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Original Article

Comparison of a reverse-transverse cross pin technique with a same side cross pin type II external skeletal fixator in 89 dogs

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Abstract: The objective of this study was to determine whether a novel reverse-transverse cross pin insertion technique could increase the stability of type II external skeletal fixators (ESF) in dogs compared with an alternate, same side cross pin ESF. Reverse-transverse cross pin technique and type II ESFs same side cross pin technique were applied and compared among subjects. Two of 42 ESFs (4.8%) applied with the reverse-transverse cross pin technique and 39 of 47 ESFs (83%) applied with the same side cross pin technique were subjectively unstable at the time of fixator removal ($P < 0.001$). The same side cross pin ESFs had significantly more pin tract new bone formation than the reverse-transverse ESFs ($P = 0.038$). In summary, this approach may provide a method of treating a variety of musculoskeletal conditions and soft tissue cases, which reverse-transverse cross pin ESFs are tolerated in dogs for a variety of conditions.

Keywords: External skeletal fixation, fracture, type II fixator, canine

Introduction

External skeletal fixation (ESF) has been described in both human and veterinary medicine for over 100 years and has, over the past 25 years, become increasingly popular [1]. In a review of ESFs, Palmer [2] acknowledged that ESF is a versatile method of fracture repair. Indeed, ESF is advocated for myriad conditions such as stable and unstable fractures, open and infected fractures, comminuted fractures [3], osteotomies, arthrodesis, ligament and tendon reconstruction, limb lengthening, delayed unions and nonunions, and periarticular fractures, among others as described in multiple publications.

Like any fracture repair technique, ESFs remain an imperfect system and complications can and do arise. One of the weakest links in the ESF system is the pin-bone interface, even though a multitude of different pin types (e.g., negative or profile pins, nonthreaded pins) are available. Successful ESF mandates that the apparatus remains stable and that the integrity of the pin-bone interface is maintained. Pin-bone interface weakening can lead to pin premature loosening, pain, and pin tract sepsis, culminating in fixator failure [2, 3]. Pin loosening may cause complication in small animal orthopedics [4, 5]. Factors that cause premature pin loosening include pin design, methods of pin placement, dynamic loading of the implant, initial bone quality, the osseous response to pin implantation, and pin size [6-10].

Method of fracture repair is typically selected based on surgeon's preference and is often decided on a case-by-case basis [11]. In fact, fracture repair does involve a certain amount of creativity, particularly in cases with complex fractures. For example, although intra-articular fractures are frequently treated via internal fixation, such fixators cannot be applied in some cases (e.g., in the presence of bone fragments). This "artistic leeway" enjoyed by orthopedic surgeons is widely accepted as long as appropriate aseptic technique and fracture repair principles are followed, such as those described by Kraus et al [12]. Advantages of ESFs include their rigid construct, the absence of an implant at the fracture site, they can be applied "closed" with minimal disturbance of the surrounding soft tissues, they are versatile and can be configured to match the dog's anatomy, they can be combined with other fixation methods, and there are no residual implants. Various commercial ESFs are currently available; however, studies comparing different ESF designs are lacking and clear clinical recommendations indicating which type of ESF is best suited to a certain clinical situation do not exist.

The purposes of this study were to describe a novel reverse-transverse cross pin insertion technique for use with a type II ESF and to compare the stability of the reverse-transverse cross pin technique with as same side cross pin type II ESF. Basic principles of external fixation surgery were used regardless of the ESF used in the included cases. The authors hypothesized that the reverse-transverse pin insertion technique would stabilize the configuration of the fixator (and therefore the fracture site). Dogs applied with the reverse-transverse cross pin ESFs had pin loosening but increased stability of configuration frame.

Materials and methods

Subjects

Between Jan 2008 and Dec 2011, client-owned dogs treated at a small animal referral clinic in Taiwan were prospectively enrolled in this study. Dogs were included if they underwent skin grafting over the stifle area and were then fitted with a transarticular ESF to prevent graft motion and if the dogs were diagnosed with either diaphyseal tibial fractures or intra-articular fractures of the distal femur. Dogs that underwent autograft skin grafting had either large areas of necrosis or a wound near the stifle joint, and skin grafting with external fixation to restrict joint activity was the treatment of choice in those cases. All included dogs were otherwise healthy.

Dogs were assigned to two groups: the same side cross pin ESF technique group and the novel reverse-transverse ESF procedure, which the intersections of the crossed pins on alternating sides of the bone (both sides crossed pins group), based on date of presentation for either skin grafting or fracture repair. All cases had applied four pins and the articular fracture group and skin graft group had all transarticular configurations. All owners provided informed written consent.

Surgical technique

The same side cross pin type II ESFs were applied using standard surgical procedures and aseptic technique was strictly adhered to guideline [12, 13]. In all dogs, the connecting bars were made from acrylic to facilitate angling across the joint (when necessary), so different and appropriate sizes of pins could be used, and to be able to angle the pin during insertion (in the reverse-transverse ESF group). The diameter of the connecting bars was customized to match the size of each individual dog, which was 2-3 times the diameter of the bone in which the fixator was being applied. Equal length of the medial and lateral connecting bars and was applied to both groups. The goal was to ensure the frame was capable of adequately supporting the fracture to abrogate further damage to the tissues.

Pin angles were measured intra-operatively and smooth trocar tip pins with a diameter measuring 20-30% of the diameter of the bone that was being repaired were driven directly into the bone without predrilling a pilot hole. For fixators used in dogs that had undergone skin grafting and dogs with intra-articular fractures, the angle of the stifle joints was measured on the normal (unaffected) limb prior to inducing general anesthesia. Intraoperatively, the fractured limbs were fixed at the same angle as the normal limb.

A mini driver was used to insert the pins with speed exceed over 1,000 rpm to generate a "thermal necrotic" points to induce premature pin loosening, and the pins were placed at an angle of 30-65° relative to each other, depending on the exact location of the fracture site and bone fragments. The design is following the principle of far-near-near-far to reduce stress concentration. The differences between two sides are only the angle and the pin insertion. The difference between the fixator configurations in the two groups was the cross points of the pins. In all dogs, radiographs were taken prior to surgery, immediately postoperatively, and again at the time of fixator removal.

Pre- and postoperative management

Standard surgical area preparation and aseptic surgical procedures were applied. Preoperative blood work included a complete blood count, serum biochemical profile, and bleeding time.

Table 1. Comparison of Baseline Characteristics of the 89 Dogs that were Treated with Either a Same Side Cross Pin ESF or a Modified ESF

Variable	ESF Procedure		*P* value
	Same side	Modified	
Weight (kg)	11 (9, 13.7)	10.1 (7.9, 13)	0.454
Age (years)	2 (1, 4)	2.0 (1.5, 4)	0.613
Sex			0.274
Male	21 (44.7)	14 (33.3)	
Female	26 (55.3)	28 (66.7)	
Pathology			0.003
Skin graft	21 (44.7)	6 (14.3)	
Intra-articular fractures	16 (34.0)	16 (38.1)	
Diaphyseal fracture	10 (21.3)	20 (47.6)	

Results were presented as median (25th, 75th percentile) for continuous outcomes and number (percentage) for categorical outcomes.

Ventrodorsal, right lateral, and left lateral radiographs of the thorax were obtained in all cases that were involved in a traffic accident. Further, two views of the fracture site (mediolateral and craniocaudal) were also obtained. Fentanyl was administered IV via continuous rate infusion (10 μg/kg/hr) throughout the pre- and post-operative periods for 1-3 days, depending on analgesia required by each included dog. Cefazolin (20 mg/kg, intravenously) was also administered throughout the pre- and post-operative periods to prevent infection.

Postoperative care including twice daily wound management specifically, the incision and pin insertion areas were first cleaned with normal saline then 10% iodine was used to disinfect those areas. The external frame and pins were covered with aseptic gauze and tape to prevent wound contamination. No other medicine was applied either orally or from the third postoperative day, except nonsteroidal anti-inflammatory drugs applied to gain pain relief in any case after day 3. None of the included cases had any subjective evidence of infection such as purulent discharge and fever, and cultures were not performed.

Postoperative assessment

The frame stability during experimental periods and at time for fixator removal will be main outcomes considerations. To subjectively assess stability of the ESF configurations, the fixator frames were moved in the same direction as the fixation pins immediately prior to removal, while the dog was under anaesthetized for radiographs with the connecting bar on before pulled the bars out.

If any movement was perceived, the fixator was considered unstable. The ratio of the pin tract new bone formation to the bone diameter was also calculated (the pin tract new bone formation was the callus or new bone around the pin tract area). The largest values were chosen from the two view radiographs for comparison. Time for fixator removal was defined as days from surgery to implant removal and was determined by calculating the area of the healing bone (on the radiographs) and the bridging callus on the fracture site(s). Thirty days was the earliest time point that the dogs were evaluated postoperatively for new bone formation and mobility of the frames. Subsequently, dogs were examined every two weeks. Fracture fixator removal time was determined based on those serial evaluations, which included radiographs, and the healing of the skin graft would be one major factor.

Statistical analysis

Data were presented as median and the 25th and 75th percentiles for continuous variables and number and percent for categorical variables. Baseline characteristics and outcomes of dogs treated with the reverse-transverse cross pin external fixator and dogs treated with a traditional external fixator were compared using a Wilcoxon rank sum test for continuous variables and a χ^2 test for categorical variables. All statistical analyses were performed using SPSS 15.0 statistics software (SPSS Inc., Chicago, IL) and a $P < 0.05$ was considered significant.

Results

Baseline characteristics

A total of 89 dogs were included in this study. Of those, 30.3% required skin grafting but without fractures prior surgery, 36% had fractures of the distal femur, and 33.7% had mid-shaft tibia fractures. Of the 89 cases, 42 had the modified reverse-transverse cross pin ESF (6 skin graft recipients, 20 diaphyseal fracture cases, and 16 dogs with intra-articular frac-

Table 2. Primary and Secondary Outcomes for Dogs Treated with Either a Same Side Cross Pin or Modified ESF Technique

Outcome	ESF Procedure		*P* value
	Same side (n = 47)	Modified (n = 42)	
Primary outcome measure			
Stability	8 (17)	40 (95.2)	< 0.001
Secondary outcome measures			
Ratio of pin tract new bone formation	0.7 (0.5, 1)	0.6 (0.4, 0.7)	0.038
Time to fixator removal (days)	30 (30, 32)	30 (30, 31)	0.605

Results were presented as median (25th, 75th percentile) for continuous variables and number (percent) for categorical variables.

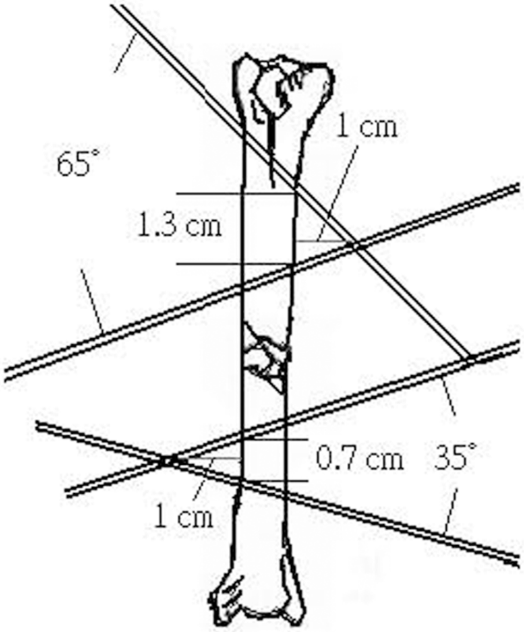

Figure 1. The cross point and angle of reverse-transverse cross pin design. When the cross point is set at 1 cm away from the cortex, the inner angle of 35° has measured as 0.7 cm and 65 has measured as 1.3 cm of bone distance between two cross pins. The cross point has the ability to stop fracture fragments moving to the cross point side if the cross point near enough to the bone. The design was to prevent the pin holes too close each other to weaken the bone after implant removal.

tures). The remaining 47 cases were treated with the same side cross pin type II ESF using a same side cross pin technique. As shown in **Table 1**, there were no significant differences in age, body weight, or gender between the two groups at baseline except fracture type.

Outcomes

A summary of the primary outcome measure (i.e., stability) has been provided in **Table 2**. In the dogs treated with the reverse-transverse ESF, 40 of 42 dogs (95%) were deemed as having stable fixators whereas only 8 of 47 dogs (17%) treated with the same side cross pin ESFs had stable fixators ($P < 0.001$). The ratio of pin tract new bone formation to bone diameter was significantly lower in the group of dogs treated with the novel reverse-transverse ESFs was observed ($P = 0.038$), but no difference in time for fixator removal was noted. It should also be noted that no evidence of infection was noted in any included dogs, and no cultures were taken of any implants.

Illustrative explanations of comparisons between reverse-transverse cross pin technique and same side cross pin type II external skeletal fixator

Figure 1 presents the cross point and angle of reverse-transverse cross pin design. The design was to prevent the pin holes too close each other to weaken the bone after implant removal.

The traditional pin insertion design and same side cross pin insertion design were shown in **Figure 2A** and **2B**, respectively. **Figure 2C** is a schematic diagram of the type II 2 × 2 acrylic frame reverse-transverse cross pin design. The cross point of the two pins is on the different side. Ideally, the cross point is as close to the bone as possible.

Figure 3 represented the radiographs to show a dog with the reverse transverse cross pin technique for repairing tibial midshaft fracture 1 mo postsurgically. **Figure 4** represented the radiograph of a dog applied with same side cross pin type II ESF 1 mo postsurgically.

Discussion

Our study provide evidence that reverse-transverse ESFs could provide stable fixators than same side cross pin ESFs. The use of ESF devices has become increasingly popular in both human and veterinary medicine over the past few decades. To date, it is not clear which type of fixator provides superior fracture heal-

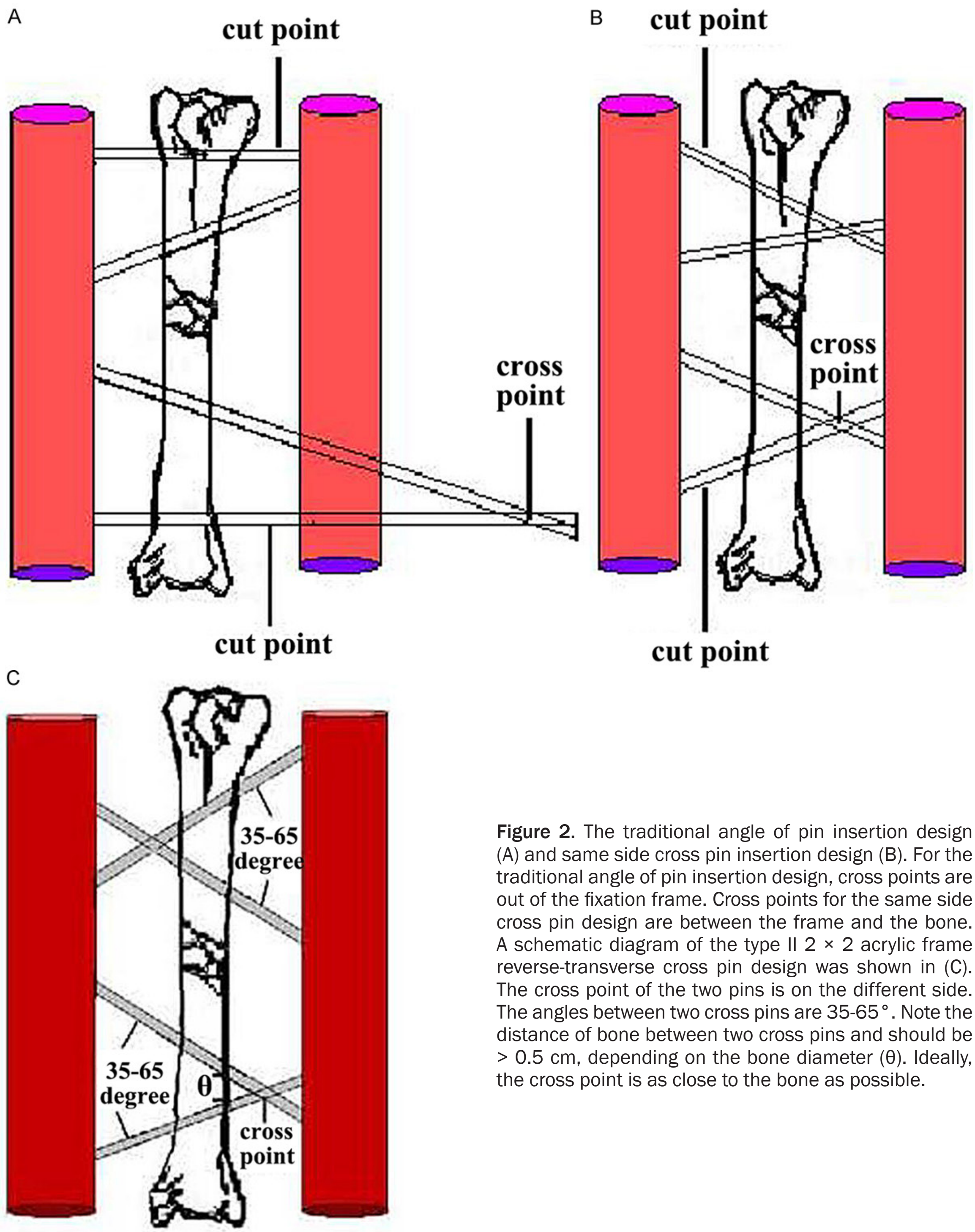

Figure 2. The traditional angle of pin insertion design (A) and same side cross pin insertion design (B). For the traditional angle of pin insertion design, cross points are out of the fixation frame. Cross points for the same side cross pin design are between the frame and the bone. A schematic diagram of the type II 2 × 2 acrylic frame reverse-transverse cross pin design was shown in (C). The cross point of the two pins is on the different side. The angles between two cross pins are 35-65°. Note the distance of bone between two cross pins and should be > 0.5 cm, depending on the bone diameter (θ). Ideally, the cross point is as close to the bone as possible.

ing, as type of fracture repair is highly dependent on each individual fracture situation [11]. Based on observations while designing the ESF described herein, it is important to note that the inner angle of the cross pins must be a minimum of 35° (measured from the fracture fragment to the nearest joint and the fracture site). Choosing an angle of at least 35° appears to allow the frame to set without influencing the animal's motion postoperatively. The function of the cross point (of the pins) was designed to stop the fracture fragment from moving toward that side; however, it appears imperative to ensure the cross point is no more than 1 cm

Figure 3. Radiographs showing the reverse transverse cross pin technique for repairing tibial midshaft fracture 1 mo postsurgically. The fracture has healed. Pin tract new bone formation can be seen around the pin tract areas both mediolateral (A) and craniocaudal (B) view.

away from the cortex. This will ensure the inner angles between the cross pins range from 35° to 65°, which ensures there is 0.7 cm to 1.3 cm of bone between the cross pins. Together, these measurements will help guarantee that there will not be too little distance between the cross pins and there will be no concentration of stress forces on the bone that could potentially precipitate refracture after implant removal.

All dogs included in the current study tolerated the ESFs well, and time for fixator removal did not differ between the two groups of dogs. The major difference between the two groups was stability. Although only subjectively assessed in this study, stability was notably poorer in the traditional ESF group of dogs than the dogs fitted with the modified fixators. In fact, less than one-quarter of the dogs included in this study that were fitted with the reverse-transverse cross pin fixators had no evidence of fixator movement at the time of fixator removal. Other reports describing the use of external fixators routinely indicate complications. For example, pin track infections occur in approximately 10-45% of dogs, and pin loosening occurs in 0.9-11% of dogs [1]. Gül and Yanik [1] reported an incidence of pin tract infections of 10.7% (infections were noted in multiple pins in 2 of 15 dogs), and the incidence of pin loosening was 1.5%. In a separate study by Higgins et al [14], 4 out of 5 dogs treated with transarticular external skeletal fixation following failed tibial tuberosity transposition had complications

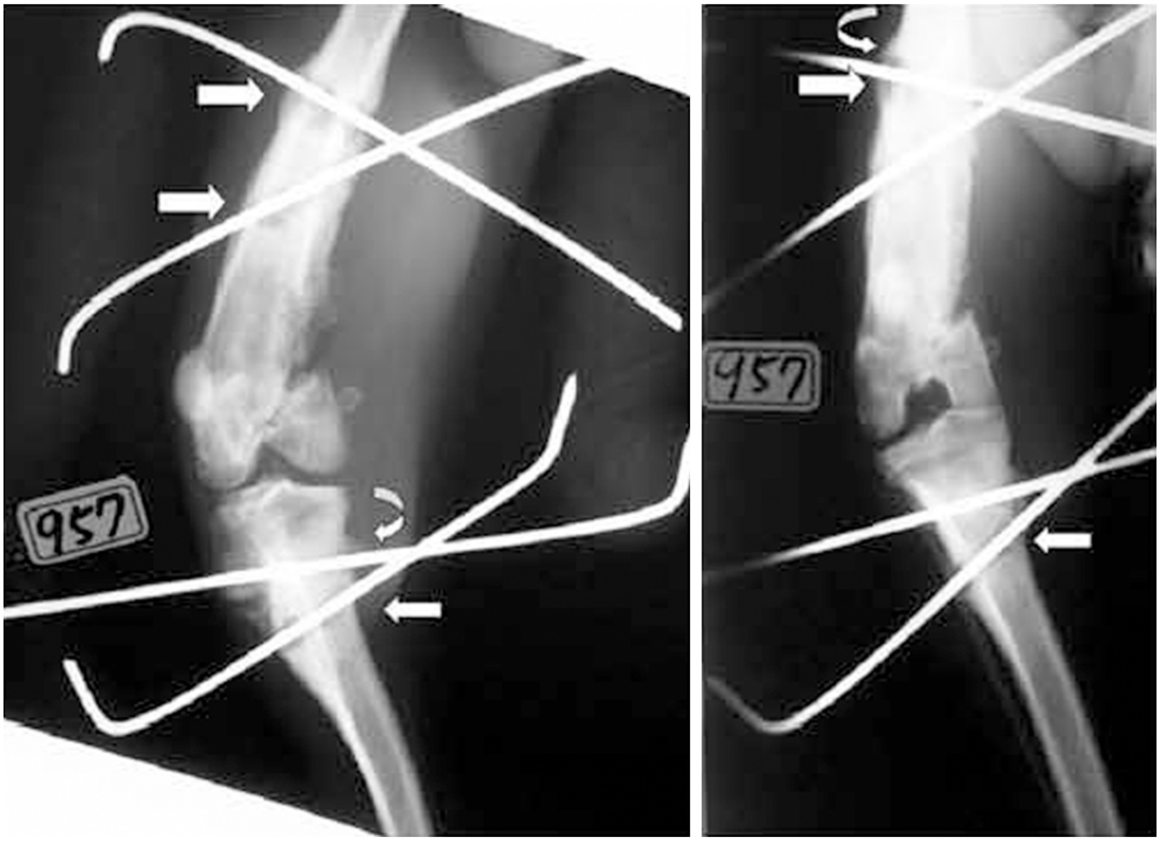

Figure 4. Radiograph of a dog treated by a same side cross pin type II ESF 1 mo postsurgically. The same side pins formed an angle > 30° and allows implant insertion on the opposite side to ensure fixation point on the opposite side prevents the bone from moving around. Note the callus formation at the fracture site, the rediolucency indicating premature pin loosening (arrows), and pin tract new bone formation (bowed arrows) around the pin tract areas.

with ESF, including pin tract discharged and osteolucency. We used high speed drivers to generate thermal necrosis to induce premature pin loosening and did not observed infections with proper postoperative assessments. Although pin lucency was noted radiographically around all pins in this study, the modification to the ESFs described herein appeared to prevent frame shifting.

In the current study, instability of the ESFs was deemed to be primarily due to pin loosening. Several factors might have contributed to pin loosening, including thermal necrosis (e.g., from the polymerizing acryclic or the high speed drilling), the use of smooth pins only (rather than threaded pins), and/or the dynamic loading on the pin-bone interface from the animal during weight bearing. Thermal necrosis can be minimized with careful surgical technique and the use of proper equipment, and threaded pins can be used instead of smooth pins; however, premature pin loosening can ultimately occur despite those precautions. In addition, dynamic loading on the pin-bone interface can be reduced by controlling the animal's activities, but those factors are unpredictable and ultimately under the control of the owners. Because both groups were treated similarly and it is assumed that owners permitted similar levels of exercise postoperatively between groups, pin instability does appear to be less common due to specific reverse-transverse cross pin design to make cross points effectively prevents frame fixators moving in current study.

In this study, stability was simply assessed manually and subjectively. Alternate means of assessing stability *in vivo* include additional imaging modalities (computed tomography, for example) and force-plate analysis [15]. Further, rigidity of the ESF could also be assessed using cadaveric limbs. In a study by White et al [16], the authors noted that rigidity is important to ensure fracture reduction and pin-bone interface integrity are maintained, and that constructing simple frames with strong components would be advantageous. In the study presented herein, rigidity of the system was not assessed; however, in the authors' opinion, this system is rigid (as evidenced by fixator stability), easy to apply, and well tolerated. Future studies that compare the rigidity/stiffness of this system via axial compression, torsion, medial-lateral bending, and cranial-caudal bending, for example, to other fixator designs as was previously performed by White et al [16] may provide more information on the rigidity.

This study also found that the ratio of pin tract new bone formation to bone diameter was higher in the same side cross pin group than the reverse-transverse cross pin group. This finding suggests that the reverse-transverse cross pin design has more stability than the same side cross pin design [17-20].

In addition to the subjective nature of the main outcome (stability), the small number of dogs included in this study and the fact that they were only based on order of presentation are also limitations of this study. In this study, a same side cross pin ESF was used as the "control", which might not necessarily be the most modern design to have used as a control considering that various modified ESFs with full and half pins are available. Another limitation worth considering is the exclusive use of smooth pins. Although threaded pins are frequently used in ESFs to limit pin loosening, the authors of this study selected smooth pins to produce a simple and economic surgical procedure for achieving stable fixation during facture repair. Time to fixator removal in skin graft dogs versus facture dogs were not analyzed separately due to the small number of dogs included in this study. Nonetheless, grouping all dogs together could have skewed the results. Finally, bilateral fixation pins are not recommended proximal to the femoral condyles due to the presence of muscle and important neurovascular structures medial to the femoral diaphysis. Further absolute reduction and stability is required to re-establish the articular surface and promote bone healing without the development of callus. The ratio of pin tract new bone formation to bone diameter relates to frame stability had not been investigated in this study. Type II ESF with unthreaded pins may not be a very robust construct; however, we tried to find out (better stability design of TYPE II ESF) the way and cheap implants for a fracture repairmen in addition to regular treatments for fractures.

Conclusions

This novel approach to external fixation of skin graft dogs and fracture repair potentially offers surgeons an additional method of treating a variety of musculoskeletal conditions and soft tissue cases (e.g., necrosis or wounds requiring grafting over a joint). Further studies are warranted to further demonstrate that reverse-transverse cross pin ESFs are well-tolerated in dogs for a variety of conditions and can be applied to hold frame stability traditionally encountered with ESFs. Moreover, studies are needed to evaluate the additional use of different types of pins (e.g., threaded) and potentially also predrilling holes, which reportedly can also increase stability and decrease pin loosening. This study also serves to demonstrate that fracture fixation remains somewhat of an art form and that repair of fractures needs to be assessed on a case-by-case basis, especially, this approach together with type II external fixators are advised to apply to the hind limbs of dogs. Reverse-transverse cross pin technique could provide an alternative choice other than positive threaded pin and smooth pin to save surgeons' unaffordable costs for economic reasons among developing and under-developed countries.

Disclosure of conflict of interest

None.

Abbreviations

ESF, external skeletal fixator.

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