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Treatment of antebrachial and crural septic nonunion fractures in dogs using circular external skeletal fixation: a retrospective study

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Summary

Objective: To evaluate the outcome of treat- ment of antebrachial and crural septic non- union fractures in dogs using circular exter- nal skeletal fixation (CESF), and to document the type and frequency of complications associated with this technique.

Methods: The medical records of all dogs with infected antebrachial and crural non- union fractures treated using the methods of Ilizarov at the Department of Animal Pathology of the University of Turin between 2006 and 2011 were retrospectively reviewed. Only dogs in which radiographic and clinical assessment were available at the time of CESF removal were included in the study.

Results: Twenty-three dogs met the inclusion criteria. Twenty nonunion fractures treated with CESF healed and three did not. The latter three cases underwent amputation of the affected limb. In the 20 dogs that achieved bone union, six had minor complications and five had major complications. The mid- term outcome was judged to be excellent (n=11), good (n=6),fair (n=2), or poor (n = 4).

Conclusions: The results of this study support the use of CESF for the management of antebrachial and crural septic nonunion fractures in dogs. Union was achieved in the majority of dogs and the complication rate was acceptable, considering the severity of the nonunion fractures that were managed in this fashion.

Introduction

Nonunion is an interruption of the fracture healing process, which negates the possibil- ity of fracture union without further surgical intervention. Nonunion fractures are characterized by formation of fibrous or cartilaginous tissue between fragments (1, 2). Nonunion fractures

are often the result of failed surgical treatment that can often be attributed to intra-operative technical errors and they may also be accompanied by chronic infection (1–6).

When assessing an infected nonunion fracture, factors such as local blood supply, mechanical stability and regenerative ability of the involved tissues must be considered when formulating a therapeutic plan(1–5). The surgical treatment of nonunion fractures remains a therapeutic challenge for orthopaedic surgeons, especially in the presence of infection, bone loss or both together (7).

One of the primary objectives in treating septic nonunion fractures is adequate debridement to reduce bacterial load and to remove necrotic tissue and sequestra (8). The debrided fracture must be restabilized with appropriate internal or external fixation (7–16).

The methods of Ilizarov using circular fixator constructs have been shown to be an effective treatment modality for managing nonunion fractures in both humans and dogs (7–11, 13, 15, 16). Circular external skeletal fixation (CESF) not only allows for initial compression of the fracture segments but also for mechanical modulation of the fracture environment during the healing process (17-19). Circular constructs can be applied using a monofocal or bifocal approach. With the monofocal approach, the two major bone segments adjacent to the fracture defect are moved toward each other resulting in bone shortening. Shortening can be done acutely during the surgical procedure or sequentially in the postoperative period. The bifocal approach, characterized by mobilizing two bone segments, involves making an osteotomy in healthy bone at a site remote from the nonunion. The nonunion defect is then resolved by either intercalary bone transport or by acute compression of the non-union fracture site and subsequent lengthening of the limb segment through a re- mote osteotomy in a metaphyseal region (7-10, 13).

There are few reports regarding the treatment of antebrachial and crural septic nonunion fractures in dogs (1, 7–13). The objective of this retrospective study was to report our results of managing such fractures in dogs using CESF and to document the type and frequency of complications associated with this technique.

Material and methods

Inclusion criteria

general anaesthesia. If a linear fixator was present from the initial surgery and judged to be unstable, the fixator was removed be- fore radiographs were obtained. The nonunion fractures were classified by one of the authors (BP) according to the Weber and Cech classification scheme (22). For the purpose of the present study, we considered oligotrophic nonunion fractures as biologically inactive nonunions based on a study by Blaeser and colleagues (1).

The medical records of dogs with antebrachial and crural infected nonunion fractures admitted to the Department of Animal Pathology of the University of Turin and treated using the methods of Ilizarov using CESF between 2006 and 2011 were reviewed. Infection was confirmed when a positive culture was obtained from a sample retrieved from the nonunion site. Dogs were only included in the study when radiographs and documented results of a physical examination at the time of fixator removal were available.

Information obtained from the medical records included breed, gender, age and body weight of the patient. Fractures were classified by the affected bone (radius and ulna or tibia and fibula), fracture localization and whether the fracture was closed or open. Open fractures were classified as type I, II or III according to a system pro- posed by Gustilo and Anderson (20). The number of previous surgical operations and methods of fixation were recorded. The time elapsed between the initial injury and application of the CESF for the treatment of the nonunion fracture was recorded. Information obtained at the time of the revision surgery included: the presence of draining tracts, the range-of-motion in the joints adjacent to the fracture, and the degree of lameness. Range-of-motion was estimated clinically and compared with that of the unaffected contralateral limb. Lameness was graded by one of the authors (BP) on a scale from 0 (no lameness) to V (consistently non-weight-bearing) (Appendix 1: available online at www.vcot-on line.com) (21).

Before the revision surgical procedure, standard orthogonal radiographic images were obtained while the patient was under general anaesthesia. If a linear fixator was present from the initial surgery and judged to be unstable, the fixator was removed before radiographs were obtained. The nonunion fractures were classified by one of the authors (BP) according to the Weber and Cech classification scheme (22). For the purpose of the present study, we considered oligotrophic nonunion fractures as biologically inactive nonunions based on a study by Blaeser and colleagues (1).

Instrumentation

Frames were assembled using components from one of two CESF systems[a,b]. The ring with the smallest diameter that could be placed around the affected antebrachium or crus, while leaving at least 1 cm of space between the skin and the inner margin of the ring, was chosen. Constructs were preassembled before surgery based on preoperative radiographs. Two rings were used to secure each major bone segment unless one of the bone segments was too short to accommodate placement of a double ring block. If the bone segment was too short, a single ring block was used to secure that bone segment, and an additional partially threaded half-pin splintage[c] was secured to the ring (23). Pin diameter was selected to be approximately 25% of the diameter of the bone segment (24). Transosseous wire[d] diameter was selected according to established guidelines (25).

Surgical technique

Methadone[e] (0.2 mg/kg, IM) was adminis- tered for pre-medication. General anaes- thesia was induced with propofol[f] (1–4 mg/ kg, IV) and maintained with 1.5–2% isofluorane[g] in oxygen.

The limb was prepared for aseptic surgery in a routine fashion. Cefazolin sodium[h] (20 mg/ kg, IV) was administered to all dogs 30 minutes before surgery. Dogs were positioned in dorsal recumbency and a standard hanging limb preparation was used for both antebrachial and crural nonunion fractures. A sterile snap-hook system was secured to the paw allowing the surgeon to disconnect the limb during the procedure.

Nonunion sites were managed in either a closed or an open fashion depending on the perceived viability of the ends of the fracture fragments, the presence of im- plants or sequestra, and the perceived need for bone grafting. Closed procedures were performed at

the surgeon's discretion in selected cases of vascular nonunion fractures previously stabilized with a linear fixator, when the underlying problem was ascribed to instability at the nonunion fracture site. In these cases, a fine needle aspirate of the nonunion site was obtained for aerobic and anaerobic culture (9).

In open procedures, the nonunion site was exposed through a standard approach and all implants were removed. Debridement of the nonunion site was achieved with one of two techniques. The first tech- nique (traditional technique) involved excision of necrotic and infected tissue, and the re-opening of the medullary canal with a high-speed burr[i] or smooth pin driven by a drill[j]. The second technique (*en bloc* ostectomy) was performed by the creation of two parallel surfaces by means of two limited ostectomies, that allowed complete exposure of the medullary canal and creation of complete circumferential bone to bone contact between the ends of the fracture fragments (1). Excised tissues, implants, or both were submitted for aerobic and anaerobic culture. Cancellous bone graft, harvested from the proximal metaphysis of the humerus, was used to fill gaps and to stimulate healing. Surgical wounds were closed in routine fashion.

The nonunion fractures were stabilized with a pre-constructed CESF frame applied according to established guidelines (25). An incomplete ring was used proximally, with the open section of the ring oriented cranially for antebrachial fractures and caudally for crural fractures, to avoid interference between the skin and CESF frame during elbow and stifle flexion respectively. Fracture reduction was assessed after placement of the first few wires using palpation or fluoroscopy. Once fracture reduction was acceptable, the fractures were further stabilized by inserting wires and threaded half-pins through the fracture segments, as required, and connecting them to the rings. The wires were tensioned intra-operatively to between 30 and 90 kg weight using a dynamometric tensioner[b]. The wire diameter was 1.0, 1.2 or 1.5 mm, depending on the bone size and dog size.

In dogs in which the loss of bone length was less than 20%, a monofocal approach was used. In monofocal procedures, CESF was used to achieve stabilization or compression of the nonunion fracture site. Compression was achieved by progressively advancing the distal block towards the

proximal one along the threaded rods. If bone loss exceeded 20%, a bifocal procedure was employed, which involved intercalary bone transport or acute bone shortening followed by lengthening at a remote site in a segment of healthy bone. Remote osteotomies were made in the proximal metaphysis using an oscillating saw[j,k].

In bifocal procedures, two linear motors positioned between the rings were used to perform the distraction.

Radiographic and clinical evaluation

Postoperative orthogonal radiographs were obtained. Dogs were treated with cephalexin[l] (20 mg/kg BID PO) until culture results became available, after which time the dogs were treated with antibiotic medications according to the culture and sensitivity.

Postoperative pain control was achieved with non-steroidal anti-inflammatory drugs that were administered for seven days. Postoperative patient management included wire and pin tract care, and restricted exercise under the direct supervision of the owner.

Dogs were divided into three treatment groups based on how the CESF was applied and utilized to manage the nonunion fractures. Group A included dogs managed with a monofocal procedure without employing the accordion manoeuvre (Figure 1). Group B included dogs managed with a monofocal procedure, and the accordion manoeuvre was employed postoperatively when callus formation was judged to be poor (26). In this procedure, acute distraction was applied and maintained for seven days followed by acute compression for another seven days. Alternating distraction and compression of 0.5 to 2 mm, depending on the size of the patient, was carried out on a weekly basis until callus formation was visible on radiographs. Group C included dogs managed with a bifocal approach. In dogs treated with bifocal procedures, bone distraction was initiated at 1 mm per day in 0.33 mm increments every eight hours after a four day latency period (25). The rate of distraction was subsequently modified according to the quality of regenerate bone present on radiography obtained during the distraction process.

All dogs were re-evaluated by one of the authors (BP) clinically and radiographically one month after surgery and then approximately every two weeks until bone union was achieved. Information recorded at re-examinations included the range-of- motion of adjacent joints, degree of lameness, presence of wire and pin tract discharge, and wire breakage. The follow-up radiographs were evaluated to assess callus and regenerate bone formation, periosteal reaction, and bone lysis associated with the fixation elements. Complications that were managed without additional surgery were considered minor. Complications that required additional surgery, or negatively affected the outcome, were considered major. Frames were removed as soon as the attending surgeon judged the fracture to be radiographically healed. Determination of the number of cortices (0 to 4) bridged by callus was the method used for assessing the progression of fracture healing; a fracture was consider- ed healed when a bridging callus was present on at least three cortices (27).

After CESF removal, radiographs were obtained to assess limb length discrepancy and limb alignment, as previously de- scribed (28–30). Frontal plane alignment (FPA) and sagittal plane alignment (SPA) were calculated; positive values represented valgus and procurvatum deviations and negative values represented varus and recurvatum deviations. Torsional malalignment was recorded as absent, mild, moderate, or severe (21). If bone healing was not achieved, revision surgery or amputation was considered. Mid-term functional out- come was evaluated six months after CESF removal using the modified ASAMI classification of bone and functional results (Appendix 2: available online at www. vcot-online.com) (31).

Results

Patients in the study

Twenty-three of the 27 dogs in which CESF was used to manage septic nonunion antebrachial or crural fractures at our institution met the inclusion criteria (Appendix 3: available online at www.vcot-online). There were 14 males, four intact females and five spayed females with a mean age of 54 months (SD: ± 41 months; range: 7–144 months) and mean body weight of 20 kg (SD: ± 14 kg; range: 3–44 kg).

Twelve antebrachial and 11 crural non- union fractures were included. Thirteen nonunion fractures were located in the metaphysis, eight in the diaphysis, and two involved the carpal joint. There were nine open fractures, five of which were grade 1 and four of which were grade 2.

Fractures had initially been stabilized with a linear external fixator (n = 11), a bone plate (n = 11), or an intramedullary pin (n = 1). One dog had previously under- gone two surgical procedures before refer- ral to our hospital. Draining tracts were present in 17 dogs and loss of carpal extension was noted in nine dogs. Five dogs had a lameness score of IV and 18 dogs had a lameness score of V. The nonunion fractures were classified as atrophic (n = 11), oligotrophic (n = 5), necrotic (n = 3), hypertrophic (n = 2), slightly hypertrophic (n = 1), and dystrophic (n = 1). The time between injury and CESF application (mean ± SD) was 76 ± 45 days (range: 15–180 days).

Surgical technique

The Hoffmann Small Bone Fixator system[b] was used in 15 cases and the Imex Circular External Skeletal Fixation system[a] in eight cases. The CESF frame was preassembled with two double-ring blocks in 11 cases and included a single-ring block in 12 cases.

One nonunion fracture was treated in a closed fashion and 22 were treated using an open procedure. Seven of the latter underwent a traditional surgical debridement and 15 underwent *en bloc* ostectomy. Sequestra were removed in 11 cases. An autologous cancellous bone graft was used in 20 dogs. Fractures that were managed in a closed fashion or with bone transport were not treated by cancellous bone grafting.

A monofocal procedure was employed in 19 dogs and compression of the nonunion fracture site was carried out in 14 cases. Limb length discrepancies were present in two antebrachial and two crural nonunion fractures, and the discrepancy ranged from 32% to 39% compared with the unaffected contralateral bone segment. Intercalary bone transport was used in two antebrachii and acute compression and subsequent lengthening method was used in two crura.

Culture results were positive in 23 cases: a single bacterial species was isolated from 21 fractures and polymicrobial species were isolated from two fractures. All cultured bacteria were aerobes and included: *Staphylococcus* spp (n = 8), *Serratia marcescens* (n = 5), *Escherichia coli* (n = 4), *Pseudomonas* spp. (n = 3), *Enterobacter Cloacae* (n = 2), *Proteus* spp. (n = 1), and *Klebsiella* spp. (n = 1). All organisms were sensitive to at least one antibiotic drug, and postoperative antimicrobial therapy was administered for a time length of (mean ± SD) 25 ± 14 days (range: 10–60 days).

Radiographic and clinical outcome

Twelve dogs were included in treatment group A, seven in treatment group B, and four in treatment group C. Of the 20 dogs in which bone union was achieved, 11 were in treatment

group A, six in treatment group B, and three in treatment group C. The time (mean ± SD) until radiographic union and subsequent implant removal was 74 ± 45 days (range: 30–240 days). In the radii, FPA (mean ± SD) was 5.6° ± 2.4° (range: 2.0°-9.0°), and mean SPA was 10.0° ± 8.0° (range: -4.0°-26.0°). In the tibiae, mean FPA was 7.7° ± 6.7° (range: 3.0°-26.0°), and mean SPA was 9.5° ± 6.7° (range: –5.0°-17.0°). Mild internal tibial torsion occurred in two cases and mild external tibial torsion in one case. One dog had mild external radial torsion. Four dogs had residual limb length discrepancies ranging from four percent to 14%. One of the treatment group C dogs (case 21) had a nonunion fracture with a large sequestrum of the distal radius involving the joint surface (Figure 2). We planned to manage the dog with a two-step procedure; intercalary bone transport first followed by a pancarpal arthrodesis with bone plate. During the first surgical procedure the bone sequestrum was removed and the articular cartilage on the radial and ulnar carpal bones was intentionally not debrided. A CESF was applied. Bone lengthening was judged to be adequate 60 days after surgery; the distraction process was then interrupted and the transport ring was locked in place with stainless steel nuts.

After one month, the mineralization of the regenerate was judged to be satisfactory and the frame was removed and a pancarpal arthrodesis was carried out. After debridement of the articular cartilage of the radial carpal bone, a cancellous bone graft was placed and an 18-hole, 2.7 mm reconstruction plate[m] was positioned dorsally extending from the radial head to the third metacarpal bone. To optimize stability, a six-hole locking plate[n] was positioned medially extending from the distal part of the regenerate to the second metacarpal bone. Bone healing was achieved 120 days after the second surgical procedure and the implants were removed.

Complications

Of the 20 dogs with nonunion fractures that achieved bone healing, six had minor complications and five had major complications. Minor complications included wire and pin tract discharge (n = 4), threaded pin loosening (n = 1), and gossybipoma (n = 1). Wire and pin tract dis- charge were solved by means of local pin tract wound care and antibiotic drug therapy. Threaded pin loosening was managed by implant removal. In one dog (case 23), a gauze sponge left in the wound during surgery was detected during re-examination and removed from the sinus tract.

Postoperative major complications included wire breakage (n = 1), premature wire loosening (n = 4), re-fracture (n = 1) and patellar luxation (n = 1). Wire break- age was addressed by wire replacement. Premature wire loosening was managed by wire replacement or ring removal. Seven days after CESF removal, one dog (case 16) suffered a re-fracture at the nonunion fracture site after minor trauma. The radius was stabilized using a nine-hole 2.0/2.7 mm cut-to-length bone plate[m] and an autogenous cancellous bone graft was ap- plied; this resulted in complete healing. Another dog (case 22) with a 26° proximal tibia valgus deformity developed a grade 2 medial patellar luxation and was mildly lame; however, the owner refused additional corrective osteotomy (Figure 3).

In three dogs, one each in groups A, B and C, the fracture did not heal. One dog (case 20), was not weight-bearing 11 days after radial bone transport and there was no radiographic evidence of bone regeneration. The distraction was interrupted for nine days but there was

no improvement and no discernible radiographic regenerate bone formation. Revision surgery was suggested but the owner opted for limb amputation. In another dog (case 8), the proximal ring was removed 120 days after application of the CESF because of premature wire loosening. The dog was not weight bearing and in addition it had severely reduced carpal extension. The entire CESF was removed 150 days after surgery and revision surgery was proposed to the owner because there was no bone union. To correct both the nonunion fracture site and the severe loss of carpal extension, a pancarpal arthrodesis was carried out using a 24-hole 2.0/2.7 mm cut-to-length bone plate[m]. However, the bone had not healed by 90 days after surgery, and the limb was amputated at the owner's request. Another dog (case 15), suffered a mid-diaphyseal radial fracture through a wire tract at the level of the proximal inner ring 120 days after surgery. In addition, the radial nonunion persisted and there was severe loss of carpal extension. In an attempt to address all three complications, a pancarpal arthrodesis was carried out using a 21-hole 1.5/2.0 mm cut-to-length bone plate[m] but bone union was never achieved and the limb was amputated at owner's re- quest. Overall, the mid-term outcome was judged excellent (n = 11), good (n = 6), fair (n=2),and poor(n=4).

Discussion

Management of antebrachial and crural septic nonunion fractures in 23 dogs using CESF resulted in bone healing in 20 dogs, while the remaining three dogs underwent amputation. Minor complications occurred in six dogs and major complication occurred in five dogs. In the planning of nonunion fracture treatment, the biological properties of the nonunion must be considered. Biologically active nonunion fractures have been defined as those that heal without debridement of the nonunion fracture site, provided that adequate stability of the fracture site is ensured (5). A septic biologically active nonunion fracture represents a major problem and debridement of the infected tissue must be considered to reduce the bacterial load (1, 36–39). In our experience, hypertrophic septic nonunion fractures can heal without debridement provided that fracture stabilization is adequate. However, when an open approach is required to remove loose and failed implants, we recommend debridement of the fracture site. Biologically inactive nonunion fractures require reactivation of the bone healing process by debridement, which can be accomplished using the traditional technique or the *en bloc* ostectomy. Both techniques require bone debridement until the so-called 'paprika sign', defined as the appearance of scattered pinpoint haemorrhage signalling good vascularity, is observed (32). Blaser and colleagues used *en bloc* ostectomy to treat both oligotrophic and inactive nonunion fractures, but we used the traditional technique for oligotrophic nonunion fractures and *en bloc* ostectomy for biologically inactive nonunion fractures (1). In our experience, the traditional technique was effective and the less invasive treatment option to achieve bone healing in five oligotrophic nonunion fractures in our series.

The methods of Ilizarov using the CESF are an effective and accepted treatment modality for the management of septic nonunion fractures in both humans and dogs (7–11, 16). Although dogs can tolerate 10% to 20% of femoral length shortening, antebrachial shortening exceeding 15% to 20% of the normal length commonly causes a mechanical lameness (33–34). The monofocal approach was therefore chosen in cases in which bone

loss after surgical debridement was less than 20% of the bone length, and a bifocal approach was used in cases in which bone loss exceeded 20%.

The monofocal approach can be used for stabilization, compression, progressive shortening, compression-distraction and the 'accordion manoeuvre' (26, 35). In our case series, we used compression at the nonunion fracture site when there was circumferential bone-to-bone contact be- tween the ends of the fracture fragments. However bone-to-bone contact was usually not achieved when the nonunion fracture site was managed by traditional debride- ment and therefore these cases were managed by using static stabilization. The 'accordion manoeuvre' was used as a method for stimulating bone healing when callus formation was judged to be inadequate, and it resulted in union in six of seven fractures.

The bifocal approach has been used for bone lengthening by intercalary bone transport or for acute compression and subsequent lengthening in healthy bone remote to the nonunion site in human patients (36–39). The successful application of the intercalary bone transport osteogenesis technique has been previously reported in the management of two crural and two antebrachial infected nonunion fractures in dogs (8–10). An experimental *in vivo* study reported the feasibility of acute bone shortening followed by gradual lengthening in the treatment of induced 30% segmental tibial defects in clinically normal dogs (13). Complications included swelling of the affected limb, bone segment translation, digit flexion contracture and frontal plane malalignment (13). Furthermore, there has been a single clinical report of acute bone shortening followed by gradual lengthening technique for the treatment of an infected antebrachial nonunion fracture in a dog (9). In our case series, four dogs were treated using a bifocal procedure. The bone defect was between 32% and 39% of the bone length in these dogs. In the absence of clear guidelines, we chose intercalary bone transport or acute compression and subsequent lengthening in healthy bone remote to the nonunion fracture site depending on the situation. Our preference was to use bone transport for antebrachial nonunion fractures and acute compression and subsequent lengthening in healthy bone remote from the nonunion fracture in crural nonunion fractures. Folding of soft tissue, nerves, and vessels during the acute compression and subsequent lengthening of healthy bone away from the nonunion fracture procedure can cause arteriolar occlusion resulting in severe oedema, tissue necrosis, or alteration in muscle mechanics (39). We believe that the antebrachium is more susceptible to these complications. Guidelines for the latency period in distraction osteogenesis in dogs range from 0 to 10 days (25, 36, 40). We chose a delay of four days because it was shown that delayed bone distraction can improve the quality and homogeneity of the regenerate

bone compared with immediate distraction, and that delayed distraction leads to a larger callus and greater capillary ingrowth (41). We used the standard distraction rate of 1 mm per day as proposed by Ferretti (25). To avoid delayed or premature consolidation, we recommend that these dogs be carefully and frequently re-examined. The complete lack of bone regenerate in one of our cases might be attributable to the 150-day delay between the first surgery and the circular fixator application, the severity of the nonunion fracture, and the large amount of bone loss.

In our case series, most of the complications were related to an unstable CESF due to pin and wire loosening and infection. Wire and pin tract discharge are complications intrinsic to the methods of Ilizarov (21, 25, 36–39, 42). Most pin and wire tract infections can be resolved with ag- gressive local pin and wire tract care and empirical antibiotic treatment

(21, 42). If the infection fails to resolve quickly, culture-specific antibiotics should be used (42). Although wire breakage is a commonly reported complication of the CESF in medium to large-breed dogs, this only occurred in one case in our series (21, 42).

The treatment was unsuccessful in four antebrachial nonunion fractures. Two were toy breed dogs with distal radial nonunion fractures. The limited soft tissue coverage and tenuous intraosseous circulation in toy and small breed dogs may have contributed to the failure (43–44). Re-fracture was attributable to premature frame removal in case 16. Failure to accurately assess bone healing was ascribed to superimposition of one of the threaded rods obscuring radio- graphic visualization of the radius. For this reason, we suggest that oblique radio- graphic views should be obtained if needed to better evaluate bone healing. The oblique views must be the same in subsequent radiographic re-evaluations for assessment and comparison of callus formation. An alternative is to use radiolucent carbon composite components to avoid superimposition (45).

Antebrachial limb alignment was judged to be satisfactory when compared with values reported by Fox and colleagues (28). Crural limb alignment was judged unsatisfactory in two dogs with valgus deformity compared with values reported by Dismukes and colleagues (29, 30). Valgus deformity resulted from the frame not being aligned with the anatomic axis of the tibia.

Conclusions

Our study has several limitations, mostly related to its retrospective nature. The time between surgery and initial weight-bearing was not specifically noted in any of the medical records. Therefore we could not determine whether functional recovery differed between dogs treated by monofocal and bifocal procedures in this case series. In our opinion, careful clinical and radiographic re-evaluations are required because persistent lack of weight-bearing accompanied by a lack of bone regenerate signals a poor prognosis. Although direct comparisons of our results with those of other studies are not possible, it is interest- ing that mean time to union of these septic nonunions was 74 ± 45 days with a range of 30 to 240 days, while union of non-septic antebrachial and crural fractures with CESF ranged from 28 to 105 days (mean $\pm$ SD of 61 ± 21 days) and from 21 to 157 days (mean $\pm$ SD of 61 ± 30 days) (21, 42). We can not compare the use of circular fix- ator with other methods of managing septic nonunion fractures in dogs because of a lack of corresponding reports. The results of the study support the use of CESF for the management of antebrachial and crural septic nonunion fractures in dogs. Union was achieved in the majority of cases and the complication rate was acceptable considering the severity of the nonunion fractures that were managed in this fashion.

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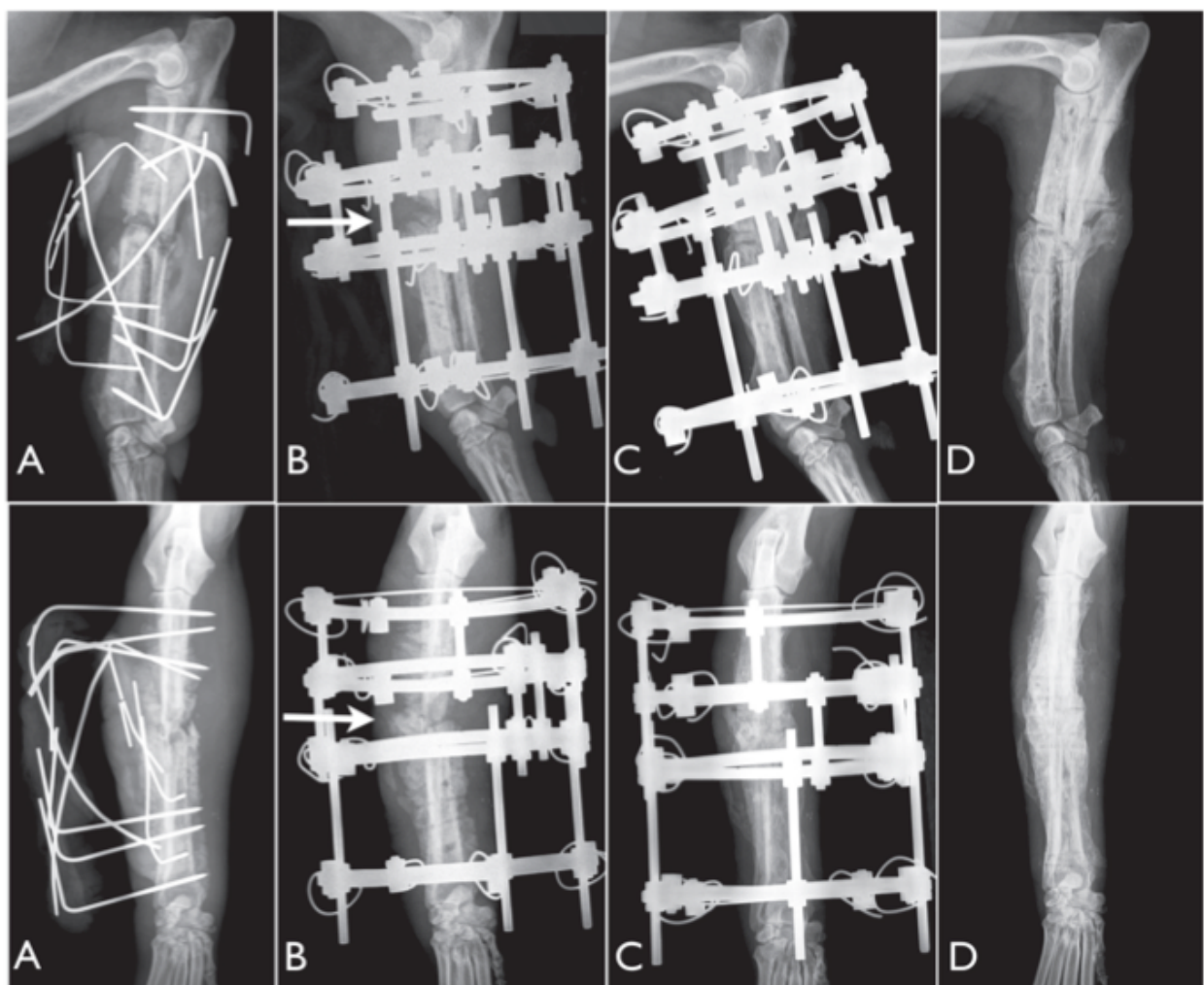
Figure 1 Radiographic images from case 7. **A)** Preoperative medio-lateral (upper panel) and cranio-caudal (lower panel) views: mid-diaphyseal radius-ulna oligotrophic septic nonunion in a eight-year-old 18 kg mongrel. An acrylic type Ia linear external skeletal fixator was applied 30 days prior to stabilize the fracture. Note the small diameter of the pins used. **B)** Immediate postoperative medio-lateral and cranio-caudal views. A traditional Ilizarov technique was performed to treat the nonunion site. A monofocal approach with acute compression was used (white arrow). **C)** 55 days follow-up image: callus formation was judged to be adequate. **D)** Radiographic images taken 55 days following implant removal – note that the radius-ulna fracture is healed.
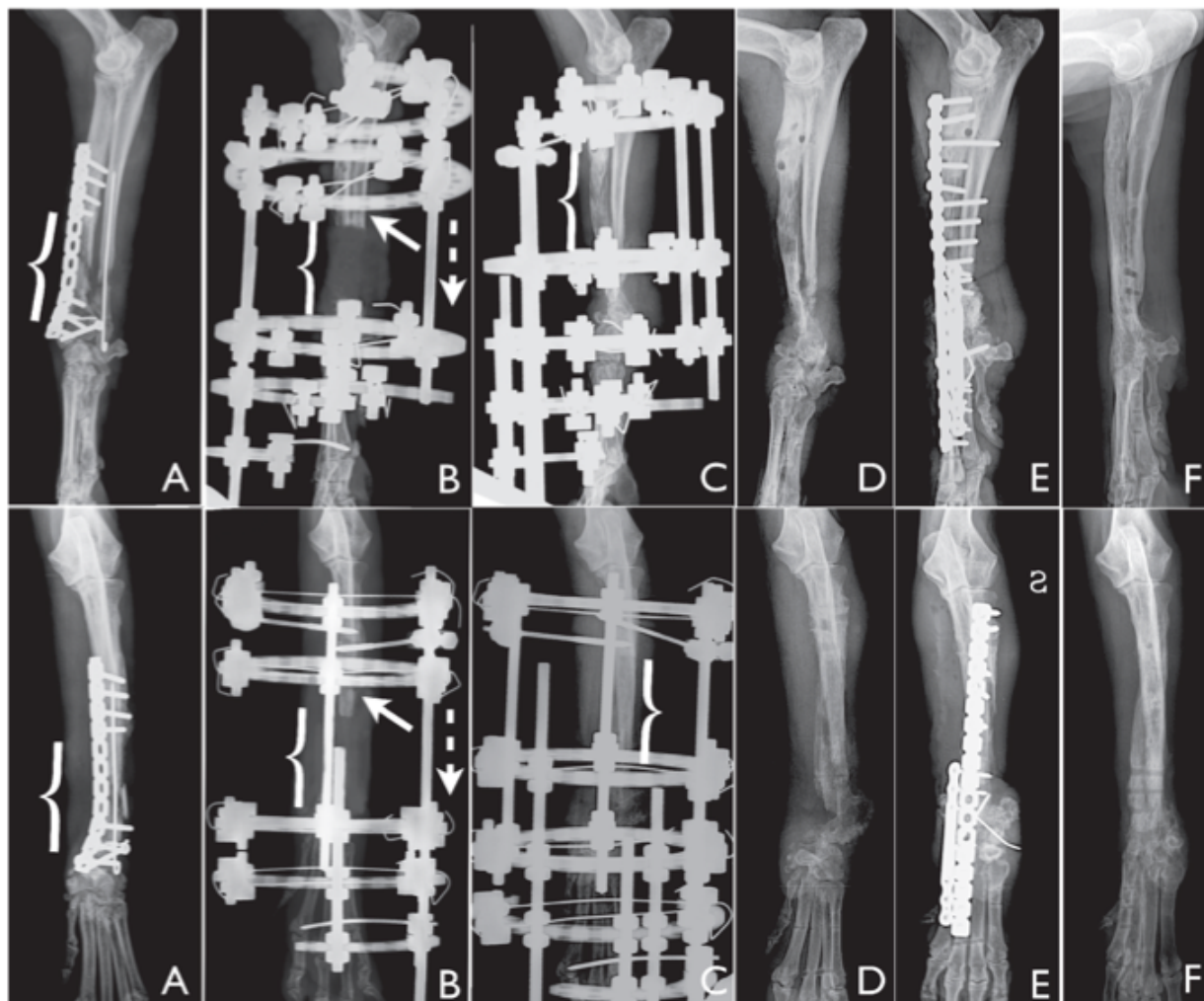
Figure 2 **Radiographic images from case 21. A)** Preoperative medio-lateral (upper panel) and cranio-caudal (lower panel) images: distal meta-physeal radius-ulna necrotic septic nonunion in a three-year-old 16 kg mongrel. A 2.7 mm lag screw, a 2.7 mm reconstruction plate, and an intramedullary pin on the ulna was applied 60 days prior to treating the fracture (brackets indicate the area of the sequestra that was removed during revision surgery). **B)** Immediate postoperative medio-lateral and cranio-caudal images. A bifocal approach for bone lengthening by intercalary bone transport was used (brackets indicate the area of the sequestra that was removed during revision surgery; solid arrows indicate the bone trans-port; dashed arrows indicate the direction of distraction). **C)** 75 days follow-up image: bone transport reaches the docking site and bone regenerate (bracket) was judged adequate. **D)** 90 days follow-up image: Circular exter-nal skeletal fixation frame removal. Compression of the docking site was not performed because of frame instability. The pancarpal arthrodesis was planned by internal fixation. **E)** Immediate postoperative medio-lateral and cranio-caudal images. An 18-hole 2.7 mm reconstruction plate was applied dorsally and a six-hole locking plate was used medially. **F)** 210 days follow-up image taken following implant removal. Bone healing was achieved.
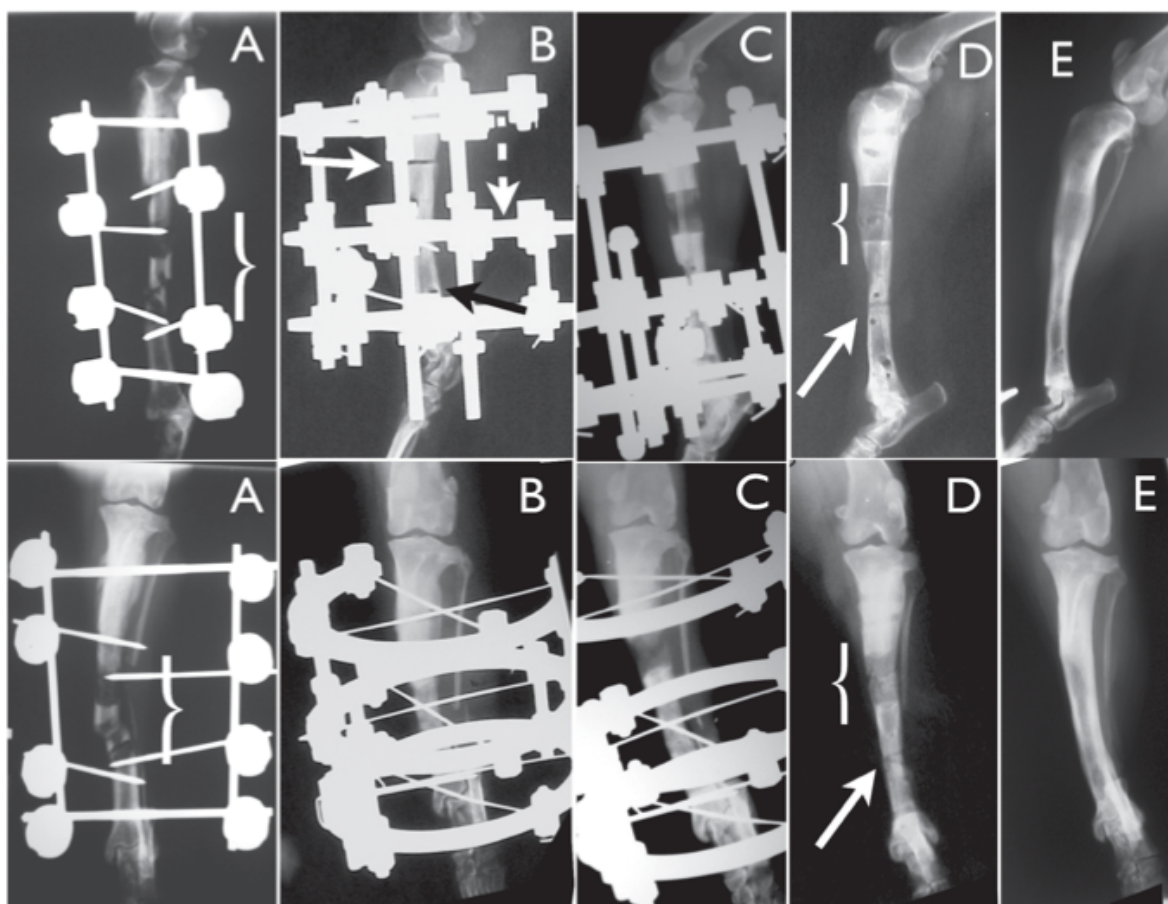
Figure 3 **Radiographic images from case 22. A)** Preoperative medio-lateral (upper panel) and cranio-caudal (lower panel) images: mid-diaphyseal tibia necrotic septic nonunion in an eight-year-old 6 kg mongrel. A type II linear external fixator was applied 45 days prior to stabilize a simple transverse fracture (brackets indicate the area of the necrotic septic nonunion that was removed during revision surgery). **B)** Immediate postoperative medio-lateral and cranio-caudal images. A bifocal approach for bone lengthening by acute compression (black arrow indicates the compression site) followed by gradual lengthening was used (solid white arrow indicates the osteotomy in the metaphyseal bone; dashed white arrow indicates the direction of distraction). **C)** 35 days follow-up images: adequate tibial length was achieved and bone regenerate was judged to be adequate and bone lengthening was interrupted. Medial patellar luxation developed secondary to valgus deformity of the tibia. **D)** 75 days follow-up radiographs: circular external skeletal fixation frame was removed (white arrows indicate healing of the nonunion site; brackets indicate bone regenerate). **E)** 180 days follow-up images: note the bone remodelling process.