Peg-in-Hole, End-to-End, and V Arthrodesis

A Comparison of Digital Stabilization in Fresh Cadaveric Specimens

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The proximal interphalangeal joint arthrodesis is frequently performed to correct hammer toe deformities. This study was conducted to compare the inherent stability of the three proximal interphalangeal joint arthrodeses—peg-in-hole, end-to-end, and V constructs—in the sagittal plane by means of load-to-failure testing of 30 fresh-frozen cadaveric specimens fixated with a 0.045 Kirschner wire. The peg-in-hole construct was associated with significantly higher peak loads at failure compared with the other two procedures. Furthermore, the peg-in-hole construct had significantly higher stiffness values as compared with the V procedure. This study thus provides evidence that the peg-in-hole procedure is the most biomechanically stable surgical construct for proximal interphalangeal joint fusions under sagittal plane loading.
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Three proximal interphalangeal joint arthrodeses are commonly performed by foot and ankle surgeons to correct hammer toe deformities[1]; these are described by their geometric constructs as peg-in-hole,[2] end-to-end,[3] and V[4] techniques. The osseous stability associated with digital stabilization, as evidenced by the ability to withstand loads imposed on the fusion site postoperatively, may be procedure-dependent. During locomotion, the vertical component of the ground-reaction force vector is larger than the shear components,[5] and the proximal interphalangeal joint axes are predominantly coincident with the sagittal plane.[6] Hence the primary direction of destabilizing load is postulated to be in extension. These postoperative destabilizing forces can occur with premature mobilization of the digit, early postoperative ambulation, and early return to footwear. Any of these clinical factors may biomechanically promote fusion-site disruption.[4]

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Literature Review

In 1996, Harmonson and Harkless[7] reviewed proximal interphalangeal joint arthrodeses from 17 articles spanning 1910 to 1996. The authors reported several complications, including metatarsalgia, residual pain, limited range of motion of the metatarsophalangeal joint, lack of toe purchase, transverse plane deviation of the digit, pin tract infections, distal interphalangeal joint flexion contracture, residual edema, numbness of the digit, scar contracture, and footwear restrictions. However, the majority of these 17 articles report only subjective observations of an individual proximal interphalangeal joint arthrodesis. No study to date has objectively assessed or compared the structural properties of these surgical procedures. The authors anticipate that postoperative complications will decrease if an optimal procedure can be identified.

The purpose of this investigation was to objectively measure the sagittal plane stability in the immediate postoperative state of the peg-in-hole, end-to-end, and V arthrodeses. Fresh cadaveric proximal interphalangeal joint arthrodeses (peg-in-hole, end-to-end, or V) were loaded to failure in a structural testing machine. These arthrodeses were quantitatively assessed according to their structural properties (stiffness, peak load at failure, and displacement at failure) to determine which method was inherently the most stable in the sagittal plane.

Materials and Methods

Thirty fresh-frozen cadaveric proximal and middle phalanges were carefully dissected from all soft tissues to avoid scoring the bone surface, which could induce stress risers. Cadaveric digits 2, 3, and 4 were randomly assigned to one of three arthrodesis procedures, resulting in ten specimens per procedure. The test jig was composed of two metal cubes mounted on Plexiglas (Röhm, Darmstadt, Germany) sleds (Fig. 1). A 0.045 alignment Kirschner wire was inserted into the medullary canal of each phalanx. The free end of the Kirschner wire was then placed through a prefabricated cannulated screw located in the center of the metal cube (1 × 1 × 0.5 inch). This ensured that the phalanx was centered in the cube prior to back-filling with polymethyl methacrylate (PMMA). The proximal phalanx base and middle phalanx head were each potted in PMMA within their respective metal cubes in the test jig while being held in a vertical orientation. Once the PMMA had cured, the alignment Kirschner wire was removed from the phalanx and the potted bone was removed from the cube. Each arthrodesis was then performed in a repeatable fashion with anatomical landmarks used to designate the amount of bone resection. Fixation was achieved with a standard 0.045 Kirschner wire inserted through the middle phalanx head to the proximal phalanx base via the previously described guide holes. The Kirschner wire was sectioned flush with the base of the proximal phalanx. Although in clinical practice the Kirschner wire traverses both the distal interphalangeal joint and the proximal interphalangeal joint, the investigators chose to exclude the distal phalanx and isolate the proximal interphalangeal joint in order to improve the control and repeatability of the test construct. Care was taken not to extend the Kirschner wire past the phalanx into the PMMA, which would increase stiffness beyond physiologic levels.

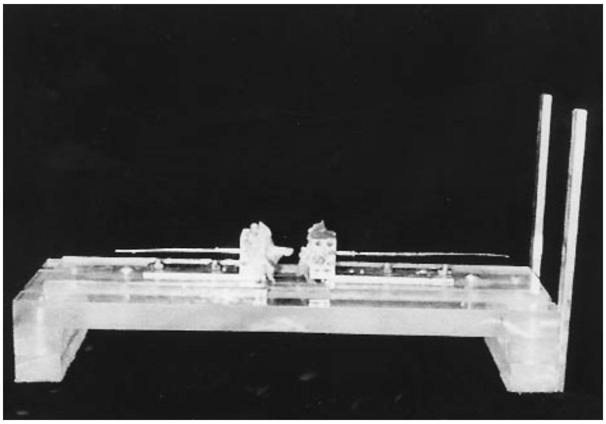

Figure 1. The test jig had two purposes: the vertical orientation of the jig was used for back-filling with polymethyl methacrylate (PMMA), and the horizontal orientation was used for insertion of the Kirschner wire after the bone resection.

After each procedure was completed, the specimens were loaded in an Instron 4201 (Instron Corp, Canton, Massachusetts) structural testing machine. With the use of Series IX software, the Instron was under General Purpose Instrumentation Bus (GPIB) control of a 66-MHz 486 microcomputer. The cube containing the middle phalanx was mechanically grounded to an (x,y) adjustable mounting stage within the Instron. The cube containing the proximal phalanx was attached to the load cell within the crosshead of the Instron and loaded to failure in tension at a rate of 500 mm/min (Figs. 2 and 3). Load-*versus*-displacement curves were generated from cantilever loading of each specimen (Fig. 4). The following structural parameters were calculated:

1) Y_m = Young's Modulus: the slope of the load-*versus*-displacement curve in the elastic region, also known as stiffness

2) F_{max} = the maximum/peak load at failure

3) d_{max} = the maximum displacement at failure

The structural property parameters were analyzed with a factorial analysis of variance (ANOVA) model by means of StatView 5.0 software (SAS Institute,

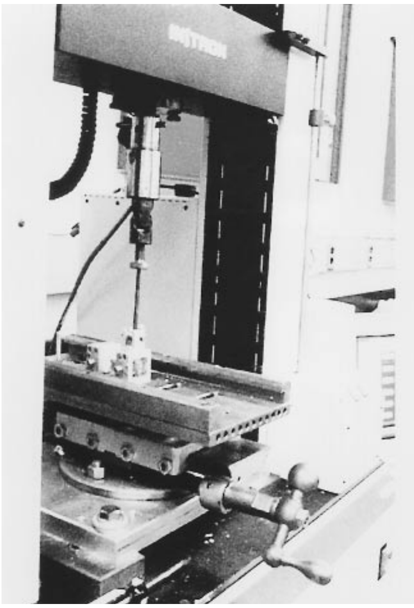

Figure 2. The Instron Materials Testing Machine (Model 4201) with the specimens within metal cubes mounted for loading.

Cary, North Carolina) on a Macintosh 250-MHz 8600 Power PC microcomputer. Fisher's Protected Least Significant Difference (PLSD) *post hoc* pairwise comparisons were performed to examine those parameters that yielded a statistically significant difference in the factorial ANOVA.

Results

The following mechanical behavior was observed with the end-to-end constructs in the Instron machine. In eight of ten trials, the proximal phalanx gradually distracted along the Kirschner wire initially, and as greater load was applied, the middle phalanx was completely displaced from the Kirschner wire. Similarly, the proximal phalanges of the V constructs gradually distracted along the Kirschner wire; however, half of the Kirschner wires remained in the proximal phalanx. The peg-in-hole construct failed more abruptly than was anticipated. The peg-in-hole procedure failed because of fracture of either the peg, the dorsal cortex of the middle phalanx, or both.

A factorial ANOVA model revealed a statistically significant difference in peak load at failure across the arthrodesis procedures ($P < .0001$). *Post hoc* comparisons with Fisher's PLSD test demonstrated a statistically significant difference between the peg-in-hole (103.7 ± 51.2 N) and end-to-end (44.0 ± 28.1 N) groups ($P = .0007$) and between the peg-in-hole and V (23.9 ± 15.0 N) groups ($P < .0001$), as shown in Figure 5. Similarly, a factorial ANOVA model revealed a statistically significant difference in stiffness across the arthrodesis procedures ($P = .004$). *Post hoc* comparisons with Fisher's PLSD test demonstrated a statistically significant difference between the end-to-end (17.3 ± 10.0 N/mm) and V (7.1 ± 4.2 N/mm) groups ($P = .045$) and between the peg-in-hole (25.1 ± 15.4 N/mm) and V groups ($P = .0009$). Finally, as summarized in Table 1, a factorial ANOVA model revealed no statistically significant difference in displacement across the arthrodesis procedures ($P = .08$).

Discussion

The common mode of failure in the end-to-end group was distraction of the middle phalanx along the Kirschner wire. Similarly, Kimmel and Garrow[8]

Figure 3. Load to failure of a specimen: each procedure demonstrated a unique mechanical behavior.

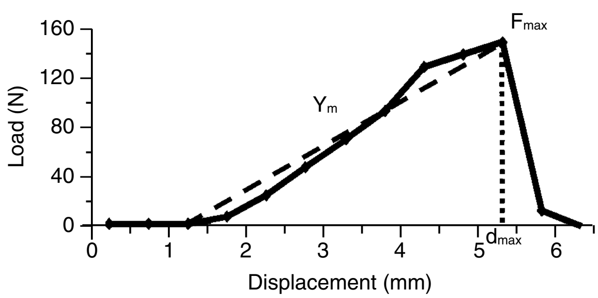

Figure 4. Load-*versus*-displacement curve generated from the load to failure of a peg-in-hole specimen. (See text for explanation of abbreviations.)

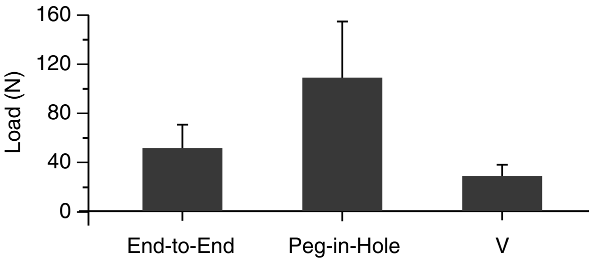

Figure 5. Average maximum load at failure for each arthrodesis group with SD bars.

found that the middle phalanx could be displaced along the Kirschner wire away from the fusion site *in vivo*. The peg-in-hole group exhibited distraction along the Kirschner wire and fracture of the peg or the dorsal cortex of the middle phalanx. Schlefman et al[2] stated that fracture of the middle phalanx cortex could occur *in vivo* and may result in nonunion or malunion. An equal number of proximal and middle phalanges demonstrated distraction along the Kirschner wire within the V group. Pichney et al[4] reported a case of delayed union that they attributed to mild distraction along the Kirschner wire in their *in vivo* study.

As the results demonstrate, the peg-in-hole procedure is structurally stronger (peak load at failure) in sagittal plane loading when compared with the end-to-end and V procedures. The peg-in-hole construct is stiffer than the V procedure but not the end-to-end procedure. Schlefman et al[2] suggested that the peg-in-hole procedure is likely to have superior structural stability owing to its geometric construct, which affords a greater surface area of bone contact. No studies have correlated the amount of intraoperative bone-to-bone contact area with the percentage of postoperative unions in the proximal interphalangeal joint arthrodesis.

Four limitations of this study are apparent: 1) The tension band effects afforded by flexor tendons and plantar soft tissues are neglected in the structural testing protocol. 2) There was a failure to examine the shear components during structural testing as potential correlates to distal distraction in the anteroposterior direction and the angular deformity in the transverse plane. 3) A definitive clinical study that statistically compares the relative complications of each procedure has not been performed. 4) Only the immediate postoperative state can be simulated in cadaveric preparations, which obviates comparison with the stability produced by physiologic healing.

Conclusion

The peg-in-hole arthrodesis offers superior strength (peak load at failure) when compared with the end-to-end and V arthrodeses. The study used a simple osseous preparation from fresh-frozen cadavers. Because capsular, ligamentous, and tendinous structures were not included in the experimental construct, it is premature to conclude that the peg-in-hole procedure should reduce postoperative complications associated with instability. A retrospective or prospective *in vivo* investigation of the clinical incidence of pedal complications for each arthrodesis is required to correlate with the findings of this study.

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Table 1. Mean (±SD) Structural Property Values

Property	End-to-End	Peg-in-Hole	V	*P* Value[a]
Load at failure (N)	44.0 ± 28.1[b]	103.7 ± 51.2[b, c]	23.9 ± 15.0[c]	<.0001
Stiffness (N/mm)	17.3 ± 10.0[d]	25.1 ± 15.4[c]	7.1 ± 4.2[c, d]	.004
Displacement (mm)	3.0 ± 1.6	5.3 ± 3.0	3.9 ± 1.6	.08

[a] Calculated from a factorial ANOVA.
[b] Fisher's PLSD *post hoc* comparisons yielded significant differences ($P < .05$) between peg-in-hole and end-to-end.
[c] Fisher's PLSD *post hoc* comparisons yielded significant differences ($P < .05$) between peg-in-hole and V.
[d] Fisher's PLSD *post hoc* comparisons yielded significant differences ($P < .05$) between end-to-end and V.

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