Stiffness of modified Type 1a linear external skeletal fixators

H. F. Reaugh1, M. C. Rochat2, C. W. Bruce3, D. S. Galloway4, M. E. Payton5
1Dallas Veterinary Surgical Center, Dallas, Texas, USA
2Department of Veterinary Clinical Sciences, Center for Veterinary Health Sciences, Oklahoma State University, Stillwater, Oklahoma, USA
3Department of Clinical Studies, Ontario Veterinary College, University of Guelph, Ontario, Canada
4US Army Veterinary Service, Okinawa, Japan
5Department of Statistics, College of Arts and Sciences, Oklahoma State University, Stillwater, Oklahoma, USA

Summary
Modifications of a Type 1a external skeletal fixator (ESF) frame were evaluated by alternatingly placing transfixation pins on opposite sides of the connecting rod (Type 1a-MOD) or by placing additional connecting rods on either of the two inside (Type 1a-INSIDE) or two outside (Type 1a-OUTSIDE) transfixation pins. The objective of this study was to evaluate the stiffness of these modifications in terms of axial compression (AC), cranial-caudal bending (CCB), and medial-lateral bending (MLB). We hypothesized that these designs would allow significant increases in unilateral frame stiffness, over Type 1a, without proportional increases in frame complexity or technical difficulty of application. All of the ESF frames were constructed using large IMEX SK™ clamps, 3.2 mm threaded fixation pins, 9.5 mm carbon fibre connecting rods and Delrin rods as bone models. Nine, eight pin frames of each design were constructed, and subjected to repetitive non-destructive loading forces (AC, CCB, MLB) using a materials testing machine. Frame construct stiffness for each force (AC, CCB, MLB) was derived from load-deformation curve analysis and displayed in N/mm. Data revealed the 1a-MOD and 1a-OUTSIDE constructs had significantly increased stiffness in CCB and AC as compared to the Type 1a constructs while all of the modified constructs were significantly stiffer in MLB than the Type 1a constructs.

Keywords
External skeletal fixation, biomechanics, Type 1a, Type 1b

Introduction
External skeletal fixation (ESF) is conceptually a simple method of stabilizing long bone fractures. However, until recently, the ability of an ESF to supply rigidity that is sufficient for fracture healing was limited by the mechanical characteristics of the commercially available equipment. These mechanical and structural limitations were especially evident when treating highly unstable fractures, such as comminuted fractures with ESF. The achievement of sufficient frame rigidity in order to allow the healing of highly unstable fractures without premature failure of the ESF elements often required the application of complicated ESF frame designs (1–5). Such frame designs are cumbersome, expensive, and time-consuming to apply. Simpler frame designs result in numerous benefits over more complicated designs including: less weight, less expense to the client and veterinarian, less dependence on aiming devices, less operative time, fewer frustrations with frame assembly and application, more latitude for fixation pin placement, and fewer fixation pin tracts. Fewer fixation pin tracts, especially when the fixation pins are placed in safe corridors, can result in decreased morbidity associated with the tracts. Some problems that can be avoided by using fewer fixation pin tracts are: pin tract drainage, premature pin loosening, decreased potential for soft tissue and neurovascular damage, less muscle atrophy and joint stiffness, and decreased pain at the pin tract with a compensatory increase in willingness to use the limb which may enhance bone healing (6–12). The study reported herein attempts to improve upon the simplest ESF configuration.

The simplest of all ESF frame designs is the unilateral, uniplaner (Type 1a) design. When used for repair of radial, tibial, and humeral fractures, the use of a Type 1a frame allows fixation pins to be placed in safe corridors, thereby lessening the soft tissue morbidity associated with fixation pin tracts (11, 12). While newer commercially available ESF systems have improved the strength of the Type 1a frame, that design is still weakest in bending in the plane perpendicular to the plane of the frame (13, 14). Despite the gains in frame rigidity, Type 1a frame designs may not be sufficiently rigid to serve as effective fixation for comminuted or other highly unstable fractures. One strategy that allows improved bending strength of the ESF frame in orthogonal planes, and yet minimizes soft tissue morbidity and adheres to the safe corridor concept is the application of a second Type 1a frame in a plane divergent from the first frame to create a unilateral, bilplanar (Type 1b) ESF.

The purpose of our study was two-fold: to evaluate the effect on frame stiffness of a modified Type 1a ESF (Type 1a MOD) frame design that would allow pin divergence by alternately placing transfixation pins on opposite sides of the connecting rod (Fig. 1), and to evaluate the effect on frame construct stiffness by adding a second connecting rod and clamps to the inside (Type 1a INSIDE) or outside (Type 1a OUTSIDE) fixation pins. These alterations to the
conventional Type 1a ESF frame design, would, in theory, improve ESF frame stiffness without increasing the number of transfixation pins.

This study evaluates the stiffness of these modifications to the 1a frame relative to standard 1a and 1b frames, in terms of axial compression (AC), cranial-caudal bending (CCB), and medial-lateral bending (MLB). We hypothesized that alternate placement of transfixation pins, on opposite sides of the connecting rod in a Type 1a frame or adding a second connector rod, would significantly increase in the frame construct stiffness in AC, CCB, and MLB in comparison to the standard Type 1a frames without increasing the number of transfixation pins in the construct.

Materials and methods

The external fixators that were used in the study were constructed with large ESF clamps, 9.5 mm diameter carbon fibre rods and 3.2 mm cortically threaded, positive-profile, medium pins (IMEX SK®. IMEX Veterinary Inc., Longview, TX, USA). Solid 19 mm Delrin rods (IMEX Veterinary Inc., Longview, TX, USA) were used to simulate the proximal and distal segments of a fractured bone. Five different eight pin (four pins per fragment), unilateral external skeletal fixator constructs were examined: Type 1a, Type 1a MOD, Type 1a INSIDE, Type 1a OUTSIDE and Type 1b. The Type 1a frame was a standard unilateral, uniplanar frame (Fig. 2). The Type 1a MOD was assembled with four pins per segment alternating cranio-lateral and caudo-lateral to the connecting rod (Figs. 1 and 3). The Type 1b frame was assembled as a unilateral, biplanar frame with four pins per segment alternating between cranial and lateral connecting rods (Fig. 4). The 1a INSIDE frames were standard Type 1a frames with an additional carbon fibre rod attached to the two middle transfixation pins with two additional clamps mounted outside the primary connecting rod (Fig. 5). The 1a OUTSIDE frames were standard Type 1a frames with an additional carbon fibre rod attached to the most proximal and most distal transfixation pins with two additional clamps outside the primary connecting rod (Fig. 6). The clamps of the 1a INSIDE and 1a OUTSIDE frame designs that held the additional carbon fibre rod were placed backwards and on the opposite side of the fixation pins and then placed at the same level as the adjacent connecting rod in order to simulate the placement of an additional rod on a patient with the intent of keeping the frame from impinging on adjacent soft tissues (Fig. 7A, B).

The following parameters were held constant for all ESF frames: distance from cortex to connecting clamp (25 mm), fixation pin type and diameter, intrafragmentary pin separation (30 mm), pin separation across fracture gap (50 mm), fracture gap (20 mm), connecting rod type and diameter, and connecting clamp type.

The frames were constructed using accepted ESF application techniques with all pins placed with low speed insertion after being pre-drilled with a 3.1 mm drill bit into the Delrin rods. The three Type 1a frames had pin placement in a single plane through the central longitudinal axis of the Delrin rods. The 1b frames had pin placement through the central longitudinal axis of the Delrin rod, with 90° pin divergence. The 1a MOD frames had pin placement alternating about the connecting rod with 35° pin divergence such that they intersected the central longitudinal axis of the rod. Nine frames of
each design were tested in AC, CCB, and MLB using a material testing machine (Model 8500 Instron Corporation) with Series IX software (version 8.24.08) and a load cell of 1000 N. For AC, the load was applied along the longitudinal axis of the Delrin rod. For the CCB and MLB tests, the load was applied in the transverse plane, via four point bending with the proximal and distal ends of the Delrin rod secured to rollers 30 cm apart with the load applied 1 cm to either side of the fracture gap. The frames were loaded to 130 N for axial compression and 140 N for bending as previously described by Bouvy and Bronson (1, 15). Each frame was repetitively tested four times and stiffness was measured by the slope of the linear portion of the load displacement curve and displayed in N/mm. The crosshead speed was set at 2 mm per minute. Statistical analysis was performed with PC SAS version 8.2 (SAS Institute, Cary, NC, USA). The analysis of variance procedures (PROC MIXED) was utilized to assess differences in constructs. If the analysis of variance was significant at the 0.05 level, pair-wise t-tests using a DIFF option in an LSMEANS statement were performed to make individual comparisons among the construct levels. The significance for these comparisons was also set at 0.05.

Results
Axial compression

The Type 1b frame was the stiffest frame tested in AC with a mean value of 410.7 N/mm (P<0.001, Table 1). The difference in stiffness between the Type 1a OUTSIDE frame and the Type 1a MOD frame was not significant, but both were statistically stiffer than the Type 1a frame (p<0.001).

Cranial caudal bending

The differences between the frames for CCB stiffness were similar to those recorded for axial compression. The 1b frame mean stiffness was 132.9 N/mm. The difference between the 1a OUTSIDE frame and the 1a MOD frame was not significant, but both were significantly stiffer than the 1a frame (P<0.001).
Medial lateral bending

The 1b, 1a MOD and 1a OUTSIDE frames were not significantly different from each other, but were all stiffer than the 1a frame (p=0.0014).

Discussion

In this study, the modifications of the Type 1a ESF frame were compared to a standard Type 1a ESF frame and a standard Type 1b ESF frame. The results supported previous reports that demonstrated the Type 1b frame to be much stronger than the Type 1a frame in axial compression and cranial-caudal bending. However, the important new findings from our study were that the three modifications to the Type 1a frame also significantly increased the stiffness of this frame.

For example, the Type 1a OUTSIDE and Type 1a MOD were 7.2% and 5.8% stronger in AC, respectively and 7.96% and 6.3% stronger in CCB, respectively. Also, in MLB the Type 1a MOD frames performed very similar to the Type 1b frames with the Type 1b and Type 1a MOD having an 11.6% and 8.8% gain in construct stiffness over the other Type 1a frames.

The increased stiffness of the Type 1a MOD frame over the Type 1a frame in both CCB and MLB is probably a result of the pins being placed at a 35 degrees divergence from the connecting rod. The degree of pin divergence obtained with this frame is a function of the fixation clamp size, rod diameter, and the distance the clamp is placed from the point where the fixation pins intersect the central axis of the bone. In keeping with proper ESF application standards, the distance from the clamp to the skin surface should be minimized to 1–2 cm. Assuming that this is the case, pin divergence from the central axis of the bone to the fixation clamp is dependent on the amount of soft tissues between the bone and ESF. Type 1a MOD frames applied to long bones with lesser amounts of soft tissue would have a greater fixation pin divergence angle than for bones with larger amounts of soft tissue and therefore greater frame stiffness. In this study, the pin divergence angle was maximized within the physical dimensions of the chosen connecting rod and fixation clamps to approximately 35 degrees. The only method for achieving a greater divergence angle would have been to place the clamps and connecting rod closer to the Delrin rod. Doing so would have created a clinically unrealistic scenario for many fractures since even with bones that have little soft tissue coverage, e.g., the medial edge of the radius or tibia, there is often significant soft tissue edema, thereby making it difficult to place the connecting rod and clamps any closer to the edge of the bone without the clamps impinging on the soft tissues. This will likely limit the use of the Type 1a MOD to only the radius and tibia. Another limitation to the Type 1a MOD is that the distance of the clamp and connecting rod to the soft tissues cannot be changed once the divergent pins are placed. Therefore, if the soft tissues have significant swelling and start impinging on the clamps, the clamps and rods cannot be moved any closer or farther to the soft tissues without removing the diverging transfixation pins. Care must be taken to place the clamps and rods at an appropriate distance to account for post operative swelling.

The Type 1a MOD and Type 1a OUTSIDE frames were significantly stronger than the standard Type 1a frames but the clinical relevance of this increased strength is not yet known. The in vitro mechanical testing process that was used cannot fully evaluate the effect of frame design modification on the complex forces that act on a fracture site during the healing process. However, this data does support the concept that alternate placement of fixation pins on opposite sides of the connecting rod, or adding a second connecting rod are simple, quick, inexpensive and effective methods for increasing the stiffness of the fixation device when increased ESF frame strength is required.

Acknowledgements

Thanks go to Kris Novotne, Animal Science Department, Oklahoma State University, USA.

References


Correspondence to:
H. Fulton Reaugh
6042 Revere Place
Dallas, Texas
75206 USA
Phone: +1 972 267 8100, Fax +1 972 267 8700
E-mail: hreaugh@sbcglobal.net