median of 34.5 (range 3.5 to 118) months after presentation. Eight dogs were reported to be walking normally without lameness within 8 weeks of the fracture occurring. Three dogs were back to normal within 12 weeks. Eleven dogs were reported to have had no subsequent lameness in the affected leg. One dog (dog 2) never returned to normal and took a year to reach the current level of lameness (occasionally stiff after rest). Further treatment was reported in two dogs: surgical site infection which resolved with antibiotic therapy by the primary care veterinarian (one) and surgical removal of a K-wire causing irritation (one). Full questionnaire data can be viewed in Table S3.

Postoperative complications

There were no catastrophic complications. Eight major complications were recorded in seven of 25 (28%) dogs. Twelve minor complications were recorded in 10 of 25 (40%) dogs. Complication data are detailed in Table 2.

Functional outcome

Final follow-up was by clinical examination in 13 cases at a median of 6 (4 to 46) weeks. Full function was reported in 11 of 13, and acceptable function in two of 13. Final follow-up by owner assessment was available in 12 cases at a median of 34.5 (3.5 to 118) months. Full function was reported in 11 of 12 cases and acceptable function in one of 12. All functional outcome data can be viewed in Table S4.

DISCUSSION

In this study, proximal metaphyseal curvilinear tibial fractures occurred at a median age of 4 months in small breed dogs, most commonly with minimal trauma. The fractures were most commonly non-displaced or cranially displaced and the majority demonstrated caudal angulation. Most fractures underwent surgical stabilisation and of these, the majority demonstrated full

FIG 2. (a) Preoperative, (b) postoperative and (c) follow-up radiographs demonstrating open reduction and internal fixation of fractures of dogs 17, 19 and 20, respectively

limb function by the time of final follow-up. Fracture reduction was inadequate with valgus mal-reduction present in 18% of cases. All cases healed but valgus deviation and excessive TPA were evident on follow-up radiographs in 24 and 25% of all cases, respectively. All cases that underwent conservative management developed an excessive TPA as a result of further fracture displacement and angulation caudally. As such, the authors believe that prompt surgical reduction and fixation is the most appropriate treatment method and particular attention should be paid to fracture reduction to avoid the risk of angular deformity.

Table 2. Fracture management and postoperative complication data

Dog no.	Stabilisation technique	Surgical approach	Fixation apparatus	Surgical complications	Details of postoperative antibiotics	Postoperative complications
1	Internal fixation	Medial	2.0-mm T-plate (6-hole)	None	Potentiated amoxicillin 13 mg/kg BID for 7 days	X
2	Conservative management	X	Light supportive dressing	X	None	Bandage complications (major), excessive TPA requiring CCWO (major)
3	Internal fixation	Medial and lateral	2×0.9-mm K-wires (cr-ca) and TBW. 2× k-wires (L-M and M-L)	None	Cephalexin 21.4 mg/kg BID for 7 days	X
4	Internal fixation	Medial	1.5-mm T-plate (5-hole)	None	None	X
5	Internal fixation	Medial	2.0-mm PAX locking T-plate (2 + 3-hole)	Proximal screw in fibular head†	None	Plate removed once healed due to concern over potential valgus deformity (major)
6	Internal fixation	Medial	2×1.1-mm K-wires (cr-ca) and TBW	Mal-reduction: valgus†, excessive TPA†	None	Surgical site infection (<4 weeks postsurgery) treated with antibiotics (major)
7	Internal fixation	Medial	2×1.1-mm K-wires (cr-ca) and TBW	None	None	X
8	Conservative management	X	Cage rest alone	X	None	Excessive TPA (minor)
9	Internal fixation	Medial	2.0-mm T-plate (6-hole)	Proximal screw in joint†, mal-reduction: valgus‡	Potentiated amoxicillin 19 mg/kg BID for 7 days	Screw pull-out (minor), valgus deformity (minor)
10	External fixation	Medial	Modified type II hybrid ESF	None	None	Pin tract infection (<4 weeks postsurgery) treated with antibiotics (major)
11	External fixation	Medial	Type 1b ESF	None	None	Pin loosening – incidental (minor), excessive TPA (minor)
12	Internal fixation	Medial	K-wire (cr-ca) and TBW, crossed K-wires (L-M and M-L)	None	None	Pin loosening – incidental (minor)
13	Internal fixation	Medial	K-wire (cr-ca) and TBW	None	None	Pin irritation and removal once healed (major)
14	Internal fixation	Medial	1.5-mm T-plate (6-hole)	Proximal screw penetrating physis†	Potentiated amoxicillin 25 mg/kg BID for 7 days	Valgus deformity (minor)
15	Internal fixation	Medial	2.0-mm locking T-plate (5-hole) and 2× K-wires (cr-ca and M-L)	Proximal screw penetrating physis†	None	X
16	Internal fixation	Medial	2.4-mm locking T-plate (7-hole) and K-wire (cr-ca)	Mal-reduction: valgus†	None	Plate fractured before union, revised with orthogonal LCP (major), valgus deformity (minor)
17	Internal fixation	Medial	2.0-mm locking TPLO plate (6-hole)	None	None	X
18	Internal fixation	Medial	2.0-mm LCP (6-hole) medially +1.5 mm VCP (8-hole) cranially	Proximal screw penetrating physis†	None	Valgus deformity (minor)
19	Internal fixation	Medial	1.1-mm K-wire (cr-ca) and TBW	None	None	X
20	Internal fixation	Medial	2.0-mm T-plate (7-hole) and K-wire (cr-ca)	None	Cephalexin 16.6 mg/kg BID for 7 days	X
21	Internal fixation	Medial	1.1-mm K-wire (cr-ca) and TBW, crossed K-wires (L-M, M-L)	Mal-reduction: valgus, excessive TPA†	None	Pin removed due to pin fracture (major), excessive TPA (minor) and valgus deformity (minor)
22	Internal fixation	Medial	2.0-mm T-plate (6-hole) and cerclage wire	Wire slipped into physis of tibial tuberosity‡	None	X
23	Internal fixation	Medial	2.0-mm locking TPLO plate (6-hole) and 0.8-mm interfragmentary wire	None	None	X
24	Conservative management	X	Cage rest alone	X	None	Excessive TPA (minor)
25	Internal fixation	Medial	2.4-mm PAX locking T-plate (2 + 3-hole)	None	None	X

BID Twice daily, TPA Tibial plateau angle, CCWO Cranial closing wedge ostectomy, cr-ca Cranio-caudal, TBW Tension band wire, L-M Latero-medial, M-L Medio-lateral, PAX Poly axial, ESF External skeletal fixator, LCP Locking compression plate, TPLO Tibial plateau levelling osteotomy, VCP Veterinary cuttable plate
†Complication noted on postoperative radiographs
‡Complication noted intraoperatively

FIG 3. Follow-up radiographs of cases 2, 8 and 24. All were managed conservatively and demonstrate an excessive tibial plateau angle of 49°, 44° and 37°, respectively

Numerous studies have documented valgus deformity after these fractures in children. This is most prevalent with greenstick and complete fractures (Skak *et al.* 1987) when managed conservatively (Müller *et al.* 2002). In our study, proximal tibial valgus was noted in five of /21 fractures in which we were able to assess alignment at follow-up. Whilst three of these valgus deformities were a consequence of valgus mal-reduction, two developed a valgus deformity between immediate postoperative and follow-up radiographs. In both fractures that developed a valgus deformity, the lateral aspect of the proximal tibial physis was penetrated with a screw that may have halted growth, resulting in valgus deformity.

Excessive TPA is an additional concern with these fractures, which contrasts with children where excessive TPA does not appear to be an associated complication. Excessive TPA may increase the strain on the cranial cruciate ligament (Haynes *et al.* 2015) and in turn may predispose these dogs to cranial cruciate ligament disease. Of the five fractures in our study where an excessive TPA was evident on follow-up radiographs, two were managed surgically and three were managed conservatively. Dog 2 (initially managed conservatively) required corrective surgery for its excessive TPA due to persistent lameness. Due to the excessive TPA (49°), there was a concern that a large wedge may distalise the patella and reduce limb length (Talaat *et al.* 2006). The operating surgeon aimed for a TPA of 14°, but on postoperative radiographs the TPA was measured as 23°. The owners were informed that further surgery may be required, but they never returned and reported the dog to have stiffness after rest at the time of questionnaire follow-up, which may be due to undercorrection of the TPA. The remaining four dogs achieved full limb function at final follow-up.

All fractures that were managed conservatively underwent conservative management due to late presentation, and all three developed marked callus formation and an excessive TPA. The authors believe that conservative management and external coaptation should be used with caution and implemented only in chronic fractures or where there are financial constraints. These cases also highlight the importance of prompt radiographic imaging for lame juvenile dogs as satisfactory fracture reduction is challenging after significant callus formation, which occurs rapidly in immature dogs.

Overall, the angular deformities did not appear to negatively impact functional outcome within the study time frame, though owner follow-up was only available for three of five dogs with excessive TPA and none of the cases with valgus deformity. A larger sample size, consistent availability of contralateral limb radiographs and longer-term follow-up are necessary to evaluate the incidence and clinical impact of angular deformity and particularly the effect of excessive TPA on the development of cranial cruciate ligament disease.

Surgical management was employed in most fractures, and where owner follow-up was available, owners felt that their dog had completely recovered within 3 months. One of the most common surgical complications was penetration of the proximal tibial physis which occurred in 31% of fractures managed with plate and screws. With this in mind, the size of the proximal segment is an important consideration as, intuitively, a smaller segment is more likely to result in unsatisfactory screw placement. When the fracture line was close to the physis, pin and tension band constructs were favoured, all of which healed within an acceptable time frame with full function at final follow-up. When the fracture was further distal, the decision-making was more difficult. Surgeons could consider the use of fluoroscopy to help guide screw placement. Locking plate technology may be of benefit in small fracture segments due to the comparable mechanical performance between two locking screws and three cortical screws (Grawe *et al.* 2012). Despite the mechanical advantage of locking constructs, the fixed-angle systems limit the ability to direct screws away from the physis and this must be considered during implant selection. In fractures where the proximal tibial physis has been penetrated with an implant, efforts should be made to remove and reposition the implant due to the risk of resultant angular deformity. In this study, the operating surgeons decided to leave the implants in place due to limited- or poor-quality bone stock and the concern that repositioning of the malpositioned screws was likely to cause problems in the short term.

ESF was implemented in two cases and both achieved full function at final follow-up. The main advantages to ESF are the minimally invasive approach and lack of long-term implants. Errors of angulation can be corrected by adjusting the fixator according to postoperative radiographs; however, in our study, both frames prevented visualisation of the tibial plateau and one case exhibited excessive TPA at follow-up. Other ESF considerations include owner and patient compliance and the high incidence of superficial pin-tract infections (Beever *et al.* 2018).

Whilst the overall rate of complications in this study is high, most dogs reached full limb function in the peri-operative period. Longer-term follow-up based on owner questionnaire was not possible in all cases, but 11 of 12 owners perceived their dog to have full limb function at owner follow-up. The most common complications of internal fixation related to the implants and angular deformity (valgus or excessive TPA). Pin loosening and irritation have been documented with pin and tension band constructs in the proximal tibia (Gower *et al.* 2008) and were

easily dealt with in this study. The incidence of surgical site infections was comparable to previous reports (Weese 2008, Beever *et al*. 2018). Due to the small, heterogeneous sample, complication rates between surgical fixation methods were not compared.

The limitations of this study are a consequence of the rarity of the fracture and the retrospective, multi-centre nature of the study. The limited sample size, variation in case management, inconsistent availability of radiographs of the contralateral limb, lack of follow-up radiographs and clinical follow-up for all cases all hampered our ability to make firm conclusions. Owner follow-up is susceptible to information and participation bias and was available for less than half of the dogs involved.

To conclude, the most common fixation method in our study was internal fixation, which frequently resulted in a fully functional limb. Fracture reduction was often challenging, and fluoroscopy may be a useful tool to aid with fracture reduction and implant placement. Conservative management resulted in an excessive TPA in all three cases and so should be exercised with caution. The potential for angular deformity, even with surgery, should be considered; however, the clinical impact of this is undetermined. Where owner follow-up was obtained, the outcome was full function in all cases that underwent surgical management. Future research, based on consistent follow-up data, is indicated to better classify these fractures, provide objective management guidelines and to assess the incidence and clinical impact of complications, particularly with respect to angular deformity.

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Conflict of interest

None of the authors of this article has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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Supporting Information

The following supporting information is available for this article:

Table S1. Fracture description data.

Table S2. Tibial plateau angles (TPA) and medial mechanical proximal tibial angles (mMPTA).

Table S3. Telephone questionnaire data.

Table S4. Functional outcome assessment according to Cook *et al*. (2010).