Comparison of Initial Compression of the Medial, Lateral, and Posterior Screws in an Ankle Fusion Construct

Clifford L. Jeng, MD; Sebastian F. Baumbach, MD; John Campbell, MD; Bindu Kalesan, MSc, MPH; Mark S. Myerson, MD
Baltimore, MD

ABSTRACT

Background: One of the requirements for successful ankle arthrodesis is adequate compression by the fixation across the fusion surfaces. A common screw construct for ankle fusion is three crossed screws from proximal-to-distal. Because the screws are inserted nearly orthogonal to each other, it is possible minimal additional compression is obtainable once the first screw is inserted. The aim of this study was to determine which of the three screws gave the greatest initial compression and theoretically should be inserted first.

Materials and Methods: Seventeen cadaver limbs were dissected to expose the anterior and posterior aspects of the tibiotalar joint. Three Fuji film templates were created for each ankle joint with a hole to accommodate a 7.0-mm cannulated screw. Each film was tested with a single medial, lateral, or posterior screw. The Fuji films were then analyzed for contact area, percent contact area, and pressure.

Results: There was no difference in the total contact area, percent contact area, or pressure generated between the three screws. The mean contact area for all screws was 11% of the joint surface. All three screws had greater contact area and percent contact area over the anterior half of the ankle joint. Conclusion: The medial, lateral, and posterior screws were equivalent with respect to contact area, percent contact area, and pressure generated across the tibiotalar joint. All three screws had greater contact area over the anterior half of the joint. Only 11% of the tibiotalar joint surface came in contact following the insertion of a single partially threaded screw. Clinical Relevance: In a neutrally aligned ankle arthrodesis the order of screw insertion does not affect the amount of compression ultimately achieved at the fusion site.

Key Words: Ankle Fusion; Internal Fixation; Arthrodesis; Contact Area; Pressure

INTRODUCTION

The requirements for successful ankle arthrodesis include: 1) optimal alignment of the fusion, 2) apposition of viable, vascularized bony surfaces, 3) stable fixation, and 4) compression across the fusion surfaces.5,6 There are several studies in the literature that have investigated which surgical technique provides optimal initial stability and compression across the tibio-talar fusion. One of the more common techniques used for ankle fusion consists of preparing the joint surfaces while maintaining the native contours of the distal tibia and talar dome. The joint is then compressed together using a standard three-screw configuration.

Holt et al.9 described this screw configuration, inserting a screw from the medial malleolus into the lateral talar body, a second screw from the lateral malleolus into the medial talar body, and a third screw from the posterior malleolus into the talar neck (Figure 1). The authors believed that the posterior screw was the most important because it resisted flexion and extension, pulled the ankle out of equinus, translated the talus posteriorly, and compressed the joint surfaces.

From a biomechanical standpoint, minimal additional compression across the tibio-talar joint should be attainable after the first screw is tightened because the three screws are nearly orthogonal to each other. Therefore, it would be advantageous to know which of the three screws provides the highest initial compression so that it could routinely be inserted first. The purpose of the present study was to determine which screw generates the greatest contact area, percent contact area, and pressure using a cadaver ankle fusion model.

MATERIALS AND METHODS

Eighteen fresh frozen, paired lower limbs harvested at the below-knee level were obtained from the Maryland State...
Anatomy Board. There were 12 female and six male legs, with an average age of 83 ± 14 years. All cadaveric legs were prepared using the same procedure. A standard midline anterior ankle approach was performed to expose the anterior aspect of the tibiotalar joint. A second posterior midline incision was also used to gain access to the posterior ankle joint by excising the Achilles tendon and the posterior joint capsule. The cartilage was left intact for this experiment in order to minimize variability in the congruity and surface area between the tibia and the talus. The surface area of the distal tibial articular surface was measured and three templates made of cellophane tape, one for each screw, were created from these measurements. The templates were cut so that they ended before the curvature where the distal plafond meets the medial malleolus to prevent wrinkling of the pressure sensitive film. The articular surfaces of the medial and lateral gutters were not tested in this study.

Screw insertion and pressure mapping

For each cadaver specimen, the first guidewire was inserted via a small skin incision using fluoroscopic guidance, and the appropriate screw length was measured with a cannulated depth gauge. The guidewire was then over-drilled with a 4.0-mm cannulated drill and removed. A lamina spreader was used to distract the joint and the prepared template was inserted anteriorly. In order to allow reproducible positioning of the pressure sensitive film, corresponding markings were made on the anterior tibial margin and the template. The guidewire was reinserted, assuring penetration of the template. The template was then removed and a Fuji Prescale Pressure Measuring Film (Super Low Pressure Type) was cut to match the shape of the cellophane tape template, leaving a standardized hole of 8 mm x 8 mm centered on the point of guide pin penetration. The film was then carefully sealed with a plastic adhesive covering (Tegaderm, 3M, St. Paul, MN). This was done to prevent moisture from contacting the pressure sensitive film, which can affect the color distribution and produce inaccurate results.

The Fuji Film was then carefully inserted into the tibiotalar joint and aligned. Wrinkles in the film were avoided to prevent potential artifact. The guide pin was reinserted and a 7.0-mm partially threaded stainless steel cannulated screw (Smith & Nephew, Memphis, TN) was inserted over the guide pin. No washers were used. The initial experimental protocol included the use of a digital torque screwdriver to tighten each screw with a consistent amount of torque. However, due to the age-related osteoporosis of the cadaveric ankles reliable measurements were unable to be obtained. Therefore the screws were tightened until either stripping of the screw threads was felt or until the point of the screw head’s largest diameter penetrated the outer cortex of the tibia. Because of the inherent nature of Fuji film, the peak pressure is recorded regardless of when it occurs during screw insertion. In this manner, the maximum compression achieved by each screw was measured. Both the screw and the pressure sensitive film were removed carefully. The two layers of film were separated immediately and the receptor sheet cleaned. For subsequent analysis, the Fuji film was digitized using a 10.1-megapixel digital camera and a 100-mm macro lens (Nikon).

Medial, lateral, and posterior screws were inserted separately on each cadaver leg in order to compare contact area and pressure across the tibiotalar joint (Figures 1A and 1B). To minimize bias, the order of screw insertion was varied following a standardized protocol. There were six possible permutations of the screw insertion order. Each ankle was
sequentially assigned one of these screw insertion orders and the pattern was repeated until all 18 ankles had been assigned. The guide wire for the previous screw was reinserted prior to passing the subsequent guide pin to ensure consistent alignment of the talus on the tibia between trials. The guide pins for the medial and lateral screws were inserted at 30 degrees to the longitudinal axis of the tibia with the two pins crossing above the fusion site. The guide pin for the posterior screw was inserted posterolaterally on the tibia through the posterior malleolus and directed into the center of the talar head. The ankle was fused in neutral dorsiflexion, with 5 to 10 degrees of external rotation and 5 degrees hindfoot valgus.

Analysis

The pressure sensitive film was analyzed using an image processing program (ImageJ 1.39, National Institutes of Health, Bethesda, MD). The background was adjusted to 118 graylevel. The contact area was divided by the total area of the Fuji film to calculate the percentage of the tibiotalar surface which was in contact after screw insertion (Percent Contact Area). This was evaluated by transforming the pressure sensitive film into a binary image using a histogram based tool integrated in ImageJ. For pressure measurements, the images were analyzed against a calibration curve that had been constructed by using a range of known pressures on the same Fuji film to obtain the corresponding grayscale values. Contact area, percent contact area, and pressure were calculated for each Fuji film and the data was statistically analyzed for differences between the three screw positions.

The Fuji film samples were then divided into posteromedial, anteromedial, anterolateral, and posterolateral quadrants, as well as anterior and posterior halves, medial and lateral halves (Figure 2). The data was then reanalyzed, looking for where each screw applied its greatest effect (Figure 3).

RESULTS

Testing 17 ankles resulted in 47 Fuji Film templates (24 left, 23 right). Four films could not be evaluated due to moisture contamination. One ankle specimen that was used for a pilot study to establish the experimental protocol was not included in the data analysis.

There was no significant difference in either the total contact area or percent contact area between the three screws.
The mean percent contact area for all screw positions was 11% (range, 5% to 22%). There was also no significant difference in the total pressure created by any of the three screws (Table 1). A post hoc power analysis was performed to determine if the lack of statistical significance was due to an inadequate sample size. It was determined that 110 cadaver legs per screw orientation (total, 330 legs) would have to be tested to elicit a significant difference. The power analysis indicates that even if a difference was found, it would most likely be clinically insignificant.

The analysis of the halves and quadrants of the Fuji film samples are summarized in Tables 2 through 4. The medial, lateral, and posterior screws all preferentially concentrated contact area and percent contact area over the anterior half of the ankle joint compared to the posterior half. There was no significant difference in pressure between the anterior and posterior halves for any screw. Analysis of the medial and lateral halves of the ankle joint showed no differences in contact area or pressure for any screw. Finally, while the medial screw had no preference for any quadrant, the lateral screw concentrated its contact area and percent contact area over the anterolateral quadrant and the posterior screw concentrated its contact area and percent contact area over the anteromedial and anterolateral quadrants. The quadrant analysis showed no significant difference in pressure for any screw.

**DISCUSSION**

The results of the present study show that the medial, lateral, and posterior screws in a standard three-screw ankle fusion construct are equivalent with respect to the total contact area, percent contact area, and pressure that each generates. Therefore, no recommendation can be made as to which screw should be routinely inserted first to gain the maximal initial compression. What is clear is that regardless of screw position, very little contact surface area is created during insertion of a single partially threaded screw across the ankle joint. An average of only 11% of the tibiotalar joint surface comes into contact with insertion of a single screw. Future research examining how much additional contact area is attainable following the insertion of each additional screw would be of further interest.

Further analysis from this study shows that the medial, lateral, and posterior screws preferentially generate greater contact area and percent contact area over the anterior half of the ankle joint compared to the posterior half. This

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**Table 1: Comparison of Medial, Lateral, and Posterior Ankle Fusion Screws**

<table>
<thead>
<tr>
<th></th>
<th>Medial Screw</th>
<th>Lateral Screw</th>
<th>Posterior Screw</th>
<th>ANOVA p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact Area (cm²)</td>
<td>1.1 ± 0.3</td>
<td>1.0 ± 0.3</td>
<td>0.9 ± 0.5</td>
<td>NS</td>
</tr>
<tr>
<td>Percent Contact Area (%)</td>
<td>11.9 ± 2.9</td>
<td>10.6 ± 3.8</td>
<td>10.3 ± 5.1</td>
<td>NS</td>
</tr>
<tr>
<td>Pressure (Mpa)</td>
<td>1.1 ± 0.2</td>
<td>1.1 ± 0.3</td>
<td>1.2 ± 0.2</td>
<td>NS</td>
</tr>
</tbody>
</table>

Data reported as average ± SD. n = 17 ankles.

**Table 2: Comparison of Anterior and Posterior Halves of Ankle Joint**

<table>
<thead>
<tr>
<th></th>
<th>Anterior Half</th>
<th>Posterior Half</th>
<th>ANOVA p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact Area (cm²)</td>
<td>Medial screw</td>
<td>0.7 ± 0.4</td>
<td>0.4 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>Lateral screw</td>
<td>0.7 ± 0.2</td>
<td>0.3 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>Posterior screw</td>
<td>0.7 ± 0.4</td>
<td>0.3 ± 0.2</td>
</tr>
<tr>
<td>Percent Contact Area (%)</td>
<td>Medial screw</td>
<td>15.3 ± 8.3</td>
<td>8.6 ± 6.0</td>
</tr>
<tr>
<td></td>
<td>Lateral screw</td>
<td>14.2 ± 5.2</td>
<td>7.0 ± 5.8</td>
</tr>
<tr>
<td></td>
<td>Posterior screw</td>
<td>14.9 ± 10.0</td>
<td>5.8 ± 4.4</td>
</tr>
<tr>
<td>Pressure (Mpa)</td>
<td>Medial screw</td>
<td>1.08 ± 0.24</td>
<td>1.05 ± 0.20</td>
</tr>
<tr>
<td></td>
<td>Lateral screw</td>
<td>1.09 ± 0.26</td>
<td>1.00 ± 0.20</td>
</tr>
<tr>
<td></td>
<td>Posterior screw</td>
<td>1.18 ± 0.24</td>
<td>1.11 ± 0.21</td>
</tr>
</tbody>
</table>

Data reported as average ± SD. n = 17 ankles.
knowledge may be useful intraoperatively when the surgeon is trying to correct deformity or manage bony deficiencies. It is of interest to note that in this model the ankle was fused in situ, i.e. no deformity was present, and no translation or angular correction was attempted. This is not the situation in many clinical cases, however, where multiplanar angulation, translation or deformity may be present. In such cases, it may be advantageous to insert a particular screw first. For example, with valgus tibiotalar deformity, one may wish to commence with the medial screw following reduction of the joint with a bone reduction clamp. The converse may apply to a varus ankle deformity, and in the presence of anterior translation of the joint, commencing with insertion of the posterior screw may be preferable. As noted above however, we can not make a definitive recommendation for the order of screw insertion in a planar joint.

Numerous studies have investigated the optimal fixation technique for ankle arthrodesis. These have focused on the number of screws to use and the optimal screw orientation. Friedman et al. in a cadaver study using flat bony cuts showed that two crossed screws inserted proximally-to-distal provided better resistance to eversion and dorsiflexion as well as greater torsional stability than two distal-to-proximal screws which were parallel. The authors did note that the two parallel screws were more rigid during plantarflexion and inversion testing. Vazquez et al. published two articles studying ankle fusion constructs using finite element analysis. The authors found that three screws were more stable than two screws. They also showed that in a three screw construct, an anterior screw was better at resisting torsion, whereas a posterior screw was better at resisting dorsiflexion. Finally, they determined that the optimal screw orientation when fixing an ankle fusion with two proximal to distal crossed screws is at an angle 30 degrees to the tibial shaft axis with the two screws crossing above the level of the ankle joint.
Ogilvie-Harris et al. performed a similar study to the current one using a cadaver model with anterior, medial, and lateral screws and Fuji film. The authors found that the three-screw construct gave greater compression than a two-screw construct (medial and lateral only). They also showed that the lateral screw had significantly greater compression than the other two screws. However, their lateral screw was inserted through the fibula and the joints were prepared using flat cuts.5

This study does have obvious limitations. As with all cadaveric studies, direct correlation with in vivo fixation techniques may be difficult due to the age of the specimens. With a mean age of 85 years, the cadaver specimens were older than the average age of patients undergoing ankle fusion and therefore the bones likely were more osteoporotic. However, this would likely not affect the relative compression strength of the screws compared to each other within the same cadaver ankle. Similar to other experimental fusion models in the literature, we left the cartilage surfaces intact to optimize congruity.1,2,11,12 In the normal clinical situation, the cartilage is denuded and the underlying bone is either buried or feathered. However, such joint preparation could introduce uncontrolled variability to the experimental model, compromising congruity and affecting the reproducibility of contact area and pressure measurements. Finally, each screw was tested individually rather than measuring the cumulative joint compression generated by all three screws. The aim of this study was to determine which of the three screws provided the greatest initial compression. A future study where the screws are placed in combination would be useful in determining how much additional compression the second or third orthogonal screw could generate after the initial screw was inserted.

REFERENCES


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