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CLINICAL RESEARCH

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Comparison of tibial alignment following bent or straight interlocking nail fixation for dogs with diaphyseal tibial fractures

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Abstract

Objective: To describe the change in tibial alignment parameters and complications between bent and straight interlocking nail (ILN) fixation of diaphyseal tibial fractures in dogs.

Study design: Retrospective study.

Animals: A total of 46 dogs with trauma-induced diaphyseal tibial fractures.

Methods: Medical records of dogs with diaphyseal tibial fractures were compiled from 2014 to 2024 and categorized into bent (bILN, $n = 27$) and straight (sILN, $n = 19$) ILN groups. Tibial plateau angle (TPA), coronal angulation (CA), and medial mechanical proximal tibial angle (mMPTA) were calculated and compared with the contralateral limb. Medullary canal fill (MCF) was calculated and compared between groups. Intraoperative and postoperative complications were recorded.

Results: Postoperative TPA in the affected limb was 5° higher than in the contralateral limb in the sILN group and 1° higher in the bILN group ($p < .0001$, $p < .0377$). Postoperative affected tibias in both groups were in 2° more valgus than their contralateral limb ($p < .0059$, $p < .0301$). No differences in mMPTA were noted. The MCF was 6.6% higher in the bILN group than the sILN group ($p < .0163$). Only one dog in the study developed a complication: moderate ILN bending and valgus. This dog was in the bILN group.

Conclusion: The increased TPA of the sILN group could be attributed to the tibia's natural recurvatum, which a sILN may not fully accommodate.

Clinical significance: While superior tibial alignment was achieved with the bILN, the detrimental effects of a higher TPA with use of a sILN need further investigation.

Abbreviations: bILN, bent interlocking nail; CA, coronal angulation; CCL, cranial cruciate ligament; CORA, center of rotation of angulation; ILN, interlocking nail; MCF, medullary canal fill; mMPTA, medial mechanical proximal tibial angle; sILN, straight interlocking nail; TPA, tibial plateau angle.

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1 | INTRODUCTION

Diaphyseal tibial fractures are among the most common orthopedic injuries encountered in veterinary practice.[1] Use of the interlocking nail (ILN) has become a widely used method for fracture stabilization in dogs due to its ability to provide robust mechanical support.[2–5] The tibia's unique anatomy, including its natural curvature and loading conditions during activity, should be considered when evaluating reduction and fixation techniques.

Certain characteristics of tibial alignment are of particular concern following fracture stabilization. The tibial plateau angle (TPA), which reflects the slope of the proximal tibial surface relative to the longitudinal mechanical axis, plays a prominent role in the biomechanics of the dog's stifle joint. An increased TPA increases the tensile loads on the cranial cruciate ligament (CCL), causing alterations to the extracellular matrix and reduced cellularity,[6] which may predispose to CCL rupture.[7] Restoring anatomic TPA is thus considered an important goal of fracture repair but the clinical implications and long-term outcomes of dogs with changes to TPA prior to CCL rupture are unknown. Poor coronal or torsional alignment may also induce unsatisfactory outcomes.[8,9]

Recent findings indicate that contouring an angle-stable ILN with 10° of recurvatum improves construct compliance, maximum compressive load, yield load, and angular deformation in tibial gap-fracture models,[10] and may enhance anatomic alignment. However, the clinical implications of this approach have not been ascertained. Specifically, the effect of implanting a bent ILN on tibial alignment remains unknown; bending an ILN may also be more technically challenging since the distal ILN holes will not align with the standard drill guide system.

The aims of this study were to (1) assess and quantify the change in tibial alignment, including TPA, between straight versus bent ILN in dogs with diaphyseal tibial fractures and (2) document the complications with each technique, including whether accuracy of bolt placement was influenced by contouring and ILN. It was hypothesized that the use of straight ILN would result in greater postoperative TPA when compared with bent ILN, but with greater rates of missing the distal bolt holes. It was also hypothesized that coronal angulation (CA) and medial mechanical proximal tibial angle (mMPTA) would not differ between groups.

2 | MATERIALS AND METHODS

Medical records from 2014 to 2024 were obtained from two veterinary institutions. Inclusion criteria for enrollment were a unilateral diaphyseal tibial fracture with ILN fixation and availability of properly positioned radiographs of both the contralateral and affected limbs. The I-Loc 3–4–5 and 6–7–8 systems (Biomedrix/Movora, Whippany, New Jersey) were used in all cases except for one where the Original Interlocking Nail System (Innovative Animal Products, Rochester, Minnesota) was used. All procedures were performed by board-certified veterinary surgeons. Dogs that developed postoperative complications were included if they met the previously described inclusion criteria. Cases were not excluded if an intraoperative complication precluded final placement of the ILN. Cases were categorized into two groups based on the surgical technique used: Those in which a straight ILN was applied (sILN group) and those in which the ILN was precontoured to match the approximate recurvatum of the contralateral tibia (bILN group). Interlocking nails were bent preoperatively or intraoperatively along the middle to proximal third of the implant using a tabletop bending press. There was no specific protocol or guideline dictating the degree to which the ILNs were bent; that is, the amount of bending was based on surgeon preference. The jig was utilized in all sILN cases and distal bolt holes of the bILN group were identified using intraoperative fluoroscopic guidance or by estimation utilizing the jig as reference, per surgeon preference. Signalment, fracture characteristics, time from trauma to repair, and date of follow up were recorded for each case.

Tibial plateau angle was determined by the angle between the tibial plateau and the longitudinal mechanical axis of the tibia, as previously described (Figure 1).[11,12] Coronal angulation was quantified as the angular deviation in the frontal plane utilizing the center of rotation of angulation (CORA) method,[13,14] and mMPTA was calculated to assess axial alignment of the proximal tibia, as previously described.[15] These data were calculated based on previously described anatomical landmarks.[7,15,16] Percentage of medullary canal fill was determined by measuring the medullary canal at the narrowest aspect of the tibia as a proportion to the diameter of the nail at the same aspect. The angle of recurvatum for ILNs in the bILN group was measured by determining the angle between the proximal and distal shafts of the ILN. All measurements were performed by only one author to eliminate interobserver variability. Postoperative radiographs and fluoroscopy images were examined for unfilled drill holes in the proximity of the ILN holes as evidence of inaccurate or missed bolt placement. Bolt holes that were missed but ultimately captured, as well as bolt holes that were missed and left uncaptured were included in examination. Bolt holes that were purposely left unfilled were not considered as missed or having an inaccurate bolt placement. Both open and minimally invasive approaches were assessed. The medical records were also reviewed for evidence of other intraoperative

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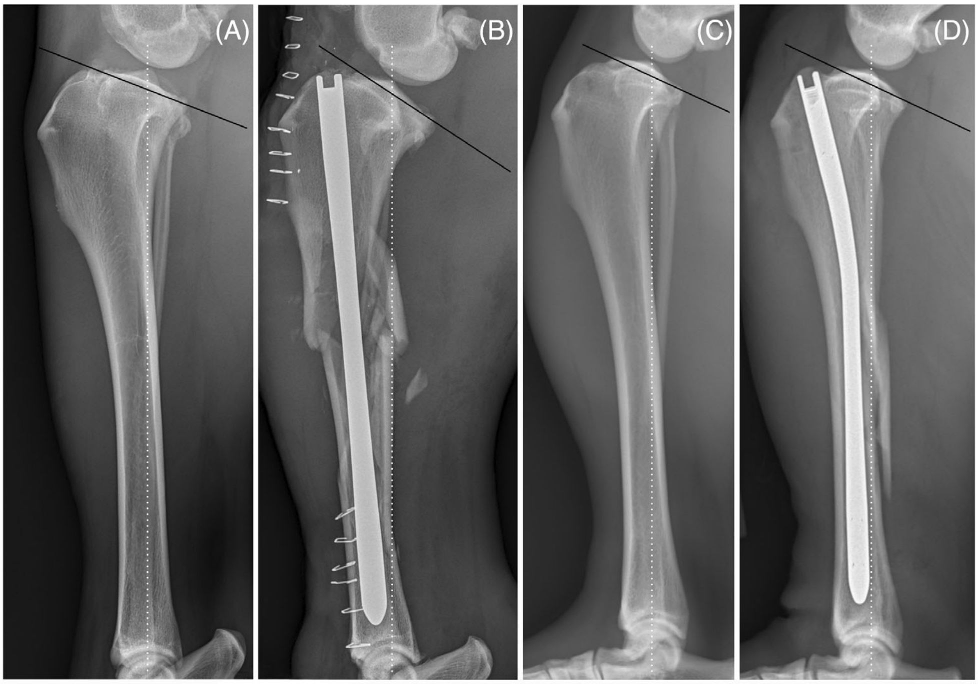

FIGURE 1 Representative contralateral and postoperative tibial plateau angle (TPA) measurements of two dogs from the straight interlocking nail (sILN) and bent interlocking nail (bILN) groups with dashed white lines representing the tibial long axis and solid black lines representing the tibial slope. (A) Contralateral TPA of sILN measuring 22.9°. (B) Postoperative TPA of sILN measuring 31.4°. (C) Contralateral TPA of bILN measuring 25.2°. (D) Postoperative TPA of bILN measuring 25.4°.

or postoperative complications. To determine long-term (>12 month) outcomes, owners were contacted by phone, email, or text message and medical records from further postoperative rechecks and examinations were evaluated for evidence of subsequent development of a CCL rupture or other conditions of the affected limb.

Tibial alignment parameters were compared between contralateral and affected limbs within each ILN group with a paired *t*-test, and between sILN and bILN groups with an unpaired *t*-test. Medullary canal fill was compared between sILN and bILN groups with an unpaired *t*-test. Frequency of missed bolt holes was compared between the sILN and bILN groups with a χ^2 test. Significance was set at $p < .05$.

3 | RESULTS

A total of 46 dogs met the inclusion criteria and were assigned to the sILN group ($n = 19$) or the bILN group ($n = 27$) based on the surgical technique used. The sILN group had a mean (± SD) weight of 30 ± 8.5 kg, and age of 5 ± 4.0 years. The bILN group had a weight of 29 ± 9.7 kg and age of 3 ± 2.4 years. The overall time to fracture repair was 4 ± 5.6 years (minimum = 1, maximum = 28) and the time to recheck was 45 ± 39.8 days (minimum = 6, maximum = 146). The mean follow-up time was 1191 ± 967 days (minimum = 158, maximum = 2989). Cases with intraoperative complications that precluded placement of the ILN were not assessed. The average angle of recurvatum applied to the ILNs in the bILN group was 9° ± 3.8°. Across both groups, 42 dogs underwent ILN fixation using larger diameter ILNs (I-Loc 6–7–8 system and one 6.5 mm novel threaded interference ILN), and four dogs, all in the bILN group, received smaller diameter ILNs (I-Loc 3–4–5 system).

In the sILN group, the postoperative TPA of the affected tibia was 5° ± 3.2° greater than that of the contralateral limb ($p < .0001$) (Figure 2). There was no difference between the immediate postoperative TPA compared with the follow-up TPA at the time of radiographic healing ($p < .5045$). In the bILN group, the postoperative TPA of the affected limb was 1° ± 2.4° higher ($p < .0377$) than the contralateral limb. The postoperative TPA in the sILN group was greater than the bILN group ($p < .0001$).

Postoperatively, the affected tibias in the sILN and bILN groups showed a mean increase in valgus of 2° ± 2.7° and 2° ± 3.8°, respectively, compared with the contralateral limb ($p < .0059$ and $p < .0301$, respectively) (Figure 3). The postoperative mMPTA of the affected tibia in sILN and bILN groups were not different ($p < .0952$ and $p < .0931$, respectively) when compared with the contralateral limb and each other ($p < .7917$) (Figure 4). The average postoperative ILN medullary canal fill was 6.6% ± 2.6% higher in the bILN group when compared with the sILN group ($p < .0163$), with fills of 82.2% (minimum = 68.2%, maximum = 96.4%) and 75.6% (minimum = 48.9%, maximum = 90%), respectively.

Only one case in the bILN had postoperative complications. On physical examination at the 1 month recheck, the dog had an obvious valgus malalignment of the affected crus, but there was no overt lameness, pain, or

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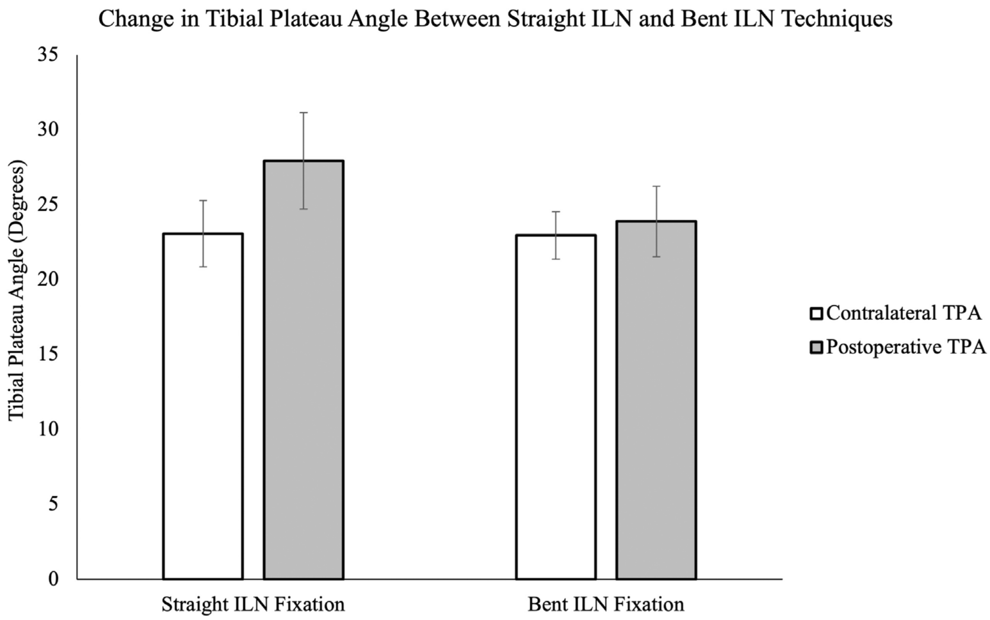
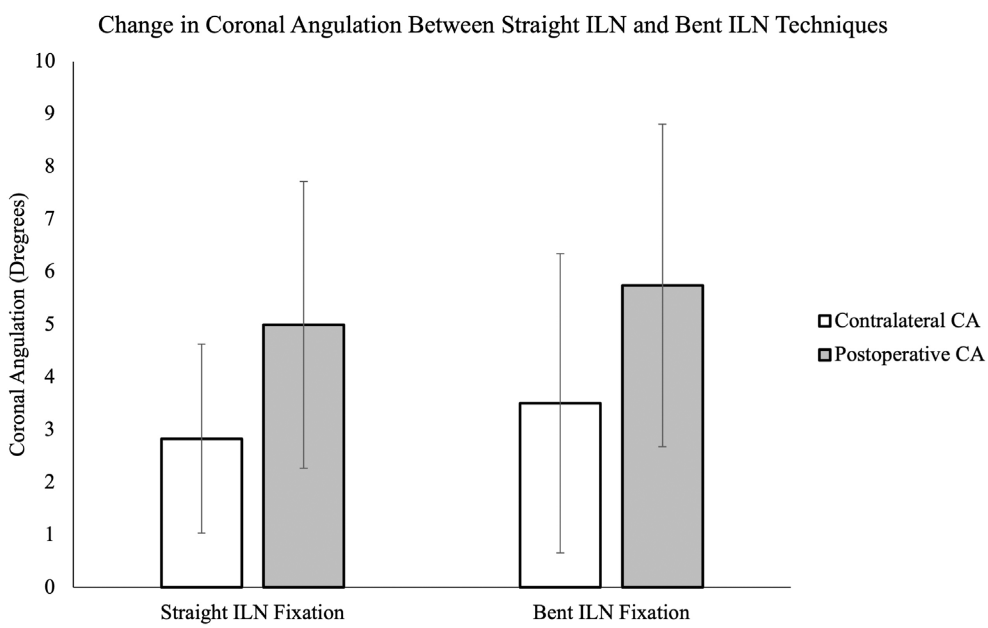


FIGURE 2 Tibial plateau angle (TPA) of straight interlocking nail (sILN) and bent interlocking nail (bILN) fixation techniques. Contralateral TPA (white) was compared with postoperative TPA (gray) in both the sILN (left) and bILN (right) groups. The sILN group had a 5° increase in TPA compared with the contralateral normallimb. The bILN group had a 1° increase in TPA compared with the contralateral normal limb.

FIGURE 3 Coronal angulation (CA) of straight interlocking nail (sILN) and bent interlocking nail (bILN) techniques. Contralateral CA (white) was compared with postoperative CA (gray) in both the sILN and bILN groups. The CA of both the sILN (left) and bILN (right) had a mean increase in valgus of approximately 2°.



disability. Radiographs revealed 12° of greater valgus. This patient underwent fracture fixation with a 7 × 185 mm ILN with 10° of contoured recurvatum and 72.9% medullary canal fill. The cause of the induced valgus was unknown according to medical records and client testimony. There were no cases of implant associated infection or other complications in either group. Four dogs in the sILN group and 15 dogs in the bILN group did not return for follow-up radiographs and thus did not provide radiographic evidence to verify healing. All other dogs that returned for long-term follow up, 15 dogs in the sILN and 12 dogs in the bILN group, showed radiographic evidence of verified healing at the time of their final follow up.

Of the 46 owners, 22 responded for long-term follow-up evaluation, with six from the sILN group and 16 from the

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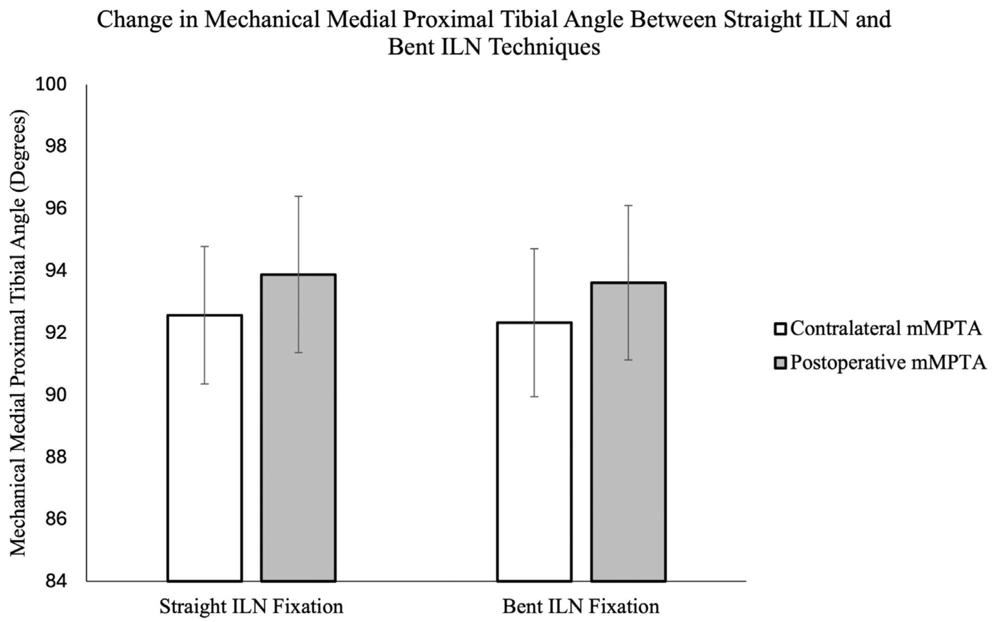

FIGURE 4 Medial mechanical proximal tibial angle (mMPTA) of straight interlocking nail (sILN) and bent interlocking nail (bILN) techniques. Contralateral mMPTA (white) was compared with postoperative mMPTA (gray) in both the sILN (left) and bILN (right) groups. There was no significant increase between contralateral and postoperative mMPTA in the sILN or bILN groups.

bILN group. Only one dog reportedly developed a CCL rupture postoperatively, and this dog was in the bILN group. The preoperative contralateral TPA was 23.3° and the affected limb's postoperative TPA was 23.7°. There was no evidence of CCL deficiency preoperatively and there were no intraoperative complications noted that affected the CCL or the region of its insertion. None of the owners responding to long term follow-up requests reported any complications or dissatisfaction with the outcome.

In the sILN group, 6/19 dogs had evidence of missed bolt holes, where two proximal and four distal bolt holes were missed. In the bILN group, 8/27 of dogs had evidence of missed bolt holes, where two proximal and six distal bolt holes were missed. Intraoperative fluoroscopy was utilized in all cases with missed bolt holes in the sILN group and 2/8 cases with missed bolt holes in the bILN group. Only one dog had missed bolts that were not ultimately captured, and this dog was in the sILN group. In this case, the distal bolt was missed due to misalignment with the jig, according to available medical records. This patient did not have any overt lameness, pain, or disability at its 1 and 2 month recheck examinations. There was no difference in the frequency of missed bolt holes in the sILN group and the bILN group ($p < .887$).

4 | DISCUSSION

The findings of this study provide insight into the impact of ILN fixation techniques on postoperative tibial alignment in dogs with diaphyseal tibial fractures. Specifically, the use of a bent ILN technique produced a postoperative TPA that was in near-anatomic alignment when compared with the contralateral limb. Conversely, the straight ILN technique resulted in a higher TPA, though only by approximately 5°. This discrepancy may be attributed to the inability of a straight ILN to accommodate the natural recurvatum of the canine tibia, thereby predisposing the tibial plateau to caudally angulate relative to the distal segment. Such misalignment may have biomechanical consequences, particularly regarding the distribution of forces across the stifle joint during weight bearing.

Despite the observed differences in TPA, no substantial changes were noted in other parameters of tibial alignment. Although ILN fixation provides only relative stability in the immediate postoperative period, alignment parameters, including TPA, were maintained until complete radiographic healing. The preservation of mMPTA also suggests that both straight and bent ILN techniques are effective in producing proper coronal angulation. The minor valgus deviations observed for both groups were unlikely to have a substantial clinical impact on limb function or gait. This study did not assess rotational deformities or tibial torsion, which may influence postoperative outcomes. Quantifying tibial torsion was considered but this parameter cannot be accurately estimated from radiographs alone.[17] Advanced imaging modalities, such as computed tomography, would be useful in future investigations.

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The clinical implications of the increased TPA observed in the sILN group remain uncertain. An increased TPA has been associated with heightened cranial tibial thrust force during weight bearing,[18] which may increase the load on the CCL and predispose it to rupture. A previous study found that a 10° increase in TPA increases the strain in the craniomedial band of the CCL during compressive loads.[6] However, no dog in the sILN group was identified that subsequently developed CCL rupture; indeed, the only case of CCL rupture during the follow-up period was in the bILN group. This study was not designed to definitively investigate the association with CCL rupture and postoperative TPA, as it had a relatively short follow-up period and small sample size. Larger scale studies with extended follow-up durations are needed to assess whether the higher TPA observed in the straight ILN group translates to an increased risk of CCL rupture or other stifle joint pathologies over time.

The focus of this study was on alignment outcomes but the comparisons raise additional questions regarding the mechanical performance of straight versus bent ILN. Previous mechanical studies have suggested that the inability of a straight ILN to accomodate the tibia's anatomy may increase the risk of implant failure.[16] We found very low rates of implant failure, regardless of contour, corroborating that the ILN is a reliable implant for tibial fracture repair. As this study did not control medullary canal fill directly and the rate of failure was very low, direct causes of implant failure related to these factors remain unknown in this specific cohort. Previous recommendations state that the ILN should fill 75% of the medullary diameter to limit the effects of stress shielding.[19] The causes of the discrepancy in medullary canal fill between the sILN and bILN groups are unclear, as implant sizes were determined by the previously described medullary fill target and implant sizing was based on this same target across both groups. The near-anatomic application of the bILN may allow for a more coaxial implantation in the distal diaphysis, which might lead to higher medullary canal fill. Other factors such as implant size availability, discrepancies in radiographic measuring and surgical planning, and individual anatomic accommodations for implant sizes may also explain these findings. The impact on longterm clinical outcome of a 6% difference in medullary canal fill also remains undefined. Whether bent ILN offers superior long-term stability and durability in clinical settings needs further investigation.

Missed bolt holes when drilling are a common intraoperative complication in the ILN technique. When using the ILN system, which relies on a fixed external jig drill guide, any bending of the ILN or guide components leads to misalignment between the drill guide and the ILN bolt holes. Misalignment of the drill guide can also occur with excessive or accidental pressure on the jig, or "skidding" of the drill bit while drilling. In this study the rate of missed bolt holes did not differ between the sILN and bILN groups. Due to the retrospective nature of the study, it was not possible to ascertain the precise reasons for missed bolt holes in each case. Placing bolts in a bent ILN may be more challenging for surgeons without access to fluoroscopy as well as limited familiarity with ILN fixation systems.

The study has several limitations that should be considered when interpreting its findings. The sample size was relatively small as it included only 46 dogs, which may not generalize to the population as a whole. In particular, dogs with unusual tibial conformations, such as those affected by chondrodystrophy, were not evaluated which limits conclusions drawn about such populations. The follow-up period was relatively short and inconsistent among the sample population, which could affect the assessment of long-term complications such as CCL rupture that may develop over a longer timeframe. The study did not assess rotational deformities or tibial torsion, which could impact postoperative outcomes. There may have also been surgeon-related variability, particularly in the amount of bending of the ILN. As far as the authors are aware, no cases were excluded due to intraoperative complications, and no cases were lost or abandoned intraoperatively due to an inability to achieve distal fixation, which could have otherwise confounded the results; however, it is possible that some cases were missed.

In summary, this study highlights the influence of ILN fixation techniques on postoperative tibial alignment in dogs, with bILN providing near-anatomic TPA alignment in comparison with sILN. Future investigations with larger populations and longer follow-up periods and advanced imaging techniques are warranted to better understand the long-term outcomes, such as development of CCL rupture, and broader clinical implications of ILN contouring.

AUTHOR CONTRIBUTIONS

Ramsey HD, DVM: Identified suitable medical records; compiled all the data, performed radiographic measurements; interpreted the data; communicated with clients; drafted and revised the manuscript. Hanlon J, DVM: Contributed to the design of the study; aided in confirmation of initial radiographic measurements. Kieves NR, DVM, DACVS (Small Animal), DACVSMR, CCRT: Aided with access to medical records; provided a critical review of the manuscript. Kim SE, BVSc, MS, DACVS (Small Animal): Developed the design of the study; aided with access to medical records; oversaw data collection;

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provided a critical inline review of the manuscript. All authors provided a critical review of the manuscript and endorsed the final version.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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