Alternative Methods of Internal Fixation of Hand Fractures:

Mechanical and Clinical Assessments

John W. Steege*, Michael I. Vendor, M.D.*, Robert F. Hall, Jr., M.D.**

* Department of Orthopaedic Surgery, Rehabilitation Engineering Program, Northwestern University, 345 E. Superior, Chicago Il., 60611.

** Division of Orthopaedic Surgery, Cook County Hospital, 1825 W. Harrison Street, Chicago, Il., 60612.

INTRODUCTION

The history of operative fixation of hand fractures is one that dates back only to the early 1900's with Albion Lambotte of Antwerp, Belgium being the first great pioneer (1). Sketches of an external fixator for a phalangeal fracture date to 1904. His 1913 book "Chirurgie Operatoire des Fractures" describes use of wires, nails, screws, and plates for internal fixation.

Various methods described through the early 1920's used carpenter's nails and steel phonograph needles (2). Also during the first three decades, Kirscner in Germany was describing his use of various sizes of piano wires.

In 1937, Bosworth used K-wires to hold a metacarpal neck fracture reduced by pinning across to an intact metacarpal (3). In 1945, Long and Fett used an intramedullary (IM) K-wire for fixation (4). Rush published an article in 1949 describing rigid IM rod fixation of fractures, including use of minature rods for metacarpal fractures (5). Kilbourne described the use of small screws for fixation of metacarpal, mettarsal, and phalangeal fractures in 1958 (6). Use of AO plates in the hand was discussed in 1970 by Simonetta (7). Green and Anderson in 1973 published their experience with k-wire fixation of phalangeal fractures (8). Intraosseous wiring of hand fractures was described by Lister in the late 1970's (9).

Open reduction and internal fixation is preferred to accurately reduce a fracture and/or to maintain reduction. A significant benefit is when the fixation is of sufficient strength to allow early ROM of adjacent joints, especially in the hand. Most of the literature regarding internal fixation of the hand has discussed surgical techniques and follow-up results of several cases, while few addressed the issues of whether one fixation provides firmer fixation than another. Various studies have attempted to compare mechanical properties of different fixation techniques (10-13). Models have included human metacarpals and phalanges, pig metacarpals, and chicken femurs. Fixation quality has been assessed by cantilever and four point beam bending tests while monitoring specimen deflection in conjunction with either applied load, applied moment, or bone surface strain. Load-deflection relations, compressive surface strain-deflection relations, bending stiffness, and maximum bending moment have all been used as fixation quality criteria.

Consideration needs to be given to mode of failure, i.e. device failure, bone failure, or device-bone interface failure. The type of failure mode has direct bearing on both the comparability of *in vitro* biomechanical studies and the clinical stability and successful use of these fixation devices *in vivo* .

The advantages of closed IM rodding over other forms of fixation are the lessening of blood loss do to limited surgical exposure, the decreased risk of infection (especially at the fracture site), and the preservation of periosteal attachments near the fracture probably favoring early bone healing.

However, Pankovich has shown that fracture fragments in human cadaver femurs fixed with flexible IM rods (Ender rods) could markedly angulate and rotate in relation to each other. On release of the deformed force, the fracture fragments returned to their original position.(1)"Closed Ender Rodding of Femoral Shaft Fractures" Pankovich, Goldfres,Deacon. JBJS 61A No. 2 March 1979 p. 222.

The purpose of this study is to mechanically compare previously described methods of internal fixation in addition to a different plate fixation and a flexible IM rodding technique, and to examine the implications of these tests for clinical use.

MATERIALS AND METHODS

Specimens were fashioned from fresh chicken femurs stripped of all soft tissues. The bones were soaked in normal saline in stored frozen at -22 ^{o} C. No attempts were made to control for bone size or geometry, although all the specimens were noted to be of similar size and shape.

For testing, the bones were thawed to room temperature and transversely osteotomized using a power oscillating saw. The osteotomies were then fixed using several methods of internal fixation: 2 cross K-wires (smooth, 1.14 mm diam), 2 cross K-wires plus tension bands (22 gauge wire), 4 and 8 hole microplates (16 or 32 x 3.8 x 0.8 mm, 1.5 mm screws), 4 hole AO mini-plates (23 x 5 x 1 mm, 2 mm screws), large 4 hole AO plates (49 x 10 x 1 mm, 3.5 mm screws), 4 and 8 flexible IM rods (0.8 mm diam), and 4 hole microplates with 4 IM rods.

Cross K-wires were chosen because of their ready availability to essentially all surgeons and their very common use as a form of internal fixation. AO plates represent the current AO standard of metacarpal internal fixation. In addition, a miniature plate system was tested, smaller than the AO mini-plates. Of particular interest were the flexible IM rods, similar to larger flexable IM rods used in long bones. Cross K-wires plus tension band and combined microplate with IM rods were tested as well.

The prepared specimens were placed in a four point bending jig. To prevent slippage, four small grooves were created on each bone at locations corresponding to the load points of the jig by use of a small file. The outer points of the jig were 2.50 inches apart while the inner points were 1.00 inches apart. The jig with specimen was placed between the crosshead and ram of a materials testing machine (Model 810, MTS Inc., Minneapolis MN). The test set up is pictured in Figure 1. A constant displacement rate of 0.127 mm/sec was then applied to the system. Force and displacement data were monitored on a X-Y plotter. Visual measurements were made intermittently of specimen apex-dorsal ??? angulation.

Five intact specimens of varying size were tested as controls. Several IM (4 and 8) rod specimens were laterally constrained at both ends as shown schematically in figure 2 to prevent fracture interface separation. All specimens were eventually taken to failure and, when appropriate, peak loads noted.

ANALYSIS

In a four point bent beam configuration, constant and equal applied bending moments exist across the fracture site. If the fracture site were to act as a continuous cylinder and the dimensions of each cylinder were assumed equal, an equivalent stress environment would exist for each test and device type. However, this is not the case for this system. Alexander, et. al., examined the fracture fixed bone as a composite structure. They concluded that slippage of the devices they tested accounted for the low bending stiffness they measured for IM rod and K-wire fixation. In this study, no assumptions are made regarding the situation at the fracture site.

Developed loads are reported as developed bending moments. By geometry, displacements are transformed into angular deflections about the fracture site by asuming simple pivoting, small deflections and rigidity of bone (Figure 3). Therefore, fixation quality is based simply on the bending moment, the resulting deflection, and the point at which the deflection-moment curve becomes nonlinear (defined here as the yield point, see Figure 4). The final fracture strength as reported by Massengil, et al., was not considered, seeing as the deformations and/or moments present at failure are far beyond that seen in the clinical situation. In addition, different bone fixation constructs do not behave in a similar manner near failure, making comparison difficult. Statistical comparisons of bending moment/deflection relations (hereafter refered to as 'bending stiffness') and yield points are made between each fixation technique.

RESULTS

Mean deflection-moment plots of all device type and constraint situations are presented in Figure 5.

DISCUSSION

It is most typical to judge internal fixation by measuring rigidity. It is also common to measure failure strength. Rayhack, et al., chose to measure only stress-strain relations and not address failure levels. While various studies tested to 'failure', they did not specifically define the point of failure. It is difficult to determine in an experimental (or clinical) situation what the point of failure is. Is it where the bone/fixation construct becomes completely unstable? We chose our endpoint to be the 'yield point'. That is the point at which the slope of the applied load versus angular deflection becomes nonlinear. We chose this because we feel it; 1) is more reproducible then the failure point (i.e. the point where the construct is completely unstable), 2) deals with applied applied closer to the range of forces seen in the hand clinically , and 3) helps to eliminate the differences seen in failure because of differing modes of failure (i.e. rod slip vs screw slip vs bone fracture).

Our results show bone fixation performance as judged by stiffness falling into two groups distinct from the strength of intact bone (controls). The various plates fall into one group and the various rods and K-wires compose the other. K-wires with tension bands approach the performance of plates. Similar groupings occur when using moment at yield as the fixation criterea.

More specifically, the five control specimens' stiffness and yield moment (but not yield angulation) were much greater than those of all plates, K-wires, and IM rods ($p < 0.05$). Plates provided greater than three times stiffer fixation than IM rods or simple K-wires ($p < 0.05$), with yield points well beyond most reported physiologic joint moments (14,15) but less than the stiffness of intact specimens ($p < 0.05$).

Comparing the various plates, it is seen that the stiffness of the large AO plates, 8 hole and 4hole microplates are essentially the same, while that of the small AO plate is much less ($p < 0.05$). The yield moments of the large AO plate and 8 hole microplate are greater than the the small AO plate ($p < 0.05$), which is greater than the yield moment for the four hole microplate ($p < 0.05$).

K-wires with tension band approach the stiffness profile of plates, but do not withstand the larger moments endured by plates. There is a great difference between the stiffness and angle at yield of K-wires with tension band and that of K-wires alone (p <

0.05). There is also a great difference between the stiffness and angle of the yield for K-wires with tension band and 4 and 8 IM rods ($p < 0.05$).

Simple cross K-wires and 8 IM rods provide approximately the same amount of fixation, while both provide statistically significant better fixation (stiffness and yield moment) than 4 IM rods. It appears that deformation would occur with these techniques with normal hand activity.

A simple clinical demonstration was performed in conjunction with this experiment. Three days and six days post closed IM rodding of a fresh fifth metacarpal shaft fracture in a 26 year old, examination under flouroscopy was performed. This exam was also performed after MC block to eliminate pain. X-rays were taken at maximum flexion and extension. It was seen under flouro (and shown in these x-rays) that there was no clinically observable motion at the fracture site and no change in the shape of the rods.

If in the experimental situation, the IM rods appear so weak, why do they perform adequately clinically as shown by Hall (16) and in the clinical demonstration noted previously? Perhaps the forces in the clinical situation are low compared to our experimental trials. Perhaps there are factors *in vivo*, such as the soft tissue or bony structures that tend to increase stability, especially for IM rodding.

Rush described the principles of three point fixation and intramedullary rodding by saying that success of fixation does not (necessarily) depend on bulk of the implants, but upon the implants own dynamic forces and the utilization- of the muscular forces of the extremity (17). Pankovich has shown that fracture fragments in human cadaver femurs fixed with flexible IM rods (Ender rods) could markedly angulate and rotate in relation to each other. However, on release of the deforming force, the fracture fragment returned to their original position (18).

We did attempt to mimic some *in vivo* soft tissue constraints by constraining the ends of the 4 and 8 IM rods to simulate the *in vivo* situation by preventing interface separation. Attempts were made to apply these constraints so as only to allow sliding of the bone ends in the direction of the applied load. For 8 IM rods, stiffness was increased, but this change was not as great as expected. Otherwise there were no statistically significant changes in results. This study could be augmented using stripped cadaver metacarpals and comparing to cadaver metacarpals with the soft tissues and joint structures intact, thus perhaps showing a greater difference in rigidity than our attempt at passive constraint.

CONCLUSIONS

Since there is no great difference seen in the fracture healing of plates , wires, or IM rods clinically, wires or rods are recommended (except in cases of severe fracture) due to their noninvasive qualities. This suggests that the mechanical environment around the healing metacarpal is not severe and/or the amount of rigidity and compression in the bony structures of the hand is large. Chao says there can be up to 190 Newtons of compression on the metacarpal joint during activity.

However, another point to consider in the use of IM rods is that of axial torques on the bone. Chao has reported that large axial moments can occur *in vivo*, and this can be imagined to be very bad for IM rod fixation seeing as it appears as IM rods merely align the bone halves and does not 'fix' them.

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Construct	Stiffness (Nm/deg)	n	Yield Point Moment (Nm)	n	Yield Point Angle (deg)	n	Failure Point Moment (Nm)	n	Failure Point Angle (deg)	n
Control	0.313	5	0.336	5	10.50	5	4.22	5	18.05	5
Large AO Plate	0.171	6	1.63	6	9.94	6	2.85	6	26.46	6
4 Hole Micro Plate	0.159	10	0.840	9	6.29	9	1.06	9	12.36	9
8 Hole Micro Plate	0.155	7	1.71	6	12.96	6	2.16	6	18.78	6
Small AO Plate	0.097	8	1.03	8	11.30	8	1.52	8	24.07	8
K-wires w/Tension Band	0.069	7	0.330	7	5.81	7	0.61	7	13.36	7
8 IM Rods Constrained	0.033	3	0.430	2	14.35	2	-	0	-	0
K-wires	0.025	8	0.460	8	18.17	8	0.63	8	33.15	8
8 IM Rods Unconstrained	0.022	6	0.400	4	17.61	4	1.14	4	66.02	4
4 IM Rods Constrained	0.016	11	0.18	5	10.12	5	-	0	-	0
4 IM Rods Unconstrained	0.014	9	0.240	6	19.40	6	0.78	4	66.50	

Significance levels (p; T-test) of differences between **Stiffness** values of the constructs.

ns : not significant (p > .05) na : not available < or ⋀ points to larger magnitude

	4-hole micro-plate	8-hole micro plate	Small AO plate	Large AO plate	K-wires	K-wires tension band	4 IM rods	8 IM rods (n=6)	Samp size n
Control	< .02	< .02	< .002	< .01	< .001	< .001	< .001	< .001	5
4-hole micro-plate	-	.ns	.na	.ns	< .001	< .001	< .001	< .001	6
8-hole micro plate		-	.ns	.ns	< .001	< .006	< .001	< .001	7
Small AO			-	⋀ .02	.na	< .05	.na	<.001	8
Large AO				-	< .001	< .001	< .001	< .001	6
K-wires					-	⋀ .001	< .001	.ns	8
K-wires tension band						-	< .001	< .001	7
4 IM rods							-	⋀ .001	9

Significance levels (p; T-test) of differences between **Yield Angle** values of the constructs.

ns : not significant (p > .05) na : not available < or ∧ points to larger magnitude

	4-hole micro-plate	8-hole micro plate	Small AO plate	Large AO plate	K-wires	K-wires tension band	4 IM rods	8 IM rods (n=6)	Samp size n
Control	< .04	.ns	.na	.ns	.ns	< .03	.ns	∧ .02	5
4-hole micro-plate	-	∧ .03	.na	.ns	∧ .02	.ns	∧ .03	∧ .002	5
8-hole micro plate		-	.ns	.ns	< .001	< .006	< .001	< .001	7
Small AO			-	∧ .02	.na	< .05	.na	<.001	8
Large AO				-	< .001	< .001	< .001	< .001	6
K-wires					-	∧ .001	< .001	.ns	8
K-wires tension band						-	< .001	< .001	7
4 IM rods							-	∧ .001	9