Use of an interlocking nail-hybrid fixator construct for distal femoral deformity correction in three dogs

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Summary
Our purpose was to report the use of an interlocking nail-hybrid external fixator construct to correct distal femoral deformities in three dogs. Radiographs, computed tomography and a three-dimensional model were used to plan the surgical procedure. A femoral osteotomy or osteotomy was performed at the level of the centre of rotation of angulation in all three dogs. Angular and rotational deformities were corrected acutely. Distraction osteogenesis was performed to lengthen each femur postoperatively. All three dogs had additional anatomic abnormalities of the affected hindlimb complicating the correction of the distal femoral deformity. While the interlocking nail-hybrid fixator construct allowed for stable distraction of the femur, all three dogs developed complications during the postoperative convalescent period, and each had some degree of residual lameness. Lengthening the femur following acute deformity correction is problematic and additional experimental and clinical studies are warranted to decrease postoperative morbidity and improve functional results.

Introduction
Distraction osteogenesis is the process of controlled separation of two stabilized bone segments resulting in an enlarging osteotomy gap and regenerate bone formation (1–4). The clinical application of distraction osteogenesis in human patients is credited to Ilizarov who pioneered the development of circular external skeletal fixation (3, 4). Circular fixators, and the phenomenon of distraction osteogenesis, have been used in dogs to correct angular limb deformities, resolve limb length discrepancies, and to perform bone transport (5–10). Use of traditional circular fixator constructs proximal to the elbow and stifle is difficult due to anatomical constraints and therefore most reports describing the application of Ilizarov’s methods in dogs involve abnormalities affecting the antebrachium and crus (6, 8, 10–16). Only a few reports have described the clinical use of distraction osteogenesis involving other limb segments in dogs (5, 7, 9).

Hybrid fixators utilize both circular and linear fixator components and confer advantages inherent to both systems (11). Partially threaded titanium hybrid rods are the fundamental components essential for constructing hybrid frames. The smooth shaft of a hybrid rod accommodates linear fixator clamps, which are used to secure fixation pins. The threaded segment located at one end of each hybrid rod can be secured through a hole in the ring component to assemble a linear-circular hybrid construct (11). The linear components facilitate application of hybrid fixators to the humerus and femur, whereas the circular components allow for stable, multiplanar fixation of short juxta-articular bone segments (11, 12, 17, 18). Hybrid fixators have proven useful for static applications such as the stabilization of fractures (11, 12, 19) or osteotomies performed to acutely correct limb deformities (11, 12, 17–19).

A new component, the linear distractor-compressor device, has been developed for performing distraction osteogenesis with hybrid fixator constructs (20). The distractor-compressor device accepts a threaded rod at each end. While one end of the device accepts standard right-handed threaded rods, the opposite end of the device accepts specially manufactured left-handed threaded hybrid rods. When the secured rods are incorporated into a hybrid construct, turning the body of the device in the direction marked ‘open’ results in distraction of the frame and the secured bone segments. Turning the device in the opposite direction, marked ‘close’, results in compression (20).

In human patients, distraction osteogenesis of the femur is often performed using an external fixator in conjunction with an interlocking nail. The interlocking nail functions to improve patient comfort during the distraction phase, to help neutralize the forces acting on the femur during the distraction and consolidation periods, and to shorten the time to fixator removal (21–23). There is one report which describes using an interlocking nail to stabilize correction of a dog’s femoral deformity caused by malunion of a diaphyseal fracture. An acute opening wedge osteotomy was done and the nail was applied.
in a static fashion (24). The purpose of this report is to describe the use of an interlocking nail-hybrid external fixator construct to perform distraction osteogenesis in correcting distal femoral deformities in three dogs.

Case reports

Three dogs were referred to the University of Florida Veterinary Medical Center for evaluation of hindlimb lameness that was ascribed to unilateral femoral shortening with angular or torsional deformity of the distal femur, or a combination of both. Case 1 was a five-month-old, 22 kg, intact female Dogo Argentine dog that had a pronounced, predominantly non-weight-bearing left hindlimb lameness. The dog had a marked valgus deformity of the left distal femur and was not amenable to flexion and extension of the left stifle. Extension and abduction of the left coxofemoral joint also elicited signs of pain. Case 2 was a 12-month-old, 38 kg, spayed female German Shepherd dog that placed nominal weight on the right hindlimb and had an obvious valgus deformity of the right distal femur. Extension of the right stifle was limited and elicited signs of pain. Milder signs of pain were also obtained on extension and abduction of both the coxofemoral joints. Case 3 was a 21-month-old, 17 kg, spayed female Australian Cattle Dog that had a moderate weight-bearing lameness of the right hindlimb with marked external rotation of the right hindlimb and a grade III right medial patella luxation.

Imaging

Radiographic images of the femora of each dog were obtained utilizing a computed radiography system and viewed using a dedicated workstation (25). The radiographs were used to measure frontal and sagittal plane angulation of the femur as previously described (Table 1) (25). The femoral abnormalities in all three dogs were ascribed to malunion of a prior distal physeal fracture. In case 1, the left femur was seven percent shorter than the right femur, and there was marked translation with valgus and procurvatum of the distal metaphyseal-epiphyseal femoral segment (Fig. 1; Table 1). The medial and lateral cortical margins were indistinct and severely thickened with smoothly marginated periosteal callus formation. The proximal femoral physis was open and the distal femoral physis was closed. However, the right femoral physis was open and the distal femoral physis was closed. In case 2, the right femur was 23% shorter than the left femur, and it also had external rotation of the distal metaphyseal-epiphyseal femoral segment with valgus and recurvatum (Fig. 2; Table 1). There was smoothly marginated contiguous periosteal callus at the level of the deformity, and the lateral cortex of the remainder of the femoral diaphysis was markedly thickened. The proximal and distal femoral physis were open. However, the lateral aspect of the distal physis extended more proximally than the medial aspect of the distal physis. There was subluxation of both coxofemoral joints; subluxation was more severe in the left coxofemoral joint without any evidence of osteoarthritis. In case 3, the right femur was 12% shorter than the left femur, and it also had marked external rotation of the right distal metaphyseal-epiphyseal femoral segment, varus, and procurvatum (Fig. 3; Table 1). The cortices in the region of the deformity were smooth and contiguous. The proximal and distal physis were closed in both femora. The right femoral neck was elongated and retroverted with the base of the neck more distally positioned than in the contralateral limb, which was ascribed to prior trauma. However, the right femoral head was not subluxated.

Computed tomography (CT) scans using helical acquisition were obtained of the affected hindlimbs and femoral angulation and torsion were measured preoperatively.

Table 1 Comparative radiographic and computed tomographic measurements of the deformed and normal femur of three dogs with unilateral femoral deformities.

<table>
<thead>
<tr>
<th>Case</th>
<th>Femoral length (mm)</th>
<th>Femoral frontal plane angulation (degrees)</th>
<th>Femoral sagittal plane angulation (degrees)</th>
<th>Tibial length (mm)</th>
<th>Femoral frontal plane angulation (degrees)</th>
<th>Femoral torsion (degrees)</th>
<th>Femoral length (mm)</th>
<th>Femoral frontal plane angulation (degrees)</th>
<th>Femoral sagittal plane angulation (degrees)</th>
<th>Femoral torsion (degrees)</th>
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<tr>
<td>1</td>
<td>196</td>
<td>211</td>
<td>28 VAL</td>
<td>4 VAR</td>
<td>222</td>
<td>25 PRO</td>
<td>28 VAL</td>
<td>NA</td>
<td>8 VAR</td>
<td>205</td>
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<td>31 PRO</td>
<td>49 VAL</td>
<td>14 VAR</td>
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<td>125</td>
<td>142</td>
<td>27 VAR</td>
<td>8 VAR</td>
<td>132</td>
<td>23 PRO</td>
<td>3 VAR</td>
<td>None</td>
<td>62</td>
<td>138</td>
</tr>
</tbody>
</table>

Key: DF - deformed femur; NF - normal femur; VAR - varus; VAL - valgus; PRO - Procurvatum; REC - Recurvatum; NA - not available.

Using a software program, three-dimensional models for each deformed femur were made from the CT scans. These models clearly defined the anatomical abnormalities in each dog, facilitated accurate planning of the corrective procedure and were used to determine appropriate interlocking nail diameter. The planned location for the distal osteotomy was through the centre of rotation of angulation, perpendicular to the proximal femoral anatomical axis in the frontal and sagittal planes. If a closing wedge osteotomy was planned, a second osteotomy was planned perpendicular to the distal femoral anatomical axis in the frontal and sagittal planes such that the osteotomies converged at the concave cortex of the deformity. The osteotomies were planned to straighten the femur in both the frontal and sagittal planes to allow the nail to be seated centrally within the distal femoral segment. Torsional deformity correction was planned based on the amount of torsional deformity measured on the preoperative CT and visual assessment of the models. Marks were made on the cranial surface of the proximal and distal femoral segments on the models adjacent to the sites of the proposed osteotomies. The circumferential distance between these two marks was measured and utilized during surgery to correct the torsional deformity.

**Surgical procedures**

All three dogs were sedated with acepromazine (0.05 mg/kg IM) and an opioid. Hydromorphone (0.1 mg/kg IM) was used in cases 1 and 2 and morphine (0.5 mg/kg IM) was used in case 3. Anaesthesia was induced using propofol (given IV to effect) in case 1 and ketamine (5 mg/kg IV) and valium (0.25 mg/kg IV) in cases 2 and 3. All three dogs received a morphine epidural (0.1 mg/kg) and anaesthesia was maintained with isoflurane. Perioperative cefazolin (22 mg/kg IV) was administered every 90 minutes in all three dogs. At surgery, a combined parapatellar approach to the stifle and lat-
eral approach to the femur was performed (27). Fluoroscopy was used to accurately define the location of the osteotomies, assess alignment of the femur following correction, and facilitate proper implant placement. A cuneiform closing wedge osteotomy was performed in cases 1 and 2 and the angular and torsional components of the deformity were acutely corrected. A transverse osteotomy was performed in case 3 to correct torsional deformity (28). Longitudinal marks were incised in the proximal and distal femoral segments, adjacent to the osteotomies and before the osteotomies were completed. Alignment of these marks was used to correct torsional deformity.

The femur was stabilized with a 6 mm (case 3) or 8 mm (case 1 and 2) diameter interlocking nail placed in normograde fashion. The nail was inserted through the trochanteric fossa in cases 1 and 2, and through the greater trochanter in case 3. Two Steinmann pins were placed as full-splintage pins engaging the distal femoral segment while passing through the distal holes in the interlocking nail. In cases 1 and 2, 3.2 mm pins were inserted through the holes in the 8 mm interlocking nail, and in case 3, 2.4 mm pins were inserted through the holes in the 6 mm interlocking nail. Pin placement was done using a jig and a femoral extension. Once the pins were placed, the jig and extension were removed. The protruding segments of the Steinmann pins were secured to a stretch ring placed around the cranial aspect of the stifle (Fig. 4). The lateral portions of the full-pins were secured via a short segment of threaded rod which was secured to the stretch ring distally and a linear distractor-compressor device proximally. A left threaded hybrid rod was secured proximally in the distractor-compressor device. Partially-threaded half-pins were on the hybrid rod engaging the proximal femoral segment, but not the nail. Three positive profile, end-threaded half-pins were used in case 1. One positive profile, end-threaded half-pin, and two negative profile, end-threaded half-pins were used in cases 2 and 3. A custom designed extension was threaded into the extension attachment hole in the proximal end of the implanted nail. The extension protruded through the incision proximally. The protruding end of the extension had left-handed 6 mm threads which were secured into a distractor-compressor device. A short hybrid rod was secured into the opposite end of the distractor-compressor device. A carbon fibre connecting rod and two double clamps were used to articulate the short hybrid rod with the hybrid fixator. The portions of the full-splintage pins protruding medially were connected to a short hybrid rod which was secured to the stretch ring. A second linear distractor-compressor device was attached to the cranial aspect of the stretch ring using a short segment of threaded rod. A short left-threaded hybrid rod was secured proximally in the cranially positioned distractor-compressor device, and the proximal end of this rod was secured to the end of one of the proximal fixation pins using a diagonal carbon fibre rod, and proximally and distally clamps (Fig. 4). In case 3, an additional linear distractor-compressor device was mounted on the lateral aspect of the stretch ring, which was articulated with the proximal portion of the lateral hybrid rod to improve construct stability.

**Postoperative management**

All dogs received non-steroidal anti-inflammatory drugs (NSAID) and hydromorphone (0.05–0.1 mg/kg IV) immed-
ately postoperatively. The NSAID administered in case 1 and 2 was carprofen (4 mg/kg SQ), and meloxicam (0.2 mg/kg SQ) was administered in case 3. All three dogs were maintained on a continuous rate infusion of ketamine (0.17 mg/kg/hr) and morphine (0.1 mg/kg/hr) in case 1, and lidocaine (25 mcg/kg/hr) in cases 2 and 3. Immediate postoperative radiographs showed that axial alignment of the distal femur was greatly improved in all three dogs (Fig. 5 and 6; Table 1). In case 3, the right patella was still luxated, but the severity of the luxation had decreased to a grade II luxation. The limb and the frame were bandaged for the first week following surgery and the bandage was changed every other day to assess the incisions and allow cleaning of the pin-skin interfaces with 0.05 %.

Fig. 4 Intramedullary interlocking nail-hybrid fixator construct used in case 3. (A) Interlocking nail, (B) distractor-compressor device, (C) left-handed threaded rod, (D) partially-threaded hybrid rod, (E) custom-designed nail extension, and (F) the stretch ring.

Fig. 5 A) Immediate postoperative cranial-caudal view radiograph of the left femur in case 1: axial alignment of the femur is greatly improved. There is continued subluxation of the left coxofemoral joint. B) Lateral view radiograph of the left femur in case 1 obtained after 28 days of distraction. Note that there is regenerate bone formation, mainly caudally and medially, in the distraction gap.

Fig. 6 Immediate postoperative A) cranial-caudal and B) lateral view radiographs of the right femur in case 2. Note the improved axial alignment of the femur. The articulation between the interlocking nail and the fixator were added after the radiographs were obtained. Collimation of the lateral radiograph did not include the cranial distractor-compressor device.
chlorohexidene solution. After a latency period of five days in cases 1 and 3, and seven days in case 2, distraction was initiated at a rate of 1 mm/day with a twice daily rhythm. Case 1 was discharged from the hospital 14 days after surgery, case 2 was discharged 20 days after surgery, and case 3 was discharged three days after surgery. The dogs were re-evaluated at the hospital every three to six days following discharge during the distraction process. Case 1 was distracted for a total of 21 days, case 2 for a total of 42 days, and case 3 for a total of 26 days; however, distractions were intermittently interrupted due to complications in cases 2 and 3.

Owners were instructed to use an Elizabethan collar, restrict their dog’s activity, and to perform passive range-of-motion exercises of the hip and stifle of the limb undergoing distraction. The owners of case 2 could not restrict their dog’s activity, and the dog was consequently boarded at the hospital while the femur was being distracted. The owner of case 3 was elderly and had problems complying with the postoperative instructions.

All three dogs had complications during the postoperative convalescent period which necessitated additional surgery. The threaded portion of the extension which screwed into the end of the interlocking nail broke 27 days following surgery in case 2. Forceps were passed down the extension tract in the soft tissue to grasp and remove the threaded portion of the extension. The extension unscrewed from the proximal end of the nail 12 days after surgery in case 1. A new extension was slid down the extension tract in the soft tissues and screwed into the proximal end of the nail in both dogs. Both procedures were done under fluoroscopic imaging. All three dogs had substantial drainage and inflammation associated with the fixation pins and the interlocking nail extension protruding through the skin proximal to the femur. Case 1 required revision surgery 53 days after the initial surgery because the fixator was impinging on the dog’s thigh. The interlocking nail was replaced with an intramedullary pin and the hybrid fixator was replaced with a type I linear fixator. The fixator was removed 60 days following the initial surgery in case 2 because of pin tract drainage and loosening of the distal fixation pins. Transcortical screws were placed through the cannulations in the interlocking nail to stabilize the distracted femur. The two distal screws broke, and all of the implants were removed 139 days after the initial surgery when the femur had healed. In case 3, the medial patellar luxation increased to a grade IV, and flexion in the right stifle became severely limited as distraction progressed. Seventy-eight days following surgery, the fixator and interlocking nail were removed and the femur was stabilized with a laterally positioned 9-hole 3.5 mm dynamic compression plate with six 3.5 mm screws, and a medially positioned 15-hole 2.0/2.7 mm cut-to-length plate with nine 2.7 mm screws. A tibial tuberosity transposition was also done at that time to resolve the patella luxation.

None of the dogs made a confluent column of regenerate bone which fully bridged the distraction gap. While there was consistent regenerate bone formation along the caudomedial aspects of the distraction gap, the presence of regenerate bone was less consistent cranio-laterally. Autogenous cancellous bone graft was placed in the distraction gap at the time of revision surgery in all three dogs and all three dogs eventually achieved union. Based on radiographs obtained after the fixators were removed, the left femur of case 1 had been distracted 9 mm and was 10% shorter than the right femur, the right femur of case 2 had been distracted 33 mm and was 10% shorter than the left femur, and the right femur of case 3 had been distracted 13 mm and was three percent shorter than the left femur.

Long-term evaluation of each dog was done for case 1 at 634 days, for case 2 at 265 days, and for case 3 at 581 days after each dog’s initial surgery. The owners of case 1 reported that their dog had resumed all normal activities and did not have any apparent lameness. On physical examination, the dog had symmetrical hindlimb muscle mass, but a subtle intermittent left hindlimb lameness. Flexion and extension was slightly decreased in the left stifle and mild signs of pain could be elicited on extension and abduction of both coxofemoral joints. None of the dogs had problems with patella luxation.

Radiographic images obtained at the time of the long-term evaluation (Fig. 7) showed remodelling of the distracted site, osteophyte formation on the lateral aspect of the femoral condyle. There is persistent subluxation of the left coxofemoral joint.

Fig. 7 A) Cranial-caudal and B) lateral view radiographs of the left femur of case 1 obtained 634 days after surgery. The distracted site has remodelled and there is mild osteophyte formation on the lateral aspect of the femoral condyle. There is persistent subluxation of the left coxofemoral joint.

Radiographic images obtained at the time of the long-term evaluation (Fig. 7) showed remodelling of the distracted site, osteophyte formation on the lateral aspect of the femoral condyle, and persistent subluxation of both coxofemoral joints with early osteoarthritides. There was coxa valga of the right femoral head and neck with sub-
luxation, and degenerative changes were worse in the right coxofemoral joint. The owners of case 2 reported that their dog had also resumed all normal activities without apparent lameness. On physical examination, the dog had a subtle weight-bearing right hindlimb lameness. Signs of pain were elicited on extension and abduction of both coxofemoral joints, but there was a normal range-of-motion in both stifles. Radiographic images obtained at the time of the long-term evaluation (Fig. 8) showed smooth remodelling of the persistent periosteal new bone formation at the distraction site with anteversion, coxa valga, and subluxation of the right femoral head with early degenerative changes in the right coxofemoral joint. The owner of case 3 reported the dog was consistently lame on the right hindlimb. On physical examination, the dog only intermittently bore weight on the right hindlimb and held the limb in extension and abduction. There was limited flexion and only a 40° range-of-motion in the right stifle. Radiographic images obtained at the time of the long-term evaluation showed advanced remodelling of the distraction site with stable implants. There were no appreciable degenerative changes in the right coxofemoral joint, and minor osteophyte formation in the right stifle joint.

Discussion
The interlocking nail-fixator construct allowed us to effectively lengthen the femur following acute correction of the angular (cases 1 and 2) or torsional deformity (cases 2 and 3); however, all three dogs developed complications during the convalescent period which necessitated additional surgery, and all three dogs had some residual lameness at the time of the long-term evaluation. The femur cannot be lengthened with a traditional circular fixator construct as complete rings cannot be placed to secure the proximal femoral segment, thus precluding the use of wires as fixation elements in this location (12). McCartney reported using a dynamic linear fixator with an intramedullary pin to lengthen the femur in a one-year-old Doberman Pinscher that had sustained a fracture of the distal femoral physis before reaching skeletal maturity (9). The femur was lengthened 45 mm, but there was bowing of the femur and the fixator connecting rod as well as pin tract complications which necessitated a second surgery. The original construct was removed and a new fixator and intramedullary pin were placed six weeks after the initial surgery. We elected to use an interlocking nail-external fixator construct because these constructs have been advocated to lengthen femora in humans to improve patient comfort during the distraction phase, to help neutralize the forces acting on the femur during the distraction and consolidation periods, and to shorten the time to fixator removal (22, 23, 28).

The CT and three-dimensional models proved invaluable in accurately defining the deformity and planning the correction in these three dogs. Torsional deformity can preclude accurate definition of angular deformity on standard orthogonal view radiographs, as occurred in case 3. In addition, osseous distortion resultant from and compensatory to malunion can further complicate accurate definition of deformity (18, 29). The CT allowed us to more accurately define the angular and torsional components of the deformity (30). A rapid prototyping process, was used to fabricate a precise model of the deformed femur and plan the surgical correction in each dog. The computer model was extracted from the CT scans by image segmentation, converted into stereolithography file format and then sent to the three-dimensional printer for fabrication of a precise morphological model (31). The models allowed for
more accurate definition of the deformity, in particular characterizing the torsional and angular components of the deformity. Case 3 appeared to have 27° of distal femoral varus on radiographs, but only three degrees of varus on the CT images. The three dimensional model substantiated that the deformity was principally torsional. Identification of the anatomic axes and determination of the appropriate location and configuration of the osteotomies were done directly on the models. We performed a rehearsal surgery on the model fabricated from the CT of case 1 (30, 31). These models also allowed us to determine appropriate interlocking nail diameter prior to surgery, and to modify the surgical procedure to accommodate for anatomical anomalies. While interlocking nails are normally inserted in dog femora through the trochanteric fossa, the model helped us determine that abnormalities of the proximal femur in case three necessitated insertion of the nail through the greater trochanter (32).

Regenerate bone formation was inadequate to effectively bridge the distraction gap in all three dogs and grafting was done in each dog to obtain bone union. In a human study investigating complications associated with femoral and tibial lengthening stabilized with an interlocking nail-external fixator construct, delayed union was ascribed to performing osteotomies through poorly vascularised bone segments (33). One study reviewing the results of distraction osteogenesis of the femur in human patients concluded that nonunion occurred when distraction was performed at malunion sites and it was suggested that these sites had limited osteogenic potential (34). Osteotomies were performed at the location of the original fracture in all three dogs. The incised surfaces of the osteotomies exposed dense sclerotic bone rather than normal marrow elements which contribute to effective regenerate bone formation (2, 3, 35). Adhesions to the fracture site made isolation and preservation of periosteum, which is essential for effective regenerate bone formation extremely difficult when performing the osteotomies in these dogs (35, 36). Regenerate bone formation was most consistent along the caudomedial cortex of the femur.

We suspect that we were probably more effective in preserving the periosteum at sites where there are muscular insertions on the caudal cortex of the femur (37). Our difficulty in elevating and preserving the periosteum as well as the sclerotic appearance of the incised medullary bone influenced our decision to use relatively long latency periods in these dogs. Recently the need to utilize any latency period in young dogs has been questioned (9). We can not ascertain if waiting until the fifth (cases 1 and 3) and seventh (case 2) day to initiate distraction was beneficial.

Although we often performed acute correction of large torsional abnormalities prior to distraction in dogs with antebrachial deformities, studies reviewing results of lower limb lengthening in human patients revealed that acute rather than gradual correction of angular deformities exceeding 30° in any one plane resulted in poor callus formation (10, 26, 38). Cases 1 and 2 had large angular deformities and cases 2 and 3 had large torsional deformities which were all acutely corrected which may have contributed to poor regenerate bone formation.

All three dogs developed substantial pin tract complications during the distraction period. The nail extension protruding proximally from the femur was particularly problematic and had to be replaced in two dogs. Fortunately, the proximal end of the nail was still protruding from the femur in both dogs, which allowed us to remove the threaded portion of the extension that was still engaging the nail and place a new extension under fluoroscopic imaging in both dogs (case 2 and 3). Articulating the nail with the fixator may not have been necessary to provide effective linear distraction and we would advocate omitting the extension and articulation in future cases to decrease postoperative morbidity (28, 33). The extension, which was attached to the nail, made nail removal a simple process. Removing a nail that was not attached to an extension, particularly if the proximal end of the nail had been drawn into the medullary canal of the femur as the result of distraction, would have been a more involved process.

The full-splitting pins in the distal femoral segment were also consistently problematic. We used pins rather than wires as fixation elements to maximize construct stability and to simultaneously translocate the engaged nail distally as the frame was distracted. The use of wires rather than pins as fixation elements could have potentially decreased postoperative morbidity in these dogs, but it would have then raised concerns regarding construct stability. Interlocking nail pins alternatively could have also been used, which may have improved construct stability, but it would likely invoke similar postoperative morbidity.

Admittedly, distraction may have been unnecessary in at least one, if not all three dogs in this study. The preoperative length discrepancy between femurs in case 1 was approximately 15 mm (7%), case 2 was approximately 58 mm (23%), and case 3 was approximately 17 mm (12%) and all three dogs had a small amount of compensatory tibial overgrowth (39). Case 1 had not reached skeletal maturity at the time of surgery and the dog’s contralateral femur grew an additional 17 mm after surgery. In addition some length was sacrificed by performing cuneiform osteotomies in cases 1 and 2 (40). One study found that dogs can compensate for femoral shortening of at least 20% without adversely affecting amputation, however, this study was performed in normal dogs and the assessment of gait was subjective and lacked objective measures of limb function such as force plate or kinematic analysis (41). We concede that all three of these dogs may have had acceptable limb function had we only corrected the angular or torsional components of their deformity, and not subsequently attempted to lengthen the femur.

There were discrepancies in all three dogs between the measured amount of femoral lengthening and the projected amount of lengthening that would be expected based on the distraction rate and the number of days the femur was distracted. We partially ascribe these discrepancies to interruptions in distraction due to complications or a lack of compliance. In addition, cases 1 and 2 had closing wedge osteotomies which initially shortened the femur prior to distraction. Obtaining accurate measurements of initial postoperative femoral length as well as precise measure-
ments of the amount of distraction performed are very difficult due to the presence of the fixator, which does not allow the limb to be positioned in contact with the radiographic plate.

Much of the available information regarding femoral lengthening involves experimental studies done in species other than dogs, or clinical reports of applications in human patients (23, 33, 42–44). Although the femoral lengthening in the dog reported by McCartney had complications in the postoperative convalescent period that necessitated a second surgery, the dog’s limb function was stated to be normal when re-evaluated one year after the initial surgery. All three of the dogs in the current report had some degree of residual lameness at the time of their long-term evaluation, particularly in case 3, which had a very limited range-of-motion in the ipsilateral stifle. Case 3 had a grade III patellar luxation at presentation, while the depth of the trochlear groove was considered adequate at the time of the initial surgery, the tibial tuberosity was medially positioned. We did not perform a tibial tuberosity transposition at the time of the initial surgery because we had concerns regarding healing of the osteotomy site due to tension evoked by distraction of the femur (45). We ascribed the residual lameness in cases 1 and 2 to incongruity and subluxation in the coxofemoral joint, which was noted in both dogs at the time of presentation. Placement of a large diameter intramedullary implant which protrudes from the trochanteric fossa in skeletally immature dogs can induce abnormal development of the femoral head and neck, and may have contributed to the coxofemoral subluxation in cases 1 and 2 and is yet another reason we would suggest omitting articulating the nail with the fixator in future cases (46). In addition, consideration to addressing the coxofemoral joint laxity and maintaining normal or improving abnormal femoral conformation when correcting the distal femoral abnormalities may have resulted in more optimal long-term limb function in these dogs. There are obvious needs for additional clinical and experimental studies evaluating femoral deformity correction with lengthening in dogs, and we are optimistic that publishing our experience will result in improved results with fewer complications in the future.

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References


