Biomechanical Comparison of Five External Wrist Fixators

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Abstract
The relative stiffness of five different external wrist fixators currently in use for distal radius fractures was determined using a uniform fracture model consisting of wood dowels to isolate the effects of the fixators themselves. Each construct was loaded in axial compression, eccentric and cantilever modes of bending, and torsion. The stiffest of the fixators varied by a factor of three in compression, five in bending, and three in torsion. Although the ideal stiffness of a wrist fixator is unknown, there is a large variation in the stiffness of existing devices.

Fractures of the distal radius are common injuries and were described clinically as early as 1814 by Colles.1 Low energy distal radius fractures are usually treated by closed means, while higher energy injuries often require internal or external fixation. Many different types of external fixators have been designed and are currently in use. To date however, no consensus has been reached regarding the optimal fixator for management of distal radius fractures. It is thought that a stiff external fixator promotes primary fracture healing while a less rigid device promotes more of a secondary fracture healing. The optimal rigidity required to maintain the reduction in a distal radius fracture is not known.2–7 Previous biomechanical comparison studies of these fixators have demonstrated a wide range of fixator stiffness.6,8,9,10,12

The purpose of this study was to evaluate the relative stiffness of five currently used external fixator frames under standardized loading conditions. In addition to determining stiffness in axial compression (AC), torsion (T), and anterior (AB-M), posterior (PB-M), medial (MB-M), and lateral (LB-M) eccentric bending moments, our study also tested stiffness in cantilever anterior (AB-C), posterior (PB-C), medial (MB-C), and lateral (LB-C) bending. By superposition, it is then possible to calculate the fixator stiffness in any complex loading mode. The model used in this study was designed purely to allow loading in the above standardized conditions to evaluate the relative stiffness of each fixator and does not exactly replicate distal radius or Colles type fracture.

Materials and Methods
Five external fixators were tested (Fig. 1): Synthes Distal Radius Fixator (Synthes, Paoli, PA), Yellow Monotube (Howmedica-Osteonics Inc., Rutherford, NJ), Hoffman II Compact (Howmedica-Osteonics Inc., Rutherford, NJ), EBI Distal radius fixator (EBI, Parsippany, NJ), and Pennig Wrist Fixator (Orthofix, Verona, Italy).

All frames were mounted on hardwood dowels to create a standardized model replicating a distal radius or mid-diaphyseal fracture (Fig. 2). This model standardized fracture dimensions, mounting parameters, pin length, and pin spacing so that the effects of the frames themselves were isolated. The proximal piece of dowel represented the proximal radius while the distal piece represented the first metacarpal/distal radius with a 10-mm “fracture” gap. Hardwood was chosen as the media for this study because of its similar modulus of elasticity to bone and because the hardwood provided ideal purchase for the pins of the fixation devices. All fixators were mounted in a four-pin construct using pins appropriate to each fixator through holes in the dowels that
were pre-drilled to recommended sizes. The span of the two innermost pins that were on opposite sides of the “fracture” gap was held constant in all constructs at 9 cm. The free pin distance (wooden dowel to pin-bar junction) was held constant at 16 mm for all constructs. The pin-bar clamps were manually tightened by the same orthopaedic surgeon. The proximal end of each fixator was securely mounted in a vise on a servo hydraulic MTS test machine (MTS Corporation, Minneapolis, MN) for mechanical testing. An aluminum bar was secured to the distal end of each construct by screw application. It was through this bar that loads were transmitted at specific registration points. The modes that were tested when the fixator was mounted vertically were axial compression (AC), anterior (AB-M), posterior (PB-M), medial (MB-M), and lateral (LB-M) eccentric bending moments. When mounted horizontally the modes tested were cantilever anterior (AB-C), posterior (PB-C), medial (MB-C), and lateral (LB-C) bending, and torsion (T). The anteroposterior plane was defined as the plane +45° to the plane of the pins while the mediolateral plane was defined as the plane –45° to the plane of the pins. This geometry was chosen to account for standard clinical frame configuration. When the construct was secured vertically, the load was applied 44 mm from the long axis of the dowels to produce bending moments. When secured horizontally, cantilever bending was performed with the proximal end of the dowel mounted in a vise at a constant position (13 cm from proximal edge of “fracture” gap) and the distal end deflected by the actuator. For torsional bending, the construct was maintained horizontally and the load was directed at a point on the aluminum bar 53 mm from the long axis of the dowels. The constructs were loaded to a maximum of 45 N and tested over their elastic portion of the force-displacement curve. Each fixator was tested four times for each type of loading and re-applied to new dowels for further tests. No fixator was tested to failure and no pins failed during testing of these constructs.

Stiffness was calculated from the slope of the linear portion of the load versus displacement curves. The values from the final three trials of the four tests of each fixator were averaged. Stiffness values of selected pairs of fixators were compared by unpaired t-tests. Each fixator was tested:

**Figure 1** Five different external fixators used in this study (from left to right): Synthes Distal Radius Fixator (Synthes, Paoli, PA), Yellow Monotube (Howmedica-Osteonics Inc., Rutherford, NJ), Hoffman II Compact (Howmedica-Osteonics Inc., Rutherford, NJ), EBI Distal Radius Fixator (EBI, Parsippany, NJ), and Pennig Wrist Fixator (Orthofix, Verona, Italy).

**Figure 2** Experimental construct. Darkened arrows indicate points of load application. Points designated by two directions (i.e., medial/posterior, lateral/posterior, etc.) refer to the load plate being in orthogonal planes.
weighed without inclusion of the pins.

Results

Axial Compression (Figure 3)
The axial compressive range of stiffness for the fixators was from 98.7 to 309.1 (N/cm). The Yellow Monotube was the stiffest external fixator, while the Hoffman II Compact was the least stiff. The Yellow Monotube was 213% stiffer (p < 0.001) than the Hoffman II Compact and 90% stiffer (p < 0.005) than the Pennig Orthofix, the second stiffest fixator in axial compression.

Anterior Bending Moment (Eccentric Bending)
In anterior bending moment, the range of stiffness was from 17.6 to 47.2 (N-m/cm). The stiffest was Yellow Monotube while the least rigid was the Hoffman II Compact. The Yellow Monotube was 171% stiffer than the Hoffman II Compact and 44% stiffer than the Synthes, the next stiffest fixator tested with an anterior bending moment.

Posterior Bending Moment
The values for posterior bending moment ranged from 7.31 to 32.4 (N-m/cm). The stiffest was Yellow Monotube while the weakest was the Hoffman II Compact. The Yellow Monotube was 333% stiffer than the Hoffman II Compact and 63% stiffer than the Pennig Orthofix, the second stiffest fixator tested with a posterior bending moment.

Medial Bending Moment
The medial bending moment stiffness values ranged from 14.0 to 41.0 (N-m/cm). The stiffest external fixator in this configuration was the Synthes while the least stiff was the Hoffman II Compact. The Synthes was 191% stiffer than the Hoffman II Compact and only 34% stiffer than the Yellow Monotube, the next stiffest fixator tested with a medial bending moment.

Lateral Bending Moment
The lateral bending moment stiffness values ranged from 14.8 to 29.1 (N-m/cm). The stiffest fixator tested with a posterior bending moment was the Yellow Monotube while the weakest was the Hoffman II Compact. The Yellow Monotube was 94% stiffer than the Hoffman II Compact and only 27% stiffer than the Synthes, the next stiffest fixator. The EBI and Pennig Orthofix had essentially the same stiffness in this mode of testing with values of 19.7
and 19.6, respectively.

**Anterior Bending (Cantilever Bending)**
The values of the frames tested in anterior bending ranged from 0.787 to 6.92 (N/cm). The stiffest fixator in this dimension was the Yellow Monotube while the least stiff was the Hoffman II Compact. The Yellow Monotube was 800% stiffer than the Hoffman II Compact but only 33% stiffer than the EBI, the next stiffest fixator in this category.

**Posterior Bending**
The posterior bending stiffness values ranged from 0.787 to 4.92 (N/cm). The stiffest fixator tested in this direction was the Yellow Monotube while the weakest was the Hoffman II Compact. The Yellow Monotube was 538% stiffer than the Hoffman II Compact but only 28% stiffer than the Synthes, the next stiffest.

**Medial Bending**
The values of the frames tested in medial bending ranged from 3.63 to 8.19 (N/cm). The stiffest was the Synthes and the weakest was the EBI. The Synthes was 124% stiffer than the EBI and 39% stiffer than the Yellow Monotube, the next stiffest fixator tested in this mode.

**Lateral Bending**
The lateral bending stiffness values ranged from 1.93 to 5.79 (N/cm). The stiffest was the Yellow Monotube and the least stiff was the Hoffman II Compact. The Yellow Monotube was 200% more stiff than the Hoffman II Compact and 46% stiffer than the Synthes, its closest competitor in lateral bending stiffness.

**Torsion**
The values obtained for torsional bending ranged from 0.033 to 1.01 (N-m/degree). The stiffest construct was the Yellow Monotube while the least resistant construct to torsion was the Hoffman II Compact. The Yellow Monotube was 206% stiffer than the Hoffman II Compact but only 16% stiffer than its nearest competitor in torsional bend, the Pennig Orthofix.

**Weight Analysis**
The weights of the individual fixators ranged from 89 gm to 176 gm; Synthes 126 gm, Yellow Monotube 163 gm, Hoffman II Compact 89 gm, EBI 176 gm, and Pennig Orthofix 115 gm.

**Discussion**
The purpose of this study was to characterize the relative stiffness of various external fixator frames under standard loading conditions using a uniform construct. The test model maintained a standard innermost pin distance and bone-to-pin/clamp junction distance. In all loading modes tested, except the medial eccentric bending moment and medial cantilever bending modes, the Yellow Monotube was the stiffest external fixator. Presumably, Yellow Monotube’s large diameter crossbar adds significantly to its rigidity. The least rigid external fixator was the Hoffman II Compact.

Several studies have reported on the relative stiffness of various external fixators. Unfortunately, none of these reports investigated more than one of the external fixator investigated in this study, thus making comparison with the literature difficult. Sladicka and colleagues reported on eight external fixators and found that no one fixator was the absolute stiffest for all axial, torsional, or bending characteristics tested. Of their samples tested, they report that the Torus (Zimmer) was most rigid under torsional load and that the Hoffman Monotube Red (Howmedica) was the stiffest under axial loading and anteroposterior and lateral bending.

Frykman and associates compared eleven fixators and categorized them into groups I-IV (I-least rigid, II-intermediate rigidity, III-more rigid, and IV-most rigid). They concluded that the Orthofix was the stiffest fixator for axial compression and anteroposterior and lateral bending. Simpson and coworkers studied nine fixators concluding that the small Hoffman C-series rectangular frame was the most rigid in compression and extension testing.

It has been suggested that the most influential factor on initial hard-tissue and soft-tissue healing is that of initial rigid fixation. Since the purpose of an external fixator is to provide early stabilization of the fracture, it seems reasonable that a more rigid device would prove to be optimal during the initial phases of fracture healing. Thus the present data suggest that overall stability would be best achieved using the Yellow Monotube external fixation device.

Many of the concerns with fixators are not with stability, but rather with cost and weight. The fixators examined in this study ranged in price from $1,000 to $1,600, while the weights varied from 89 gm to 176 gm. The Yellow Monotube is the least expensive external fixator tested with a cost of $1,000. It is also the second heaviest at 163 gm.

The strength of this study is a standard construct simulating a distal radius fracture using wooden dowels. Although this standardized construct was designed with a single crossbar, some of the external fixator frames can support a double crossbar, which would clearly add more stability to the frame. In an attempt to avoid deforming the constructs, a limitation of this study was that the samples were not tested to failure, which may occur in the clinical setting with higher loading. As well, there was no cycling of the tested frames, which may cause loosening of the pin holders/clamps. The amount of slipping, if any, when the constructs were secured in the vice was not measured and could be a source of error.
addition, stiffness in distraction was not measured but should be similar to compression values.

This present data support the Yellow Monotube to be one of the more rigid devices on the market and clearly the stiffest of the external fixators investigated in this study.

References