Biomechanical Comparison of Fixation Methods for First Metatarsophalangeal Joint Fusion

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1. Introduction

Fusion of the first metatarsophalangeal joint is a common procedure to correct severe hallux valgus deformities and severe arthritis. Stability of the hardware construct is critical, as successful fusion relies on limiting motion at the fusion site. The advent of locking plate technology has generated considerable interest in fusion surgery, despite a lack of biomechanical data to support their use. Although feasible, biomechanical studies in cadavers are often hampered by variability in bone density and the special care required to prevent dessication of the cadaver bones. To limit the influence of these shortcomings synthetic surrogates have been designed from CT data to mimic strength and fracture properties of healthy human bone, to provide a uniform platform for hardware construct testing.

2. Hypotheses

- First metatarsophalangeal joint fusion fixation with either a one-third tubular plate or with an X-type locking plate will demonstrate equivalent biomechanical integrity.

- Fixation with either plate construct will exhibit superior stiffness when compared to two crossed screws alone.

Figure 1. A custom fixture was used for cantilever testing of the first metatarsophalangeal joint fusion constructs.

3. Methods

Twenty-four identical synthetic metatarsals and phalanges were assigned to fixation with either crossed screws alone, one crossed screw with a 1/3 tubular plate, or one crossed screw with a X-type locking plate. The three groups of eight constructs were then subjected to a cyclic cantilever bending protocol from 1-100N, for 1000 cycles using an Instron materials testing machine (Fig. 1). Stiffness was defined as the slope of the force/displacement curve between 20 and 98 Newtons and was calculated for cycles 1, 10, 50, 100, 500, and 1000. Data were analyzed using ANOVA and pairwise Student-Neuman-Keuls tests when appropriate.

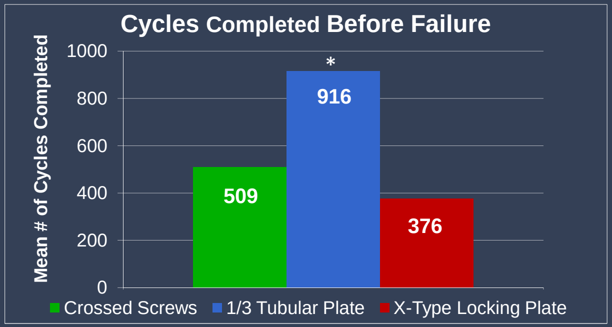

Figure 2: Mean cycles completed in each group. *=P<0.05

4. Results

Stiffness of the one-third tubular plate was 49 percent greater than the crossed screws at all cycles. When compared to the X-type locking plate, the one-third tubular plate was stiffer by an average of 25 percent, but only at cycles 50, 100, 500, and 1000. The only significant difference between the X-type plate and the crossed screws was at cycle 500, where the X-plate was 46 percent stiffer (Fig. 4).

The one-third tubular plate group completed 1.8 and 2.4 times the number of cycles prior to failure compared to the locking plate or crossed screws groups, respectively. No difference was detected in cycles to failure between the locking plate and the crossed screws groups (Fig. 2).

Figure 3. X-type locking plate specimen illustrating the typical mode of failure in this group: fracture through the screw tracts within the base of the proximal phalanx.

5. Conclusions

We hypothesized that the 1/3 tubular plate and X-type locking plate would be equivalent and that both would be superior to crossed screws alone. In contrast to these hypotheses, it was found that:

- The 1/3 tubular plate construct was stiffer than the two crossed screws and X-type locking plate constructs.
- The 1/3 tubular plate was more durable than the crossed screws and X-type locking plate.
- The crossed screws and X-type locking plate were approximately equivalent in stiffness and durability.

Stiffness of the fixation construct is important in reducing motion at the fusion site. Selection of the appropriate implant is important, because optimizing the stiffness of fixation has been shown to shorten healing times (1). In sheep tibia fractures, increased rigidity of an external fixator decreased healing time by increasing initial vascularization and promoting rapid bone regrowth at the fracture site (2). In this study, consistent failure of the X-type plate constructs occurred through the base of the proximal phalanx, possibly due to force concentration (Fig. 3). The present study provides the orthopaedic surgeon with valuable biomechanical data that may be used for selecting an optimal fixation method for first metatarsophalangeal fusion; however clinical trials are needed before final recommendations are rendered.

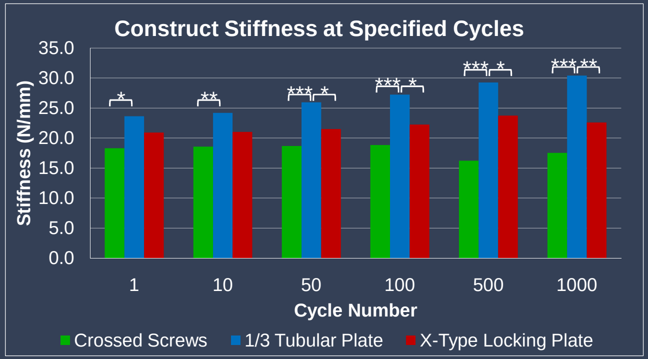

Figure 4: Mean construct stiffness compared at each cycle.
*=P<0.05, **=P<0.01, ***=P<0.001

6. References

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2. Lienau, J, Schell, H, Duda, GN, et al. 2005. Initial vascularization and tissue differentiation are influenced by fixation stability. J Orthop Res 23: 639-645.

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