Biomechanical Evaluation of 10 Configurations of a Small External Fixator Set

Leonid I. Katolik, MD, Mark Stewart, MD, John Fernandez, MD, Allison MacLennan, MD, and Mark Cohen, MD

Abstract

The small AO (Synthes, Paoli, Pa) external fixator is a valuable tool for the treatment of distal radius fractures. The construct has many possible bar and pin configurations. However, there are no data regarding which construct is optimal with respect to strength and versatility.

We tested 10 configurations to determine bending stiffness, rotation, and axial loading. Although slight variations were found between constructs for bending and rotation forces, there were marked differences between constructs during axial loading. A frame design without bar-to-bar clamps was determined stiffest. However, this configuration may be more difficult to apply and adjust in the clinical setting.

Although an "ideal" construct applicable to all fracture types does not exist, knowledge of the strengths of various configurations may allow for optimization of fixator assembly to meet specific clinical needs.

Numerous clinical series support the efficacy of external fixation for the treatment of comminuted fractures of the wrist.[1-15] The small AO external fixator (Synthes, Paoli, Pa) was developed in the 1970s. Its basic components are 2.5- and 4-mm Schantz screws, 4-mm carbon fiber connecting rods, and 2 types of nuts that couple connecting bars with screws. This fixator allows for customized constructs of varying stiffness to meet particular needs.

In 1985, Nakata and colleagues[16] found it to be up to twice as stiff as other external fixation devices commercially available at the time. In 1993, Frykman and colleagues[17] found it to be of average stiffness in comparison with 12 other devices. However, only one frame configuration was tested. Currently, no data exist to guide a particular frame configuration based on stiffness, versatility, or application ease.

In the present study, we compared various configurations of the small AO external fixator in relation to stiffness in axial loading, bending, and rotation. It is our hope that our results will aid in clinical application of the device.

Materials and Methods

Ten constructs of the small AO external fixator were chosen for evaluation (Figure 1). Testing was performed with an Instron materials testing apparatus (Norwood, Mass) per the specifications of the American Society for Testing and Materials.[18]

To ensure consistency in our model, we mounted fixator constructs onto a polyethylene bar 1.25 cm in diameter. Polyethylene was chosen in an effort to minimize creep at the pin–bar interface.

Each polyethylene dowel was cut to 30 cm. The dowel was secured in the Instron apparatus. Four 4.0-mm threaded external fixator pins were drilled into the bar at distances of 5, 8, 19, and 22 cm from the end of the polyethylene bar in a parallel fashion. These distances were chosen in an effort to simulate the clinical application of pins in the radius and metacarpal bones and to standardize the testing sequences. For the application of bending loads, a fifth pin was placed 24 cm from the end of the bar. Two transverse cuts were made in the center of the bar, and a 3-cm section of polyethylene was removed. Carbon fiber rods (3 mm in diameter; 200, 120, and 100 mm in length) were used for the fixator constructs. Rods were placed 2 cm above the polyethylene bar. The second level of the construct was placed 1 cm above the lower bar. A calibrated torque wrench was used to tighten all rod and pin connector bolts to 3.5 Nm of force. Distances between the 2 proximal and distal pins, angle of the pins to the dowel, and distance between the dowel and the fixator bar were kept constant in all constructs.

The frames were stressed in the Instron apparatus. A typical load-versus-displacement curve is depicted in Figure 2. Construct stiffness was defined as the slope of the steepest portion of the linear portion of the graph before the yield point. Yield point was defined as the

Dr. Katolik is Assistant Professor, Department of Orthopaedic Surgery, Thomas Jefferson University School of Medicine, and Attending Surgeon, The Philadelphia Hand Center, PC, Philadelphia, Pennsylvania.
Dr. Stewart is in private practice in Moline, Illinois.
Dr. Fernandez is Assistant Professor, Department of Orthopaedic Surgery, Rush–Presbyterian–St. Luke's Medical Center, Chicago, Illinois.
Dr. MacLennan is Fellow, Hand Surgery, Roosevelt-St.Luke's Hospital, New York, New York.
Dr. Cohen is Professor, Department of Orthopaedic Surgery, Rush–Presbyterian–St. Luke's Medical Center, Chicago, Illinois.

Address correspondence to: Leonid I. Katolik, MD, 700 S Henderson Road, King of Prussia, PA 19046 (tel, 484-904-2116; e-mail, likatolik@handcenters.com).

***Am J Orthop.* 2008;37(9):462-465.**

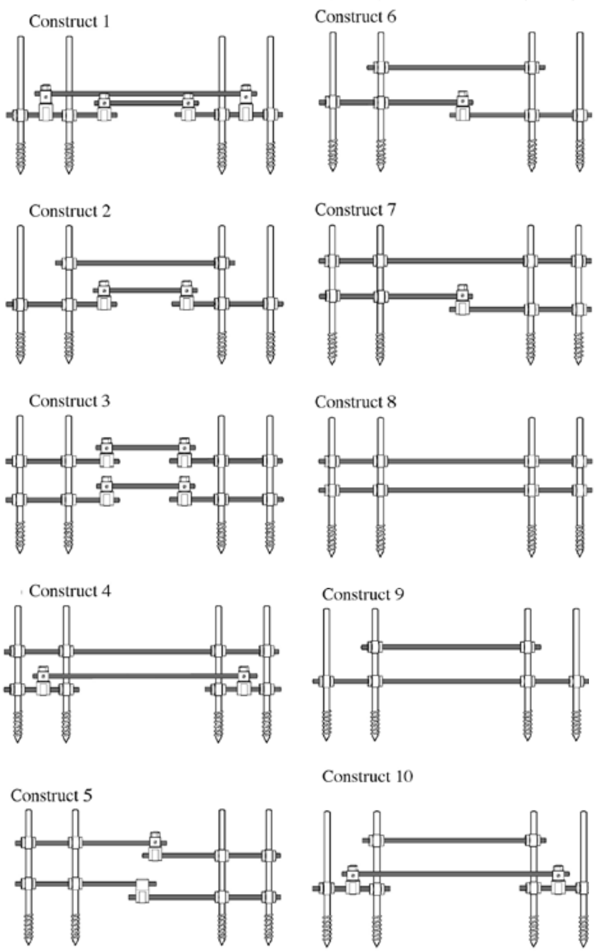

Figure 1. Ten fixator constructs.

point at which the graph deviated from its original linearity. Load to failure is the point at which the construct continued to fail, resulting in a plateau of the curve. Loads were chosen to ensure failure of all constructs and to afford entry into the plateau segment of the curve. This translated into axial and bending displacement of 5 mm and rotational displacement of 5°.[19]

Axial loading (Figure 3) was tested by applying force along the longitudinal axis of the bar at a rate of 15 mm/s with a scan rate of 50/s. Rotational forces were applied perpendicular to the longitudinal axis of the bar at 15°/min with a scan rate of 50/s. Bending forces (Figure 4) were tested by applying forces perpendicular to the axis of the bar through the accessory pin while anchoring the opposite bar with a loading rate of 15 mm/s and a scan rate of 50/s.

Each of the 10 configurations was tested sequentially in an identical manner 5 times. New 4.0-mm carbon fiber bars and new polyethylene dowels were used for each testing sequence. Mean values for axial loading, bending, and rotation were calculated for each construct. The equivalent stiffness index was calculated, as described by Nakata and colleagues,[16] as the mean sum of individual rigidity values of each loading mode. This allowed for comparison of overall rigidity between different constructs. Analysis of variance and the Tukey all-group comparison test were performed with statistical significance defined as $P<.05$. A 2-tailed test was used in all cases.

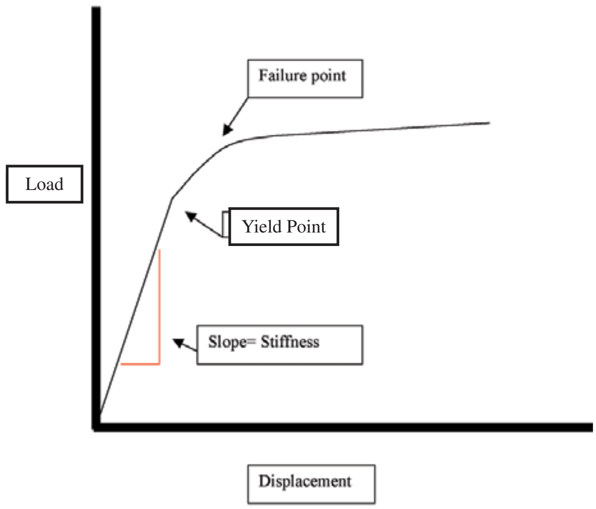

Figure 2. Typical load-displacement curve with stiffness, yield point, and failure point represented.

Figure 3. Setup for testing axial load.

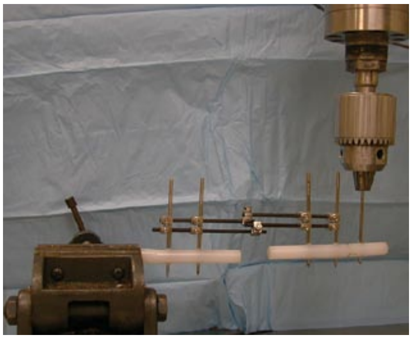

Figure 4. Setup for testing bending load.

Results

The mean values and SDs for the axial, torsional, and bending stiffness of each fixator construct and its respective series of trials were calculated (Tables I-III, Figures 5-7). Equivalent stiffness indexes were also calculated (Table IV, Figure 8).

After application of bending forces, only marginal differences in bending stiffness were noted between the different fixator designs. Construct 7 provided the greatest resistance to bending load (1.039 N/mm), and this difference was statistically significant ($P<.01$). Conversely, construct 10 demonstrated the lowest bending stiffness (0.795 N/mm), which was noted to be a statistically significant difference in comparison with constructs 2 to 8 ($P<.01$) but not construct 1 or 9.

Marginal differences were again noted between the different fixator designs when subjected to torsional stress. Construct 3 demonstrated the most resistance to torsional stress (mean stiffness, 65.9 Nmm/degree).

Table I. Axial Stiffness by Fixator Type

	Construct									
	1	2	3	4	5	6	7	8	9	10
Stiffness (N/mm)	18.02	16.57	14.78	18.25	32.36	26.58	35.36	40.11	28.33	13.22
SD	0.754	0.656	3.810	1.534	1.410	0.864	1.637	3.676	1.808	0.744

Table II. Torsional Stiffness by Fixator Type

	Construct									
	1	2	3	4	5	6	7	8	9	10
Stiffness (Nmm/degree)	52.40	59.02	65.94	58.50	55.47	55.71	55.38	51.54	50.27	55.40
SD	3.859	6.101	3.448	1.656	2.834	5.278	0.364	0.725	0.968	0.764

Table III. Bending Stiffness by Fixator Type

	Construct									
	1	2	3	4	5	6	7	8	9	10
Stiffness (N/mm)	0.84	0.90	0.91	0.92	0.94	0.92	1.04	0.95	0.83	0.79
SD	0.024	0.032	0.016	0.033	0.050	0.031	0.047	0.067	0.021	0.017

Table IV. Equivalent Stiffness Index by Fixator Type

	Construct									
	1	2	3	4	5	6	7	8	9	10
Equivalent stiffness index	23.75	25.50	27.21	25.89	29.59	27.73	30.59	30.87	26.48	23.14

This was a statistically significant difference with respect to constructs 5 to 10 ($P<.01$) and construct 4 ($P<.05$). The external fixator design least resistant to torsional stress was construct 9 (mean stiffness, 50.3 Nmm/degree). This difference was statistically significant with reference to constructs 2 to 4 ($P<.01$) but not the other constructs.

In contrast to the calculated values for bending and torsional stiffness, larger differences were measured between constructs when stressed in axial loading. Construct 8 exhibited the greatest resistance to axial loading and displacement (mean stiffness, 40.1 N/mm). This difference was statistically significant at $P<.01$ for constructs 1 to 6, 9, and 10 and at $P<.05$ for construct 7. Constructs 1 to 4 and 10 measured less than half of the axial stiffness of construct 8. In fact, constructs 1 to 4 all exhibited statistically significantly lower axial stiffness values with respect to constructs 5 to 9. Construct 10 demonstrated the least resistance to axial load (mean axial stiffness, 13.2 N/mm). This was significantly lower than the stiffness measured for constructs 1 and 4 ($P<.05$) and constructs 5 to 9 ($P<.01$).

Discussion

Use of external fixation to treat fractures of the wrist and forearm was first described by Ombredanne in 1929. In 1944, Anderson and O'Neill introduced "protracted traction" to treat comminuted distal radius fractures.[20] The term *ligamentotaxis* was introduced by Vidal in the 1970s.[21] Vidal found distraction particularly applicable

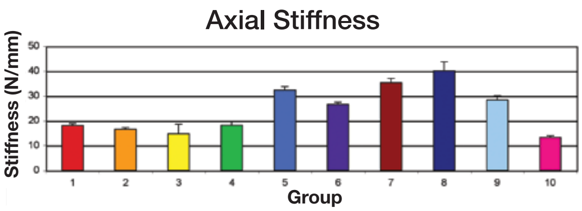

Figure 5. Graphical representation of axial stiffness versus fixator type.

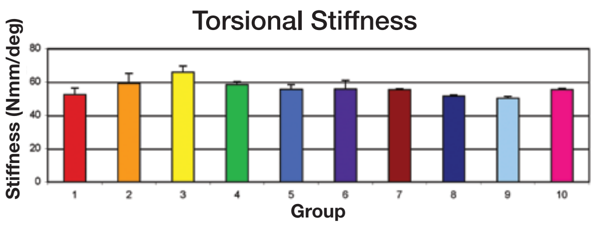

Figure 6. Graphical representation of torsional stiffness versus fixator type.

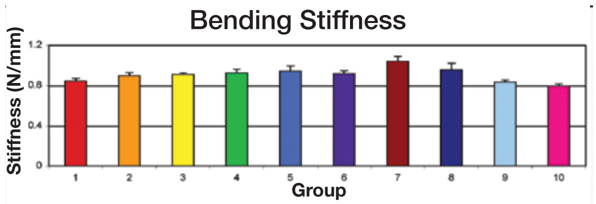

Figure 7. Graphical representation of bending stiffness versus fixator type.

Figure 8. Graphical representation of equivalent stiffness index versus fixator type.

to treating comminuted fractures of the wrist. Numerous clinical series have since supported use of external fixation to treat comminuted fractures of the wrist.[1-15]

In the present study, we compared bending stiffness, rotation, and axial loading of 10 different configurations of the small AO external fixator. Pin number, pin separation, and bar height were kept constant to allow for uniform testing. Similarly, bar diameter was kept constant for proximal and distal pin insertion sites. Although a more rigid construct may aid in reduction maintenance, the versatility of this system allows the surgeon to tailor a frame to a given fracture. An "ideal" fixator configuration for this device was not previously established.

Frykman and colleagues[17] studied the stiffness of 13 commercially available external fixators for use on the distal radius. The small AO fixator had a stiffness index of 13.7, which fell into the intermediate range (5.2-42.3) of fixators tested. However, different pin and bar arrangements were not evaluated.

Our results suggest few differences between frame configurations tested in bending and torsion. However, axial stiffness was affected by bar-and-clamp design, which may be the most important parameter for fracture settling.[22,23] Constructs 5 to 9 resisted axial shortening more than the other configurations tested. Although it is not clear if these differences are clinically relevant, construct 8 was the stiffest. However, this configuration may have the least clinical applicability. It requires the 4 Schantz pins to be exactly parallel in all planes to allow for stabilization without bar-to-bar clamps. This also decreases the ability to adjust the frame once applied. Constructs 7 to 9 have similar limitations. The more bar-to-bar clamps used, the more versatile the frame. However, constructs 1 and 3, the only designs with 4 such clamps, were significantly less stiff in axial loading. Thus, there may be a trade-off between stiffness and ease of clinical application.

It is not clear whether an optimal configuration exists for the small AO external fixator. The technical ease with which a device can be applied and adjusted and the comfort and experience of the surgeon must be taken into account. Using our model, construct 5, with 2 bar-to-bar clamps may allow for optimal stiffness and versatility. Construct 6 appears to be an alternative. With one bar-to-bar clamp, it may be simpler to apply.

In recent years, with increased interest being focused on fixed-angle volar plating devices and their application in the treatment of distal radius fractures, one fact has been ignored—that little in the literature supports use of such devices over spanning external fixators[6,14, 24, 25] It must be remembered that all treatments rely on sound planning and technical expertise with the implants used. It is hoped that our study data on the comparative rigidity of various configurations will allow surgeons to tailor fixation needs to particular patients, fracture types, and rehabilitative needs.

Authors' Disclosure Statement and Acknowledgments

The authors report no actual or potential conflict of interest in relation to this article.

References

1. Bishay M, Aguilera X, Grant J, Dunkerley DR. The results of external fixation of the radius in the treatment of comminuted intraarticular fractures of the distal end. *J Hand Surg Br.* 1994;19(3):378-383.
2. Cooney WP. Distal radius fractures: external fixation proves best. *J Hand Surg Am.* 1998;23(6):1119-1121.
3. Hegeman JH, Oskam J, Vierhout PA, Ten Duis HJ. External fixation for unstable intra-articular distal radial fractures in women older than 55 years. Acceptable functional end results in the majority of the patients despite significant secondary displacement. *Injury.* 2005;36(2):339-344
4. Herrera M, Chapman CB, Roh M, Strauch RJ, Rosenwasser MP. Treatment of unstable distal radius fractures with cancellous allograft and external fixation. *J Hand Surg Am.* 1999;24(6):1269-1278.
5. Jakim I, Pieterse HS, Sweet MB. External fixation for intra-articular fractures of the distal radius. *J Bone Joint Surg Br.* 1991;73(2):302-306.
6. Kapoor H, Agarwal A, Dhaon BK. Displaced intra-articular fractures of distal radius: a comparative evaluation of results following closed reduction, external fixation and open reduction with internal fixation. *Injury.* 2000;31(2):75-79.
7. Prince H, Worlock P. The small AO external fixator in the treatment of unstable distal forearm fractures. *J Hand Surg Br.* 1988;13(3):294-297.
8. Rikli DA, Küpfer K, Bodoky A. Long-term results of the external fixation of distal radius fractures. *J Trauma.* 1998;44(6):970-976.
9. Sakano H, Koshino T, Takeuchi R, Sakai N, Saito T. Treatment of the unstable distal radius fracture with external fixation and a hydroxyapatite spacer. *J Hand Surg Am.* 2001;26(5):923-930.
10. Sanders RA, Keppel FL, Waldrop JI. External fixation of distal radial fractures: results and complications. *J Hand Surg Am.* 1991;16(3):385-391.
11. Seitz WH Jr, Froimson AI, Leb R, Shapiro JD. Augmented external fixation of unstable distal radius fractures. *J Hand Surg Am.* 1991;16(6):1010-1016.
12. Stein H, Volpin G, Horesh Z, Hoerer D. Cast or external fixation for fracture of the distal radius. A prospective study of 126 cases. *Acta Orthop Scand.* 1990;61(5):453-456.
13. Vaughan PA, Lui SM, Harrington IJ, Maistrelli GL. Treatment of unstable fractures of the distal radius by external fixation. *J Bone Joint Surg Br.* 1985;67(3):385-389.
14. Wright TW, Horodyski M, Smith DW. Functional outcome of unstable distal radius fractures: ORIF with a volar fixed-angle tine plate versus external fixation [published correction appears in *J Hand Surg Am.* 2005;30(3):629]. *J Hand Surg Am.* 2005;30(2):289-299.
15. Zanotti RM, Louis DS. Intra-articular fractures of the distal end of the radius treated with an adjustable fixator system. *J Hand Surg Am.* 1997;22(3):428-440.
16. Nakata RY, Chand Y, Matiko JD, Frykman GK, Wood VE. External fixators for wrist fractures: a biomechanical and clinical study. *J Hand Surg Am.* 1985;10(6 pt 1):845-851.
17. Frykman GK, Peckham RH, Willard K, Saha S. External fixators for treatment of unstable wrist fractures. A biomechanical, design feature, and cost comparison. *Hand Clin.* 1993;9(4):555-565.
18. Priemon-Storer RA, ed. *Standard Test Method for Static Bending Properties of Metallic Bone Plates*. Philadelphia, Pa: American Society for Testing and Materials; 1985:90-93.
19. Finlay BJ, Eng P, Moroz TK, Rorabeck CH, Davey JR, Bourne RB. Stability of ten configurations of the Hoffmann external-fixation frame. *J Bone Joint Surg Am.* 1987;69(5):734-744.
20. Fernandez DL, Flury MC. History, evolution, and biomechanics of external fixation of the wrist joint. *Injury.* 1994;25(suppl 4):2-13.
21. Cooney WP. External fixation of distal radius fractures. *Clin Orthop.* 1983;(180):44-49.
22. Chhabra A, Hale JE, Milbrandt TA, Carmines DV, Degnan GG. Biomechanical efficacy of an internal fixator for treatment of distal radius fractures. *Clin Orthop.* 2001;(393):318-325.
23. Wolfe SW, Austin G, Lorenze M, Swigart CR, Panjabi MM. A biomechanical comparison of different wrist external fixators with and without K-wire augmentation. *J Hand Surg Am.* 1999;24(3):516-524.
24. Grewal R, Perey B, Wilmink M, Stothers K. A randomized prospective study on the treatment of intra-articular distal radius fractures: open reduction and internal fixation with dorsal plating versus mini open reduction, percutaneous fixation, and external fixation. *J Hand Surg Am.* 2005;30(4):764-772.
25. Margoliot Z, Haase SC, Kotsis SV, Kim HM, Chung KC. A meta-analysis of outcomes of external fixation versus plate osteosynthesis for unstable distal radius fractures. *J Hand Surg Am.* 2005;30(6):1185-1199.