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Retrospective study of the early clinical experience with a precontoured angle-stable interlocking nail for fracture repair in dogs and cats

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OBJECTIVE
To report indications, outcomes, and complications with a precontoured angle-stable interlocking nail (CAS-ILN).

ANIMALS
90 client-owned animals.

METHODS
Dogs and cats treated with the CAS-ILN between 2020 and 2022 were retrospectively reviewed. Collected data included body weight, fracture configuration, percentage of medullary canal filled, limb alignment, complications, and follow-up. Favorable outcomes were defined when full functional restoration was observed.

RESULTS
Thirty-eight dogs and 52 cats were included. Median body weight was 4.3 kg (range, 1.5 to 6.7 kg) for cats and 25 kg (range, 6.8 to 54 kg) for dogs. A total of 54 femurs, 31 tibias, and 5 humeri were treated, including 65 comminuted fractures and 26 metaphyseal fractures. The median percentage of medullary canal occupied by the nail was 76.5% (range, 53% to 97.6%). Radiographic postoperative bone alignment was good in 85.5% (59/69) and satisfactory in 10 cases. The median duration of follow-up (57/90) was 476 days (range, 56 to 1,057 days). In the perioperative period (0 to 12 weeks), lameness had resolved or was mild in all (51/52) but 1 case. In the long-term postoperative period (> 12 months), 97.1% (34/35) of cases showed restoration of full function and 1 case had an unacceptable function. An overall complication rate of 11.5% (7/61) was reported including 1 catastrophic and 6 major complications.

CLINICAL RELEVANCE
Long-term functional outcomes following the CAS-ILN were favorable in 97.1% (34/35) of cases. Complication rates were comparable to previous studies. The CAS-ILN appears to be an alternative surgical option for most long-bone fracture repairs.

Keywords: interlocking nail, precontoured, angle-stable, fracture repair, dogs and cats

Interlocking nails (ILNs) offer several advantages over plate implants to treat long-bone fractures.[1–11] Contouring may not be necessary and extramedullary bone vascularization and soft tissue are better preserved.[8–12] Furthermore, ILNs are placed neutral to the long axis of the nail-bone construct and, therefore, provide a more homogenous area moment of inertia and are better able to resist bending forces than plates.[1,13,14] Based on these features, several ILN devices have been developed in veterinary medicine. Biomechanical studies[13–20]

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have proven the superiority of these devices over plate-rod systems in resisting bending, torsion, and compressive stresses.

ILNs have been modified and adapted over the years to overcome the different limitations encountered during their clinical applications, and the angular stability of the latest implants has demonstrated mechanical superiority.[7,8,11,21,22] Nevertheless, current ILN devices have a straight shape, which may not adequately conform to the native recurvatum or procurvatum of some bones, such as the dog tibia and femur.[23–26] Furthermore, screws or locking bolts may be misplaced when using standard ILNs.[4,7,11,23,24,27]

To address these issues, a precontoured angle-stable interlocking nail (CAS-ILN) system was recently designed and showed promising results in preclinical mechanical assessments.[28] This implant is curved in the sagittal plane to better adapt to the anatomy of most small animal long bones. It is cannulated, permitting verification of the locking screw location within the nail during placement. A biomechanical study[28] showed that a 6-mm CAS-ILN had higher stiffness and higher resistance to failure, with no observable slack, when compared to a 3.5-mm 12-hole locking compression plate. However, clinical evaluation of the CAS-ILN has not yet been conducted. The objective of this study was to describe indications, outcomes, and complications associated with the CAS-ILN in dogs and cats.

Figure 1—Illustration of the curved shape of the precontoured angle-stable interlocking nail and the dedicated instrumentation including the extension, bracket, extension wheel, targeting arm, targeting arm wheel, targeting sleeves, and trans-cortex drill bit.

Methods

Implant design

The CAS-ILN and instrumentation design were previously published in an ex vivo study.[28] The nail is made in titanium alloy (TiAl4V) and is available in 5 diameters (3.5, 4, 5, 6, and 8 mm) and several lengths ranging from 70 to 150 mm in 8-mm increments for cats and small dogs and from 134 to 234 mm in 12.5-mm increments for medium and large dogs. The radius of the CAS-ILN curvature was chosen according to a radiographic analysis conducted by the manufacturer Surg'X. The radius of curvature is positioned between the 2 inner screw holes **(Supplementary Figure S1)**. The CAS-ILN is cannulated and 3 screw holes are present at each end of the nail: 2 standard mediolateral and 1 orthogonal craniocaudal locking hole **(Figures 1 and 2)**. The cannulation diameter is 1.4 mm for the short 3.5-, 4-, and 5-mm CAS-ILN sizes and 1.7 mm for the long 5-, 6-, and 8-mm CAS-ILN sizes. The guide wire is made of nitinol (Surg'X) and available in 2 sizes: 1.2-mm diameter for the short 3.5-, 4-, and 5-mm CAS-ILN sizes (270-mm length) and 1.5-mm diameter for the long 5-, 6, and 8-mm CAS-ILN sizes (400-mm length). Bicortical screws (titanium alloy; Surg'X) are locked in the nail and in the cis cortex of the bone by a threaded profile. Four screw sizes (2, 2.5, 3, and 3.5 mm) are available according to the nail diameter with several lengths ranging from 10 to 20 mm in 2-mm increments for 2-mm screw, from 12 to 26 mm in 2-mm increments for 2.5-mm screw, from 14 to 36 mm in 2-mm increments for 3-mm screw, and from 16 to 48 mm in 2-mm increments for 3.5-mm screw. The length of the nonthreaded part of the screw, at the trans-cortex end, increases with screw length and ranges from 4 to 7 mm for 2 mm, from 4.5 to 8 mm for 2.5 mm, from 5.5 to 9.5 mm for 3 mm, and from 6 to 11 mm for 3.5 mm. The same screws are used in both the metaphyseal and diaphyseal parts of the bone.

Study population

This study retrospectively enrolled dogs and cats with long-bone fractures treated with a CAS-ILN in 1 of 6 veterinary centers (National Colleges of Veterinary Medicine of Lyon and Nantes and Veterinary Hospitals of Atlantia, Frégis, Pommery, and Nordvet) from September 2020 to April 2022. The study was approved by the Clinical Research Committee at VetAgro Sup, Marcy l'Etoile, France (Ethics Committee No. 2058). A signed informed consent form was obtained from the owners. Information collected from the medical records included signalment (age, sex, breed, and body weight); cause of fracture; fracture localization, type (closed or open with the Gustilo-Anderson open fracture classification)[29] and pattern (simple or comminuted); concurrent injuries; preoperative radiographs; surgical approach; ILN size; screw configuration; additional repair needed; postoperative radiographs; and complications.

Surgical planning

Orthogonal standard radiographs of the affected bone were used preoperatively to determine fracture type, pattern, and location. Surgical planning was generally conducted preoperatively using contralateral bone radiographs (similarly orientated)

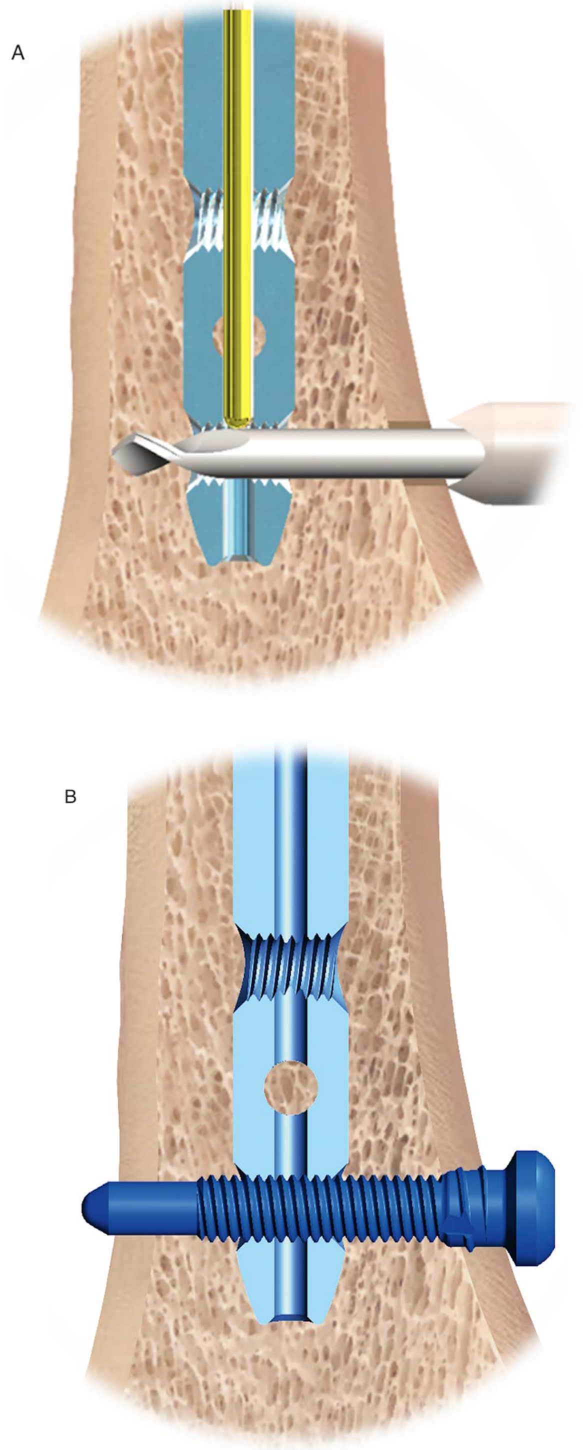

Figure 2—Illustration of the precontoured angle-stable interlocking nail components. A—The guide wire is inserted into the nail to control the correct positioning of the drill bit or screw in the nail. B—The locking system of the screw is composed of a threaded locking profile in the interlocking nail and a second locking profile of the screw into the cis cortex.

with a 25-mm spherical marker for radiographic calibration to select the implant, including nail diameter, length, and screw distribution. In some cases of reconstructible fractures, surgical planning was based on the surgeon's experience, using radiographs of the affected bone and adjusting the nail length intraoperatively as reamers are graduated. Nail diameter was chosen based on the weight of dogs and cats and to ensure the nail would fill close to 80% of the bone medullary cavity at the isthmus. The longest nail was chosen to fit the bone and fracture configuration.

Surgical technique

All surgeries were performed by a veterinarian with practice limited to surgery. Dogs and cats were placed under general anesthesia, and the affected limb was aseptically prepared. Surgeons used a standard approach with a medial incision for tibias and a lateral incision for femurs and humeri. The method of reduction (open but do not touch, minimally invasive nail osteosynthesis, or open reduction internal fixation) and additional repair (if needed) were chosen at the surgeon's discretion.

With the use of a square awl reamer, the cortex was manually drilled at the nail insertion point. Fractures were reduced with bone-holding forceps using direct or indirect techniques based on the surgeon's preference. The proximal and distal metaphyseal bone beds were sequentially expanded with straight but flexible intramedullary reamers of increasing diameter at least up to the diameter of the chosen nail. Endocortical reaming of the diaphysis was not performed. A flexible guide wire made in nitinol (Surg'X) was introduced into the medullary canal, while fracture reduction was maintained by forceps. The chosen cannulated nail mounted on the extension system was inserted into the bone by sliding over the flexible wire. The bracket was placed, and the targeting arm was locked onto the nail bracket. Screw holes were drilled starting with the most distal hole. For each screw, the cis-cortex drill bit was used to drill the cis cortex only. The trans-cortex drill bit was then slid through the nail hole.

To verify the correct positioning of the drill bit through the locking hole, the guide wire was inserted into the cannulated nail and had to touch the trans-cortex drill bit (Figure 2). Then, the trans cortex was drilled. For orthogonal holes, the targeting arm was oriented perpendicular to its initial position. Screw holes were drilled as previously described. All drill bits were left in place in the holes to maintain the correct alignment of the nail into the bone (Figure 1). A depth gauge was used in coordination with a sleeve to assess the screw length. The chosen screw had to be 1 or 2 mm longer than the measurement. Screws were then inserted and did not need to be cut. The aiming device was removed, and the wounds were closed routinely.

Postoperative radiographic assessment: alignment and medullary canal diameter

Bone alignment—In the frontal plane, femoral and tibial varus and valgus were evaluated on postoperative craniocaudal radiographs as previously described.[25,26,30,31] In the sagittal plane, the tibial plateau angle was measured on lateral radiographs.[26] When contralateral bone radiographs were not available, postoperative angles were compared with reported normal ranges.[25,26,30] Cases with poor positioning of the radiographs were excluded. Procurvatum and recurvatum of femurs were subjectively assessed based on a subjective 3-level scale: incorrect, satisfactory, or good. Femoral torsion was evaluated according to the location of the femoral head in relation to the proximal cranial femoral cortex and described as anatomical, anteverted, or retroverted. Tibial torsion was assessed based on a 3-level scale that evaluated the position of the caudal edges of the tibial plateau as anatomical, external, or internal.

Medullary canal diameter and missed cannulation—On the immediate postoperative radiograph, the percentage of the medullary canal diameter filled by the nail was determined by comparing the width of the medullary cavity diameter at the bone isthmus to the nail diameter. Screw misplacement was also evaluated.

Follow-up

For follow-up, dogs and cats were evaluated if they had at least 1 radiographic follow-up showing complete fracture healing or if a complication was encountered during the follow-up.

Complications—All complications encountered from the intraoperative placement of the CAS-ILN to the latest follow-up were recorded. Complications were categorized as catastrophic when the complication caused permanent unacceptable function, major I when the complication required surgical treatment, major II when it required medical treatment, or minor when no additional surgical or medical treatment was required, as previously described.[32]

Fracture healing—Fractures were considered to be healed if continuity of 3 cortices in 2 orthogonal radiographic projections was identified on at least 1 radiographic follow up.

Outcomes—For outcomes, dogs and cats were evaluated if they had at least 1 radiographic follow-up showing complete fracture healing. Clinical and radiographic rechecks were recommended between 4 and 6 weeks and between 10 and 12 weeks postoperatively, including full clinical and orthopedic examination with evaluation of pain or discomfort. In the perioperative period (0 to 12 weeks), the use of the operated limb was evaluated using 4 severity levels: excellent (no lameness); good (favoring the limb after exercise); fair (obvious and constant lameness); and poor (no use of the limb for support). For follow-ups beyond 12 weeks, limb function was assessed as full (or favorable), acceptable, or unacceptable, as previously described.[32] When a recheck examination was missed, an owner telephone interview or mailed questionnaire was conducted to evaluate comfort, lameness, daily activity, and postoperative recovery.

Data description

Data are reported as absolute number and percentage for fracture etiology, localization, pattern and type, concurrent injuries, surgical approach, ILN size, screw configuration, bone alignment, and percentage of medullary canal filled and fracture healing. Median with range is used for age and body weight, and mean with SD is used for bone alignment measurements.

Results

Population

Between 2020 and 2022, 38 dogs and 52 cats were treated with the CAS-ILN. The median age was 1.5 years (range, 2.4 months to 15.2 years) for cats and 2.8 years (range, 3.6 months to 15.3 years) for dogs. The median body weight was 4.3 kg (range, 1.5 to 6.7 kg) for cats and 25 kg (range, 6.8 to 54 kg) for dogs. The study population included 8.9% (8/90) female cats, 48.9% (44/90) male cats, 25.5% (23/90) female dogs, and 16.7% (15/90) male dogs.

Fracture etiology and pattern

For cats, the long-bone fracture was due to suspected trauma or road traffic accident in 57.7% (30/52) of cases, fall in 13.5% (7/52) of cases, revision surgery following previous implant failure in 3.8% (2/52) of cases, gunshot in 5.8% (3/52) of cases, dog bite in 1 case (1/52), and unknown cause in 9/52 cases. In dogs, fracture etiology included 71.1% (27/38) of road traffic accidents, 10.5% (4/38) of falls, 2 cases (2/38) of revision surgeries following previous implant failure, 2 (2/38) trauma during play, 2 (2/38) cases with unknown etiology, and 1 (1/38) trauma during hunting.

A total of 54/90 (60%) femoral fractures (35 cats and 19 dogs), 31/90 (34.4%) tibial fractures (12 cats and 19 dogs), and 5/90 (5.6%) humeral fractures (5 cats) were treated. Metaphyseal fractures were seen in 13 cats and 13 dogs (26/90, 28.9%): 9 were classified as simple and 17 as comminuted. Diaphyseal fractures were observed in 39 cats and 25 dogs (64/90, 71.1%): 16 were simple and 48 were comminuted. Overall, 72.2% (65/90) of fractures were comminuted. There were 15.6% (14/90) of open fractures (6 cats and 8 dogs) all classified as type I. Concurrent injuries were seen in 10 cats and 17 dogs (27/90, 30%).

Surgical procedure

An open but do not touch approach was performed in 50% (45/90) of cases, a minimally invasive nail osteosynthesis approach in 32.2% (29/90) of cases, and an open reduction internal fixation approach in 17.8% (16/90) of cases. An additional repair was used in 11 cases by placing cerclage wires. No significant intraoperative complications were encountered except 5 misplaced screws (5/365, 1.37%) that were successfully reoriented intraoperatively in all but 1 case (final missed cannulation rate of 1/365, 0.27%).

Postoperative assessment

Median weight and nail diameter—For cats, a 3.5-mm-diameter ILN was used in 25 cases showing a median weight of 4.1 kg (range, 1.5 to 6.2 kg); a 4-mm-diameter ILN was used in 26 cases showing a median weight of 4.5 kg (range, 2 to 6.7 kg) and 1 cat (4.3 kg) was treated with a 5-mm-diameter ILN.

For dogs, a 4-mm-diameter ILN was used in 4 cases showing a median weight of 7.6 kg (range, 6.8 to 8.6 kg); a 5-mm-diameter ILN was used in 12 cases showing a median weight of 16 kg (range, 8 to 27 kg); a 6-mm-diameter ILN was used in 9 cases showing a median weight of 26.5 kg (range, 20 to 41 kg) and 13 cases were treated with an 8-mm-diameter ILN, showing a median weight of 30 kg (range, 18.1 to 54 kg).

Screw distribution—P refers to parallel screws and O to orthogonal. For cats, a 2P:2P distribution was performed in 44 cases, 2P:2O in 2 cases, 2O:2P in 2 cases, 3:2P in 2 cases, 2P:1P in 1 case, and 1P:2P in 1 case. For dogs, 33 cases had a 2P:2P screw distribution, 1 had a 2P: 2O, 3 had a 2P: 3, and 1 had a 3: 3 screw distribution.

Bone alignment—Among the 90 treated cases, 21 cases had poor radiographic positioning precluding bone alignment measurement. Thus, 69 bones were analyzed (38 femurs and 31 tibias). Thirty-one bones were compared to the contralateral measurement and 38 bones were compared to the normal reference angle. Measured angles in the frontal and sagittal plane for tibias and femurs were within 2° of the intact contralateral bone in 43.5% (30/69) of cases and within the normal reference range in 55.1% (38/69) of cases. In 1 cat (1/69), mild femoral valgus was observed on postoperative radiographs. Femoral procurvatum and recurvatum were considered to be satisfactory or good in 94.7% (36/38) of femurs and incorrect in 2/38 cases (2 cats). Increased femoral neck anteversion was identified in 3/38 cases (3 cats) and retroversion was identified in 1/38 case (1 dog; **Supplementary Figures S2 and S3**). Tibial torsion with mild internal rotation was observed in 3/31 cases (1 cat and 2 dogs). Measurements of femoral and tibial varus, valgus, and tibial plateau angle are summarized **(Table 1)**.

Percentage of medullary canal occupied by the nail—The median percentage of medullary canal (90) occupied by the nail was 76.5% (range, 53 to 97.6%).

Table 1—Measurements for femoral and tibial valgus and varus and tibial plateau angle in 69 cases.

Bone	Angle	Cat group	Dog group
Femur	aLPFA	103 ± 2.7	98.1 ± 2
	aLDFA	93.5 ± 2.7	95.9 ± 2
Tibia	mMPTA	90.9 ± 2.5	93.5 ± 2.3
	mMDTA	103.6 ± 2.8	96.5 ± 3.3
	TPA	24 ± 1.3	26 ± 1.2

Data are reported as mean and SD.

aLDFA = Anatomic lateral distal femoral angle. aLPFA = Anatomic lateral proximal femoral angle. mMDTA = Mechanical medial distal tibial angle. mMPTA = Mechanical medial proximal tibial angle. TPA = Tibial plateau angle.

Follow-up

Between 2020 and 2022, 90 fractures were treated with a CAS-ILN. Three cases died of unrelated causes during the first month postsurgery, and no complications were reported before the death. Eighteen cases were lost to follow-up, and no radiographs were performed. No intraoperative complications nor technical errors requiring the removal of the nail occurred. Immediate postoperative radiographs were all satisfactory. In 5 out of the 18 cases, a 2-week (4/5) or 4-week (1/5) follow-up was available showing the absence of complication reported at the last orthopedic examination. In the 13 remaining cases, no postoperative follow-up was performed. Eight other cases had incomplete radiographic follow-up. Among them, 3 cases had a recheck between 4 and 6 weeks after surgery showing the absence of complication and radiographs showing fracture healing in progress. Five other cases had follow-up radiographs showing fracture healing in progress and a short-term owner interview (3 to 6 months) demonstrating resolution of lameness in all cases. No complication was reported at the last follow-up. A flow chart is available in additional materials **(Supplementary Figure S4)**.

Complications—Among the 90 cases treated with a CAS-ILN, 27 dogs and 34 cats (61/90) had at least 1 radiographic follow-up showing complete fracture healing or a complication that occurred. In these 61 cases, we recorded an overall complication rate of 11.5% (7/61), including 1 catastrophic complication, 6 major complications, and no minor complications.

The catastrophic complication occurred during the medium-term follow-up in 1 mixed-breed 41-kg dog with a closed comminuted proximal femoral fracture that was treated with an 8-mm-diameter CAS-ILN **(Supplementary Figure S5)**. During the early follow-up, the dog experienced severe lameness of the operated limb associated with proprioceptive deficits and pain during hip mobilization. A CT scan revealed osteolytic lesions of the femoral head and a large fibrous callus associated with the fracture site. Femoral head ostectomy and microdissection of the entrapped sciatic nerve from surrounding fibrous tissue were performed. No interference between the sciatic nerve and the ILN was identified perioperatively. At the most recent follow-up, the dog was still presenting a non-weight-bearing lameness without neurologic deficits that was unresponsive to medical treatment.

In the 61 evaluated cases, there were 6 major complications, representing an overall major complication rate of 9.8% (6/61), including 4 major I (6.5%) (4/61) and 2 major II (3.3%) (2/61) complications.

Implant removal was performed in the 4 cases of major I complication. In the first 3 cases, implant failure occurred by breakage at the third proximal screw hole, 3 days postoperatively in 2 cases, and 15 days postoperatively in 1 case **(Supplementary Figure S6 and Table S1)**. The first case occurred in a 27-kg dog treated with a 5-mm-diameter nail that filled 75% of the canal (recommended maximum weight of 20 kg).

The second case occurred in a 41-kg dog with a comminuted tibial fracture treated with an ILN that filled only 54% of the canal. The third case occurred in a 7.5-kg dog with a tibial fracture treated with a satisfactory medullary canal filling of 91% and a 2P:2P screw distribution. In the fourth case, femoral distal refracture with migration of the implant occurred 15 days postoperatively, in a dog with a comminuted femoral fracture that was treated with a 2P:1 screw distribution and an ILN that filled 67% of the canal **(Supplementary Figure S7)**. In these 4 cases, revision surgery was uneventfully performed to replace the nail with a plate-rod system. Apart from these cases, no other nail removal was performed in this study. In 2 animals, superficial surgical site infections, representing an overall major II complication rate of 3.3% (2/61), were identified in the early follow-up and successfully managed by systemic antibiotics.

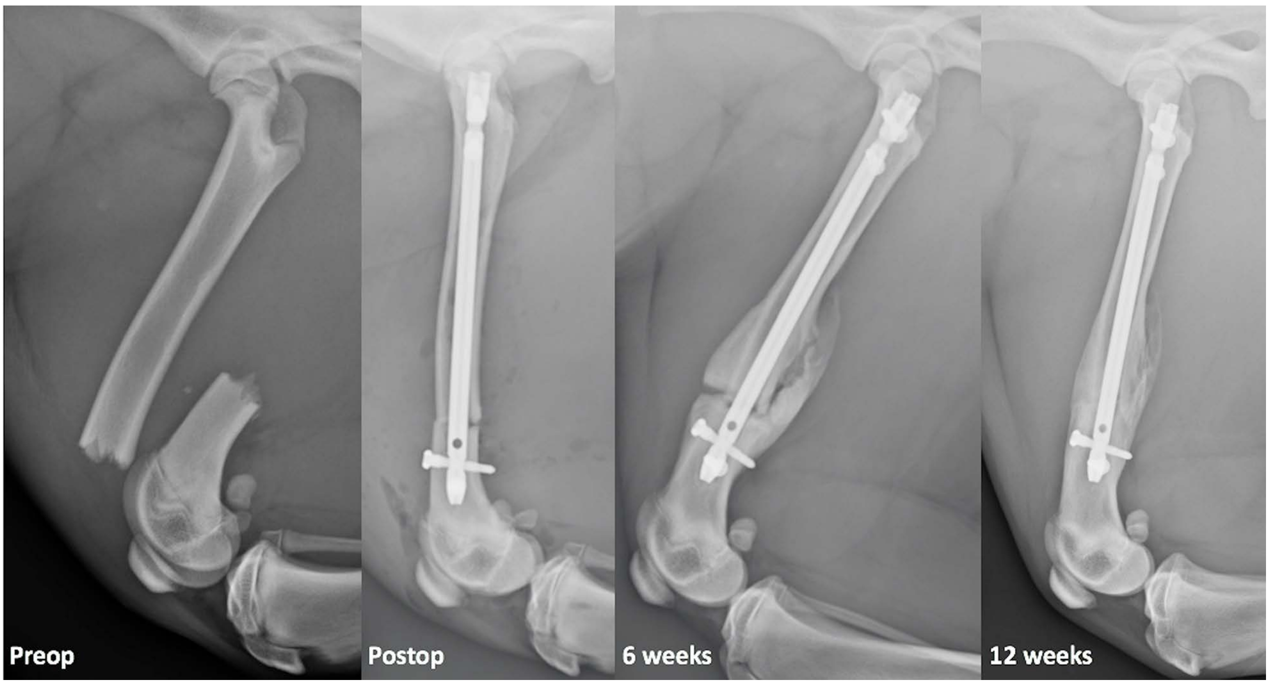

Figure 3—Follow-up mediolateral radiographs of a closed transverse distal diaphyseal femoral fracture in a 6-month-old female Labrador Retriever dog treated with a 6-mm-diameter precontoured angle-stable interlocking nail. A distal orthogonal screw was used to avoid the fracture site. Complete fracture healing was observed 12 weeks postoperatively.

Figure 4—Pre- and postoperative mediolateral radiographs of a canine femoral fracture, feline femoral fracture, and canine tibial fracture showing the interest of the precontoured angle-stable interlocking nail (CAS-ILN) curvature and the quality of the fracture reconstruction. Anatomic reduction was achieved in these cases. A—The nail respected the curved shape of the canine femora; moreover, screws were placed in the cancellous bone of the condyles. B—The CAS-ILN did not alter the straight shape of the distal feline femora. C—The nail suited with the sigmoid shape of the tibia.

Table 2—Available perioperative levels of lameness and short- to long-term outcomes for the 61 evaluable cases (at least 1 radiographic follow-up showing complete fracture healing) out of the total 90 treated, excluding the 4 cases with implant failure requiring removal of the precontoured angle-stable interlocking nail (n = 57).

Period	Outcomes	Number of cases	Number of cases evaluated	Percentage
Perioperative (0–3 months)	Excellent	31	52	59.6
	Good	20	52	38.5
	Poor	1	52	1.9
Short term (3–6 months)	Full	12	16	75
	Acceptable	4	16	25
Mid term (6–12 months)	Full	6	7	85.7
	Acceptable	1	7	14.3
	Unacceptable	–	–	–
Long term (> 12 months)	Full	34	35	97.1
	Acceptable	–	–	–
	Unacceptable	1	35	2.8

Data are reported as the number of cases on the number of cases evaluated and percentage.

Fracture healing and time to radiographic union—Among the 90 treated cases, 61 cases were evaluable for fracture healing (at least 1 radiographic follow-up showing complete fracture healing) and among them, 4 (4/61) cases had an implant removal secondary to early implant failure. In the remaining 57 cases, follow-up radiographs showed fracture healing (3/4 cortices) at the 4- to 6-week follow-up in 14 cases, at the 10- to 12-week follow-up in 32 cases, and at a follow-up longer than 14 weeks in 11 cases **(Figures 3 and 4)**.

The median time for radiographic union was 70 days (range, 28 to 497 days).

Postoperative outcomes—Among the 90 treated cases, 61 cases were evaluable for postoperative outcomes (at least 1 radiographic follow-up showing complete fracture healing). All 4 cases that experienced early implant failure were successfully retreated with a plate-rod system. The median duration of follow-up for the remaining 57 cases (57/90) was 476 days (range, 56 to 1,057 days).

Postoperative outcomes are summarized **(Table 2)**. In the perioperative period (0 to 12 weeks), 98.1% (51/52) of cases had excellent or good use of the operated limb and 1 case had poor outcomes (non-weight–bearing lameness).

In the short-term period (3 to 6 months), 75% (12/16) of cases had a restoration of full function (Table 2). In the mid-term period (6 to 12 months), only 7 cases were evaluated and had a restoration of full function in all but 1 case showing unacceptable recovery with a persistent non-weight–bearing lameness due to an aberrant fibrous callus and osteolytic lesions on the femoral head. This dog was treated by microdissection of the entrapped sciatic nerve and femoral neck ostectomy. In the long-term period (> 12 months), 97.1% (34/35) of cases showed restoration of full function and 1 case still had unacceptable outcomes.

Discussion

We report our early clinical experience, which provides evidence of the efficacy of the precontoured angle-stable interlocking nail (CAS-ILN) system to treat traumatic long-bone fractures in dogs and cats. Among the 90 treated cases, 61 cases were evaluable for postoperative outcomes (at least 1 radiographic follow-up showing complete fracture healing) and among them, 98.1% (51/52) of animals had resolution or mild lameness in the perioperative period and 97.1% (34/35) showed restoration of full function in the long-term period.

One of the new features of the CAS-ILN is the presence of a third locking hole, allowing a third screw to be inserted perpendicular to the others, providing multiple locking options and screw distribution. Overall, 6 different screw distributions were chosen in this study, proving the versatility of this contoured nail. Placing a third orthogonal screw also increases the construct rigidity in very comminuted fracture or in heavy animals as torsional rigidity is influenced by the number and configuration of the distal screws.[28,33] In our study, a third screw was placed to improve construct rigidity in 6 cases. Nevertheless, it is important to keep in mind that placement of an orthogonal screw may conflict with structures such as the femoral trochlea. For epimetaphyseal fractures, which represents 28.9% of all cases in our study, this property enables to place 2 orthogonal screws when the configuration of the fracture does not allow the placement of 2 parallel screws. However, care should be taken with the position of an empty hole close to or into the fracture line that may increase the risk of implant breakage. We encountered these conditions (empty hole close to or into the fracture line) in 5 cases, and none of them had any complications.

In addition, the CAS-ILN is made in titanium alloy showing more biocompatibility and being lighter than other veterinary ILN made in stainless steel.[28] Elasticity is improved and therefore bone resorption and poor bone remodeling are better prevented as the Young modulus of titanium alloy is closer to that of bone than stainless steel.[28] However, 316 LVM being stiffer than titanium alloy, one can assume that a larger ILN diameter may be required for titanium alloy ILN compared to 316 LVM ILN.

The curvature of the CAS-ILN shows 2 main advantages. First, it was designed to suit the curved shape of femurs in dogs and the sigmoid shape of tibias in dogs and cats. An anatomical study[34] was conducted by the manufacturer to select the radius of curvature that would be the best compromise for femurs, tibias, and humerus in both dogs and cats. Furthermore, curved nails have mechanical advantages, offering a more rigid construct (lower compliance) and showing higher failure loads compared with straight nails.[34] In our study, we did not encounter any difficulties or contraindications regarding the CAS-ILN curvature and successfully treated femoral, tibial, and humeral fractures. However, we did have a limited number of cases with postoperative misalignment in the frontal, sagittal, and axial planes, none of which required revision surgery. These events may have been also related to poor reduction and not to the implant itself. One can also argue that the curvature is small enough not to alter bone alignment in relatively straight bones such as femurs or cat's humeri. Moreover, the shorter the nail is, the less the curvature is and all cats were treated with short CAS-ILN.

Nevertheless, for tibial fracture, the contoured nail is of particular interest, as it enables anatomical reduction to be achieved while limiting damage to the cranial cruciate ligament. Indeed, the entry point of the CAS-ILN is located cranially to the insertion site of the cranial cruciate ligament while allowing an anatomical reconstruction of the tibia which is not possible with a straight nail. Moreover, the curved nail can be seated more distally in the bone, which could allow treating more distal femoral fracture but also enable positioning of the screw into cancellous bone to increase construct strength.[20,21,23] However, due to this curvature, it is important to correctly orientate the CAS-ILN in the sagittal plane. Incorrect alignment of the nail curvature may result in angular deviation (e.g., valgus/varus if the curvature is placed in the frontal plane). Further studies are warranted to demonstrate the advantages and disadvantages of the curvature of the nail.

One of the disadvantages of ILNs is the risk of missed cannulations.[1,3,7,24] Therefore, newer ILNs in veterinary medicine have been designed to eliminate the need for fluoroscopy-guided implant placement.[1–3,27] The CAS-ILN is cannulated so that surgeons can slide a guide wire into the nail to verify that the drill bit is correctly positioned before drilling the trans cortex. This step enables intraoperative reorientation of an incorrectly placed drill bit. However, to be able to use this feature for all screws, the drilling sequence must start with the most distal screw and care must be taken to avoid any distal deflection of the arm during drilling.

Cannulation could decrease the strength of the nail. Therefore, we compared the area of the moment of inertia (AMI) of CAS-ILNs with those of noncannulated nails. The cannulation diameter is 1.4 mm for the 3.5-, 4-, and 5-mm-diameter CAS-ILNs and 1.7 mm for the 6- and 8-mm-diameter CAS-ILNs. Thus, there is a maximal decrease in AMI of only 2.6% for the smallest (3.5-mm-diameter) CAS-ILN used in this study (AMI, 7.2 mm^4 vs 7.4 mm^4 with and without cannulation, respectively). These data suggest that cannulation has a limited impact on implant strength. Biomechanical studies are warranted to confirm this assumption. In our study, surgeons initially reported mismatches with the position of the guide on the distal part of the bone due to incorrect use of the extension system. This led to 4 screws needing to be replaced intraoperatively (1.37%) and 1 screw remaining misplaced (0.27%) as observed on postoperative radiographs. No other intraoperative difficulties were reported. The learning curve was judged to be rapid, suggesting ease of use. Use of a curved ILN did not seem to increase the rate of missed cannulations.

Previous ILN studies[1,3,4,9,11,23,24] report a complication rate of 17% with the standard ILN and a complication rate ranging from 10% to 23.5% during early clinical application of an angle stable ILN. A recent study[23] also reported a 6.6% complication rate using the I-Loc nail with no major complications; however, in this study, all surgeries were performed by surgeons familiar with the implant. In contrast, our study was an analysis of the initial clinical experience of 6 surgeons at multiple institutions. In our study, the overall complication rate was 11.5% (7/61), with 1 catastrophic, 6 major (4 major I and 2 major II), and no minor complications. Most of the complications we encountered were similar to those previously described with other ILN systems.[1,3,4,9,11,23,24]

In our study, CAS-ILN removal was required in 4 cases, secondary to bone refracture in 1 case (due to incorrect screw distribution) and due to implant failure in 3 cases. Implant failure was caused by undersizing of the nail in 2 cases due to poor medullary cavity filling in 1 case and a mismatch between the size of the nail and weight of the dog in the other case. Therefore, the animal's weight should be considered as well as the percentage of medullary cavity filled when choosing CAS-ILNs. In human medicine, reamed interlocking nailing is a well-established technique that includes endocortical reaming.[35–38] In our study, only preparation of the recipient cancellous bone was performed. In the third case of implant failure, no technical error was found, suggesting that this event was related to the implant itself. Interestingly, all implant failures occurred at the third most proximal screw hole. Based on these preliminary results, the implant was redesigned to increase the diameter of the proximal end of the implant distal to the third hole. After this modification, no further implant failure was observed, which may be related to both the implant modification and the surgeons' learning curve. One unusual and catastrophic complication in this study. These femoral osteolytic lesions may have occurred secondary to avascular necrosis of the femoral head following osteosynthesis.

Our study had several limitations inherent to the retrospective and multi-institutional design, such as different techniques used for revision surgery and inconsistencies in follow-up. Many cases could not be included because the owners refused follow-up radiographs as they considered the clinical recovery to be satisfactory. Furthermore, we did not use gait analysis, which may have been a more objective criterion than radiographs to evaluate functional recovery. This study did not prove the superiority of the CAS-ILN over a straight ILN.

Conclusions

This study focused on the first clinical application of the CAS-ILN by surgeons during their learning curve. We found that, although dedicated training is needed to successfully use the CAS-ILN system, this interlocking nail can be used to treat a large range of fracture patterns with restoration of full function in 97.1% (34/35 evaluable cases out of 90 treated cases) of cases at the long-term follow-up. Most cases had correct postoperative alignment, with a missed cannulation rate of only 0.27%. We had an overall complication rate of 11.5% (7/61 out of 90 treated cases), including 1 catastrophic complication, 3 implant failures (mainly due to technical errors), 1 bone refracture, and 2 superficial surgical site infections. These complications are similar to those previously reported in studies using other ILN designs. Future studies are warranted to further assess long-term outcomes after CAS-ILN use in a variety of fractures in dogs and cats and further biomechanical tests are also needed to evaluate the advantages and disadvantages of the third orthogonal screw.

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TC and OG participated in the initial development of the CAS-ILN without royalties. TC, OG, AG, GR, DL, and BD participated in the clinical evaluation of the CAS-ILN and ancillary. TC, OG, and AG run continuing education courses related to the CAS-ILN implant.

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Supplementary Materials

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