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Combined Intramedullary Pinning for the Stabilisation of Distal Diaphyseal and Metaphyseal Femoral Fractures in Five Skeletally Immature Dogs

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Abstract

The aim of this retrospective case series was to evaluate outcomes of distal normograde intramedullary pinning combined with dynamic intramedullary pinning for the stabilisation of distal diaphyseal and metaphyseal femoral fractures in five juvenile dogs. Medical records and radiographs were reviewed to evaluate signalment, interval from injury to surgery, fracture classification, concurrent injuries, apparatus, fracture healing and any complications. Final follow-up at skeletal maturity consisted of orthopaedic examination and orthogonal radiographs of bilateral femurs. Radiographs were evaluated for osteoarthritis, femoral length and alignment. Three of four dogs that returned for short-term follow-up healed without complication at 4 weeks postoperatively. One dog experienced pin migration and delayed union, requiring pin removal. All four dogs that returned for final follow-up demonstrated excellent limb function based on owner assessment and orthopaedic examination. Radiographic evaluation revealed mild stifle osteoarthritis in two dogs. All dogs demonstrated continued growth of the affected femur with mild discrepancies in length compared with the contralateral femur at skeletal maturity. Two dogs developed subclinical femoral neck retroversion relative to the normal contralateral limb. Combined intramedullary pinning may be an appropriate treatment option for select distal femoral fractures in skeletally immature dogs; however, more rigid fixation methods should be considered when possible, to effectively counter rotational forces during fracture healing.

Keywords
- ► fracture
- ► dogs
- ► femur
- ► pinning
- ► skeletally immature

Introduction

Femur fractures constitute nearly one-half of all appendicular fractures in dogs and cats, with approximately 48% of affected patients being less than 1 year of age.[1] It is important to consider that the structural and biomechanical properties of juvenile bone differ significantly from adult animals, especially in dogs less than 6 months of age.[2,3] The medullary cavity contains cancellous bone along a greater proportion of the diaphysis, which may indicate superior stabilisation with intramedullary fixation options compared with adult dogs. Furthermore, the cortical thickness and density of immature bone are both decreased when compared with mature bone.[3]

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This may especially be important to consider for femoral diaphyseal fractures, as the femoral cortices are notably thinner in comparison to other long bones.[4] It has been suggested that the use of rigid plates in juvenile bones with thin cortices provides a high risk for screw loosening, especially if the fracture is not anatomically reduced.[4] These differences between juvenile and adult dogs may warrant consideration of alternative, intramedullary fixation methods compared with adult dogs. It is also important to consider that certain fixation methods, such as the use of bone plates or angle-stable interlocking nails, may be too cost-prohibitive for certain clients. As such, intramedullary pinning techniques may provide an affordable alternative with appropriate case selection.

Intramedullary pinning techniques that have been previously described for the fixation of femoral fractures in skeletally immature dogs include the use of a single intramedullary pin, multiple intramedullary pins (stack pinning), cross pinning and dynamic intramedullary cross pinning.[5–8] It is crucial to recognise that while employment of a single intramedullary pin for the treatment of distal metaphyseal and physeal femoral fractures in dogs can yield positive outcomes, this fixation method solely provides resistance against bending forces.[5,9] This singular focus on bending resistance raises the potential for complications such as pin migration, implant failure, infection and malunion.[5] Stack pinning involves the use of multiple intramedullary pins to maximise medullary canal fill; however, it is no longer recommended due to the high risk of associated complications.[6] Traditional cross pins and dynamic intramedullary cross pins are typically described for the fixation of distal femoral physeal fractures, in which case the interdigitating pyramidal grooves and corresponding metaphyseal pegs provide an inherent resistance to rotational and shear forces.[7,8] As a result, the use of cross pins alone may not provide sufficient stability for distal diaphyseal and metaphyseal femoral fractures.

To the author's knowledge, the use of combined pinning techniques for the repair of distal diaphyseal or metaphyseal femur fractures in skeletally immature dogs has not been reported. As such, the objective of this case series is to describe the radiographic and clinical outcomes associated with combined normograde intramedullary pinning in five skeletally immature dogs with distal diaphyseal or metaphyseal femur fractures.

Materials and Methods

Study Population

Medical records from a single institution were reviewed for all skeletally immature dogs that sustained traumatic distal diaphyseal or metaphyseal femoral fractures and underwent surgical repair via combined normograde intramedullary pinning techniques between January 2017 and December 2022. For each dog, the signalment, age at presentation, body weight, interval from injury to surgery, limb affected, fracture aetiology and classification and concurrent injuries were reported. Fracture location was assessed by measuring the distance between the distal-most extent of the fracture, inclusive of any associated fissures, to the distal growth plate. In addition, fracture location was calculated as a percentage of femur length. Femur length was determined in the frontal plane using the anatomic axis, with the lower boundary corresponding to the location of the growth plate.

Surgical Technique

All procedures were performed by one of four board-certified surgeons. Dogs were clipped, aseptically prepped and draped using a hanging limb technique. Three out of five dogs were positioned in dorsal recumbency. The remaining two dogs were placed in right lateral recumbency based on surgeon preference and concurrent musculoskeletal injuries requiring fixation. A standard lateral approach to the distal femur was combined with a lateral parapatellar arthrotomy.[10] Fractures were reduced using a combination of manual limb distraction and direct reduction using bone holding forceps. In one case (case 3), fracture reduction was initially not able to be performed due to chronicity of the fracture and concurrent muscle contracture. A distal femoral ostectomy of 1.5 cm was subsequently performed using a sagittal saw to shorten the length of the femur and facilitate fracture reduction. An intramedullary pin was then normograded from distally, with a point of entry immediately proximal to the origin of the caudal cruciate ligament within the trochlear notch. Additional Kirschner wires or Steinmann pins were then placed from medial and/or lateral aspects of the femoral condyle in a dynamic intramedullary cross pin fashion. The number of additional pins ranged from one to four depending on the surgeon and fracture stability (►**Table 1**). Intraoperative fluoroscopy was used to ensure appropriate implant placement. All pins were countersunk, and stifle range of motion was assessed prior to closure.

Postoperative Radiographic Assessment

Postoperative radiographs were assessed retrospectively for femoral length, alignment and implant sizing. Femur length was defined as the length of the mechanical axis in the sagittal plane.[11] Implant sizing was described as the percentage of medullary canal fill at the level of the isthmus on the craniocaudal view.

Postoperative Care and Short-Term Follow-Up

All dogs were transitioned from intravenous opioids to oral analgesics within 24 hours of surgery. Strict activity restriction (crate confinement combined with slow, controlled leash walks) was recommended for the first 4 to 8 weeks postoperatively. Owners were instructed to perform passive range of motion exercises for the first 4 weeks postoperatively. For each follow-up appointment, orthopaedic and radiographic examination findings were recorded. Radiographic bone healing was considered complete when bridging of at least three out of four cortices was observed.[12]

Final Follow-Up

Four dogs returned for final follow-up after skeletal maturity was achieved. Owners were asked to classify limb function as

Table 1 Clinical and surgical summary of five dogs with femoral fractures repaired with combined normograde intramedullary pinning

Case no.	Signalment	Body weight (kg)	Concurrent injuries	Fracture type	Fracture location	Days from injury to surgery	Implants	IM pin medullary canal fill (%)	Total medullary canal fill (%)
1	7.5 months IM Labrador Retriever	21.1	None	Comminuted (mild)	Distal diaphyseal (92nd percentile)	2	One 7/64” (2.8mm) IM pin; Two 3/32” (2.4mm) cross pins	42	84
2	3.5 months IM Labrador Retriever	15.3	None	Comminuted (mild)	Distal diaphyseal (97th percentile)	3	One 3/32” (2.4mm) IM pin; One 0.062” (1.6mm) cross pin	26	44
3	7 months IF Mixed Breed	13.0	None	Transverse	Distal metaphyseal (95th percentile)	5	One 5/64” (2.0mm) IM pin; Four 0.062” (1.6mm) cross pins	41	87
4	7 months IF American Bulldog	11.4	Left femoral capital physeal fracture; Left ischiatic tuber-osity fracture	Spiral	Distal diaphyseal/ metaphyseal (91st percentile)	2	One 3/32” (2.4mm) IM pin; Two 0.062” (1.6mm) cross pins	33	80
5	3.5 months IF Springer Spaniel	8.8	Pulmonary contusions; Peritoneal effusion	Comminuted (mild)	Distal diaphyseal (94th percentile)	2	One 1/8” (3.2mm) IM pin; One 0.062” (1.6mm) cross pin	40	59

Abbreviations: IM, intact male; IF, intact female; IM, intramedullary.

excellent (normal), good (mild lameness only after exercise), fair (consistent mild to moderate lameness) or poor (consistently non weight bearing). All orthopaedic examinations were performed by a single board-certified surgeon.

Bilateral orthogonal femur radiographs were then obtained using cross-table craniocaudal and open-leg mediolateral views and assessed for osteoarthritis, femoral length and alignment. Femoral alignment in the frontal plane was assessed by measuring the anatomic lateral proximal and distal femoral joint angles (aLPFA, aLDFA) as well as the angle of inclination.[11,13,14] In addition, the angle of femoral neck anteversion was measured using the biplanar or trigonometric method.[11] Differences in femoral length and alignment between the affected and contralateral limb were calculated.

Results

Cases

Dogs ($n = 5$) ranged from 3 to 7 months in age and 8.8 to 21.1 kg in body weight at initial presentation (►**Table 1**). Three dogs were female and two were male. All injuries were acquired secondary to a traumatic event including two dogs with direct vehicular trauma (cases 1 and 2), two that fell from a moving motor vehicle (cases 4 and 5) and one that was subjected to domestic violence (case 3). Two dogs had concurrent injuries. Case 4 had a left femoral capital physeal fracture and a left ischiatic tuberosity avulsion, the former of which was repaired under the same anaesthetic event as the distal femoral fracture repair. Case 5 had mild peritoneal effusion and moderate pulmonary contusions requiring 24 hours of oxygen support.

On preoperative radiographic evaluation, all fractures were closed and involved the distal femoral diaphysis and/or metaphysis (►**Fig. 1**). All cases had a fracture or fissure line present within 1 cm of the distal physis, corresponding to the distal 91 to 97th percentile of the femoral length (►**Table 1**). Three of the fractures were mildly comminuted, all involving the distal femoral diaphysis (cases 1, 2 and 5). The remaining two fractures were spiral and transverse in configuration and both involved the distal femoral metaphysis.

The interval from injury to surgical repair ranged from 2 to 5 days (►**Table 1**). An intramedullary pin was placed in all

Fig. 1 Preoperative orthogonal radiographic projections of five dogs with distal diaphyseal/metaphyseal femoral fractures. Corresponding case numbers (1–5) are displayed in the bottom left corner of each radiograph.

Fig. 2 Immediate postoperative orthogonal radiographic projections of five dogs with distal diaphyseal/metaphyseal femoral fractures repaired via combined normograde intramedullary pinning. Corresponding case numbers (1–5) are displayed in the bottom left corner of each radiograph.

dogs, with sizes ranging from 26 to 42% of the medullary canal (►**Table 1**). One to four additional pins were placed, resulting in a total medullary canal fill ranging from 44 to 87% (►**Fig. 2**).

Short-Term Follow-Up

Short-term follow-up evaluations were available for 4 dogs (all except case 5). At 4 weeks postoperatively, cases 1 and 2 were fully weight bearing on the operated limb, while cases 3 and 4 had a mild weight bearing lameness. Upon radiographic evaluation, cases 1, 2 and 4 had all achieved complete fracture healing (►**Fig. 3**). Case 3 demonstrated exuberant bony callus formation with incomplete bridging of the fracture site. At 10 weeks postoperatively, the dog demonstrated a persistent mild weight bearing lameness with discomfort on stifle flexion. Radiographs revealed progressive callus formation with incomplete incorporation of the proximal femoral segment and distal migration of the intramedullary pin. Radiological differential diagnoses for delayed union included implant motion, avascular bone and infection. The intramedullary pin was surgically removed via a lateral arthrotomy. Due to the concern for possible avascular bone, the craniolateral aspect of the proximal femoral segment was carefully evaluated. Although no obvious abnormalities were detected, out of an abundance of caution micro-drilling of the cranial and lateral cortex of the proximal femoral segment was performed and autogenous proximal humeral cancellous bone graft was applied. At 4 weeks post-revision surgery

Fig. 3 Four-week postoperative orthogonal radiographic projections of all four dogs that returned for short-term follow-up. Cases number 1, 2 and 4 demonstrating complete bridging of the medial and lateral cortices. Case number 3 demonstrated exuberant bony callus formation with incomplete bridging of the fracture site.

(14 weeks post-injury), the dog was fully weight bearing on the limb and complete radiographic bone healing was achieved.

Final Follow-Up

Four dogs returned for final follow-up after skeletal maturity was achieved (all except case 2). Interval from surgery to final follow-up ranged from 139 to 1869 days (median: 447 days). All owners assessed limb function to be excellent, including the owners of case 2 (contacted by phone at 561 days post-surgery). On orthopaedic examination, all four dogs that returned for final follow-up were fully weight bearing on the affected limb with no evidence of lameness. Cases 1 and 5 had retained full range of motion of the affected hip and stifle. Case 3 had mild thickening and mild decreased extension of the affected stifle; however, no pain was elicited. Case 4 demonstrated a consistent, mild contralateral pelvic limb lameness secondary to a grade III/IV medial patellar luxation.

On radiographic assessment, cases 1 and 5 had no evidence of osteoarthritis; however, mild stifle osteoarthritis was observed in cases 3 and 4 (►**Fig. 4**). In addition, case 4

Fig. 4 Orthogonal radiographic projections of case number 3 and 4 at final follow-up, demonstrating mild osteophytosis at the base of the patella and the intercondylar notch.

had mild osteoarthritis of the ipsilateral coxofemoral joint, consistent with the history of concurrent femoral capital physeal fracture.

Femoral growth was documented in all affected limbs and ranged from 14 to 40 mm. Femoral length ranged from 121.1 to 169.5 mm for the contralateral limbs and from 104 to 162.6 mm for the affected limbs (►**Table 2**). All affected femurs were slightly shorter than the contralateral femur, with differences ranging from 5.7 to 17.1 mm or 4 to 15.2%.

Femoral alignment of both the affected and contralateral limb were measured and compared (►**Table 2**).[11,13,14] The aLPFA ranged from 95.9 to 124.6 degrees for the contralateral limb and from 96.9 to 132 degrees for the affected limb. The aLDFA ranged from 95.5 to 99.2 degrees for the contralateral limb and from 89.5 to 96.9 degrees for the affected limb. Differences in aLDFA and aLPFA between limbs were minor, ranging from 1 to 7.4 degrees. Femoral anteversion angles ranged from 17.7 to 35.7 degrees for the contralateral limbs and from 6.6 to 23.7 degrees for the affected limbs, with differences between limbs ranging from 1 to 29.1 degrees. Cases 3 and 5 developed 18.2 and 29.1 degrees increased femoral retroversion in the affected limbs relative to the contralateral limbs respectively (►**Fig. 5**). Angle of inclination ranged from 111.2 to 132 degrees for the contralateral limb and from 115.8 to 124.3 degrees for the affected limb, with differences between limbs ranging from 2.5 to 9.9 degrees. Of note, the greatest variation in aLPFA and inclination angle occurred in case 4. This case also had a femoral capital physeal fracture that likely attributed to changes in proximal femoral conformation.

Table 2 FFU: radiographic outcomes of four dogs with femoral fractures repaired with combined normograde intramedullary pinning

Case no.	Days from surgery to FFU	Age at FFU	aLPFA (degrees)			aLDFA (degrees)			Version (degrees)			Inclination (degrees)			Femoral length (mm)		
			C	A	D	C	A	D	C	A	D	C	A	D	C	A	%D
1	1,869	5 years, 10 months	95.9	96.9	−1	95.5	93.5	2	17.7	15.6	2.1	132.0	124.3	7.7	169.5	162.0	4.5
3	462[a]	1 year, 10 months	111.2	113.5	−2.3	96.2	89.5	6.7	32.2	14.0	18.2	119.4	115.8	3.6	151.9	141.2	7.3
4	139	11.5 months	124.6	132.0	−7.4	99.2	96.9	2.3	24.7	23.7	1	111.2	121.1	−9.9	121.1	104.0	15.2
5	432	1 year, 2 months	110.7	105.6	5.1	96.2	94.5	1.7	35.7	6.6	29.1	120.5	123.0	−2.5	142.1	136.4	4.1

Abbreviations: %D, percent difference between limbs; A, affected limb; aLDFA, anatomic lateral distal femoral joint angle; aLPFA, anatomic lateral proximal femoral joint angle; C, normal contralateral limb; D, difference between limbs (C-A); FFU, final follow-up.
[a]117 days from surgical revision.

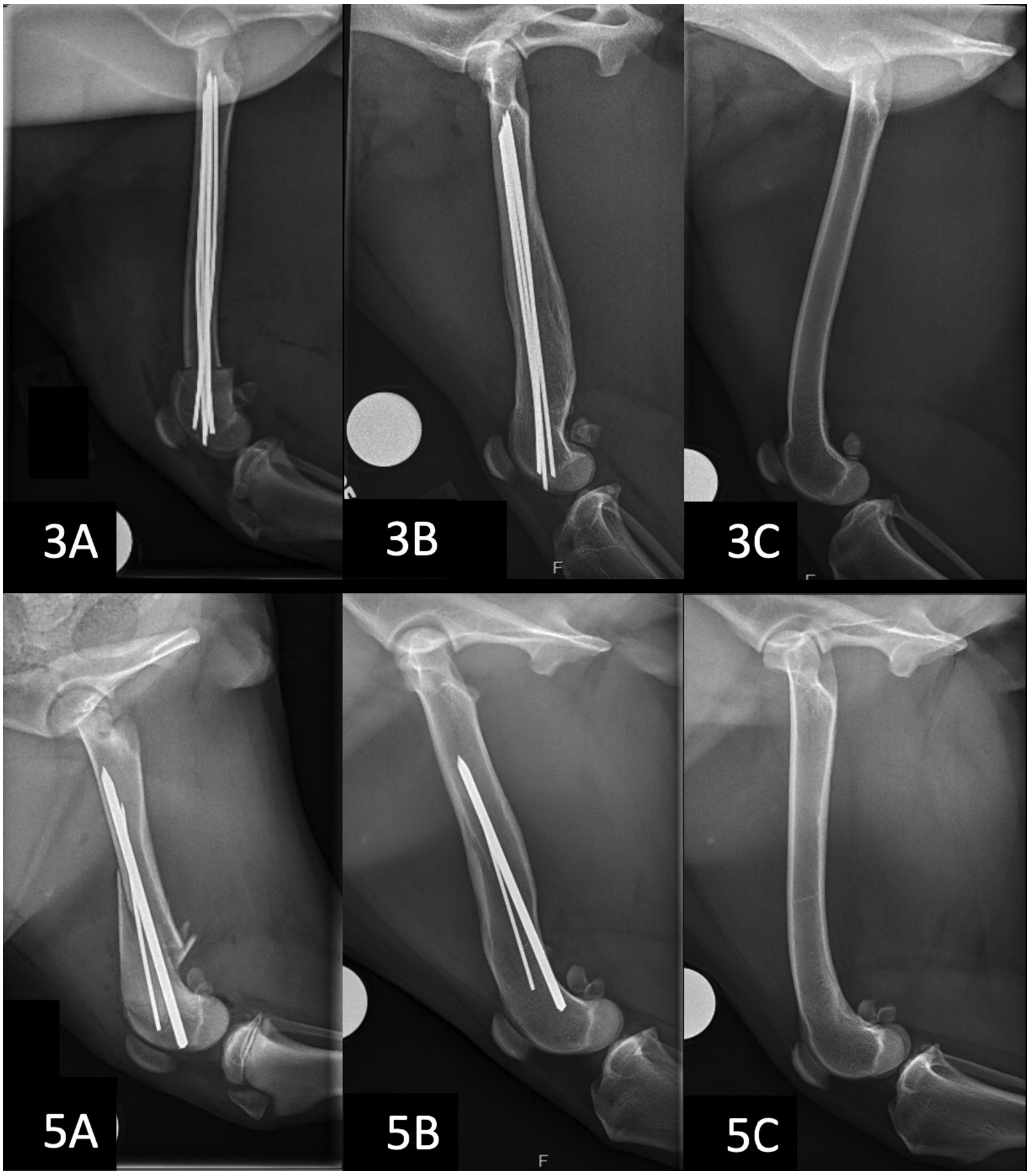

Fig. 5 Mediolateral radiographic projections of case number 3 and 5 demonstrating progressive relative femoral neck retroversion of the affected limb. (**A**) Affected limb immediately postoperative; (**B**) affected limb at final follow-up; (**C**) normal contralateral limb at final follow-up.

Discussion

This report describes the radiographic and clinical outcomes of five skeletally immature dogs that underwent distal normograde intramedullary pinning combined with dynamic intramedullary pinning for the treatment of distal diaphyseal or metaphyseal femoral fractures. Three out of four dogs that returned for short-term follow-up healed without complication at 4 weeks postoperatively and all four dogs that returned for follow-up after skeletal maturity were achieved demonstrated excellent limb function based on owner assessment and orthopaedic examination.

In this case series, differences in femoral alignment between the affected and contralateral limb at final follow-up were overall determined to be mild ($<$ 10 degrees), except for the angle of femoral neck version in two cases. Cases 3 and 5 developed subclinical femoral retroversion in the affected limbs. Based on review of immediate postoperative and serial follow-up radiographs, this relative retroversion was not induced by technical error (malalignment) in surgery, suggesting that rotational instability was present during fracture healing. Theoretically, changes in femoral version could place abnormal stress on both the coxofemoral and stifle joints, predisposing to patellar luxation and/or abnormal joint wear. Although dogs demonstrated excellent limb function at final follow-up, it seems prudent to consider the utilisation of more rigid fixation methods when possible. The use of true cross pins may have provided superior proximal cortical engagement, and thereby rotational stability; however, further research is required to substantiate this claim.

Potential disadvantages of distal normograde intramedullary pinning include possible pin migration into the stifle joint and the development of stifle osteoarthritis due to the intra-articular insertion of the distal normograded intramedullary pin. Mild subclinical stifle osteoarthritis was observed in two dogs in this study and likely resulted from the distal normograded intramedullary pin, although post-traumatic osteoarthritis remains a possibility. Both dogs demonstrated excellent limb function based on subjective owner and surgeon assessment at final follow-up. It should be noted that the dogs were still young (< 2 years) at the time of final follow-up and continued monitoring would be necessary to evaluate for any future clinical consequences of progressive osteoarthritis.

Major complications occurred in one dog and consisted of pin migration and delayed union. Revision surgery was performed to remove the loose intramedullary pin and apply autogenous bone graft, and fracture healing was achieved 4 weeks post revision. There are several factors that likely contributed to the complications observed in this case. The exuberant callus formation observed after the initial surgery supports a predominant mechanical cause for delayed union. Due to the chronicity of the injury, ostectomy of both fracture segments was performed to facilitate fracture reduction, resulting in a small fracture gap with subsequent high interfragmentary strain. In this scenario rigid fixation is required to effectively reduce interfragmentary strain and allow fracture healing to occur. As such, the combined intramedullary pinning technique likely did not provide enough stability to effectively decrease interfragmentary strain in this case. This ultimately resulted in pin loosening, which subsequently interfered with fracture healing. Despite the complications that occurred in case 3, the dog demonstrated excellent limb function at long-term follow-up (462 days).[15] Furthermore, continued femoral growth was documented (14 mm) with only a mild limb length discrepancy (7%) at skeletal maturity.

It is important to consider that most femoral long bone growth occurs at the distal femoral growth plate.[16] As such, combined intramedullary pinning may predispose to premature physeal closure, which could lead to bone shortening or angular limb deformity. Continued femoral growth was documented in all four dogs that presented for follow-up at skeletal maturity. Of note, the dog with the largest discrepancy in femoral length (14% in dog 4) also had sustained a femoral capital physeal fracture, which may have contributed to femoral shortening. The degree of femoral shortening observed in these four cases does not appear to be of clinical significance. This is supported by a previous study, which found that dogs have the ability to compensate for up to 20% femoral shortening.[17] That being said, elective implant removal could be considered to minimise any potential interference with residual growth. To facilitate elective implant removal and prevent pin migration into the bone, it may be prudent to bend the distal ends of the pins in the shape of a tight hook.[18]

This study has several limitations that require acknowledgment, including the retrospective design, small sample size, subjective clinical outcome measures and inconsistent follow-up.

In conclusion, distal normograde intramedullary pinning combined with one or two additional dynamic intramedullary cross pins may form an acceptable treatment option for select distal diaphyseal and metaphyseal fractures in skeletally immature dogs, specifically when finances and available implant choices are limited. Although the results of this case series demonstrated rapid fracture healing, continued femoral growth and excellent limb function at final follow-up, it is important to also acknowledge the high complication rate associated with this technique. Complications included pin migration, progressive rotational malalignment during fracture healing and the development of stifle osteoarthritis, all of which could result in long term clinical ramifications that extend beyond the scope of this study.

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Conflict of Interest
None declared.

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