FOOT & ANKLE INTERNATIONAL

Biomechanical Comparison of Ankle Arthrodesis Techniques: Crossed Screws vs. Blade Plate

Scott Nasson, M.D.; Charles Shuff, M.D.; David Palmer, M.D.; John Owen, B.S.; Jennifer Wayne, Ph.D.; James Carr, M.D.; Robert Adelaar, M.D.; David May, M.D.
Richmond, VA

ABSTRACT

Many different techniques for ankle arthrodesis have been described. Experience at our institution with crossed screws internal fixation has not met the 90+% union rate reported in the literature. A compression blade plate is one technique for ankle arthrodesis which has not been evaluated biomechanically. A biomechanical study comparing two groups of sawbone ankle fusion constructs fixed with crossed screws and compression blade plates was performed in order to evaluate the stiffness and rigidity of these two arthrodesis techniques.

The crossed screws construct demonstrated superior stiffness during dorsiflexion ($p < 0.001$) and valgus ($p < 0.001$) loading. The two constructs were found to have equal strength in resisting plantarflexion, varus and torsional loads although there was a trend for greater resistance by the crossed screws construct. These findings lend biomechanical support to the use of crossed screws for tibiotalar arthrodesis.

INTRODUCTION

In performing an ankle arthrodesis, the advantages of internal fixation techniques over external fixation include ease of placement, patient convenience, reduced rates of complications (such as non-union and infection), and neutralization of biomechanical forces. Dennis et al. reported clinical success with internal compression ankle arthrodesis using two crossed cancellous screws through an anterolateral approach. Union was achieved in 94% of cases.[4] Moeckel et al. reported a series of two screws placed from the anteromedial and anterolateral aspect of the tibia into the body of the talus, with a 97% union rate.[13] Mann et al. used two screws in parallel, both applied from the lateral talar process, and had similar success (94% union).[11] Thordarson et al. investigated the biomechanical properties of cadaver ankles fused with crossed screws augmented with fibular strut graft and found that the strut graft provided additional stability.[19]

Plate fixation for ankle fusion has its share of proponents. Union has been reported at 94% to 100%.[2,16,17,19]

There has been concern that screw fixation by parallel or crossed construct may not be giving a greater than 90% fusion rate as reported in the literature.[4,11,13] The objective of our laboratory study was to provide the orthopedic surgeon with data on the type and method of fixation which will provide the highest stability in ankle arthrodesis models with no severe bone loss or deformity. We proceeded with the biomechanical portion of the study based on our hypothesis that the 90° angled compression blade plate provides equivalent or superior fixation to crossed cancellous screws. To achieve this we compared the biomechanical properties of these two fixation methods in a simulated ankle model with uniform material properties.

MATERIALS AND METHODS

We modeled our experiment after the Friedman et al. study in which the bending stiffness and torsional rigidity of ankles fused with crossed versus parallel screws were compared. Their conclusion was that the crossed screws construct provided superior strength against forces of dorsiflexion, valgus, internal and external rotation.[6]

Eight, left urethane foam specimens (Sawbones, Pacific Research Laboratory, Seattle, Washington), consisting of the distal one third of the tibia and the entire talus, underwent standard planar cuts to simulate conditions of arthrodesis. Four millimeters of the talar dome and six millimeters of the distal tibial plafond (including the medial malleolus) were removed using an oscillating saw. Two groups, each consisting of four specimens, were then created for the respective crossed screws and

Corresponding Author:
Scott Nasson, M.D.,
Orthopedic Research Laboratory
Departments of Biomedical Engineering and Orthopedic Surgery
Virginia Commonwealth University
1112 East Clay Street
325 McGuire Hall Annex
Box 980694
Richmond, Virginia 23298
Phone (804) 378-5436
Fax (804) 828-4454
Email slnasson@prodigy.net

blade plate techniques. The same author (CS) performed all phases of the ankle fusion process.

Crossed Cannulated Screw Arthrodesis

A guide pin, measuring 2.5 mm in diameter, was placed proximal to distal through the medial tibial metaphysis starting two centimeters proximal to the arthrodesis site and 7.5 mm anterior to the medial sagittal axis. Similarly, a second guide pin was placed through the lateral tibial metaphysis 7.5 mm posterior to the lateral sagittal axis. Both pins were placed 60° vertical from the horizontal plane and were directed without frontal plane angulation. Using a 5.0 mm, cannulated drill bit, respective screw holes were placed over these pins. Proximal countersinking was undertaken to ensure compression at the arthrodesis site. Placement of two partially threaded, self-tapping, 6.5 mm cannulated cancellous screws (DePuy ACE, Warsaw, Indiana) were then placed over the guide pins, through its respective tibial metaphysis and into the talus. Both the medial and lateral screws measured 50 mm in length (Fig. 1).

Blade Plate Arthrodesis

For placement of the lateral plate, the anterior process of the fibular recess was removed. A partially threaded guide pin was then placed distal to proximal through the specimen to provide initial stabilization and allow for accurate pre-fixation measurement of the blade plate. The 40 mm six-hole titanium limited contact dynamic compression blade plate (Synthes, Paoli, Pennsylvania) was secured against the lateral side of the specimen with the blade rotated 180° from its anticipated final position. This assured the correct starting position for the talar guide pin and subsequent blade fixation. The talar guide pin was then placed laterally through the construct 1.0 cm distal to the arthrodesis site. The initial guide pin was then removed and our attention focused on the talus.

The accompanying drill guide was placed over the talar wire and three 4.5 mm holes were placed (lateral to medial) in the talus to allow for smooth placement of the blade portion. The blade portion was carefully tapped through the guide holes without complication. The plate section was placed against the anterolateral surface of the tibia and secured with a bone clamp.

The lateral aspect of these blade plates provided five holes for screw purchase. The proximal three holes allow dynamic compression, while the distal two are neutrally oriented. Following strict AO technique, we used the standard DCP drill guide to fill all of the holes with 4.5 mm fully threaded cortical screws. The distal hole (talar) was filled with a cortical lag screw (4.5 mm) crossing from talus to tibia and angled 45° to the arthrodesis site (Fig. 2).

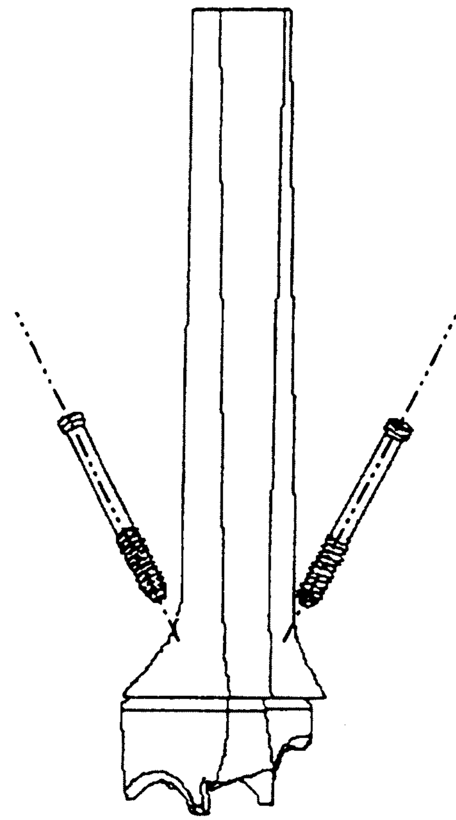

Fig. 1: Schematic representation of specimen fixation using the crossed screws technique.

Biomechanical Testing

Keeping the arthrodesis site parallel to the horizontal plane, all specimens were then potted in a polyvinyl chloride (pvc) casing using dental cement. In order to eliminate the potential for cement/plate/bone interaction that would have altered our results, a small amount of moulding clay was applied over the end of the cortical margins of the talus to prevent intrusion of dental cement into the blade/bone interface. However, the amount of moulding clay used was too small and its consistency too malleable to alter the fixation of the specimens. The proximal end of the tibia was similarly potted, thereby leaving 12 cm of exposed specimen (Figs. 1 and 2).

Rotation and bending forces were then applied using a servo-hydraulic materials testing machine (Instron, Canton, Massachusetts). Rotation was performed in both internal and external directions at a rate of 0.5°/s and was arbitrarily standardized initially at 2.5°. Subsequent increases in degrees of rotation to achieve a peak torque of 5N·m for each direction was determined by review of the immediately preceding peak rotational results (Fig. 3).

Bending moments were created by applying load 12.0 cm from the arthrodesis site and were performed

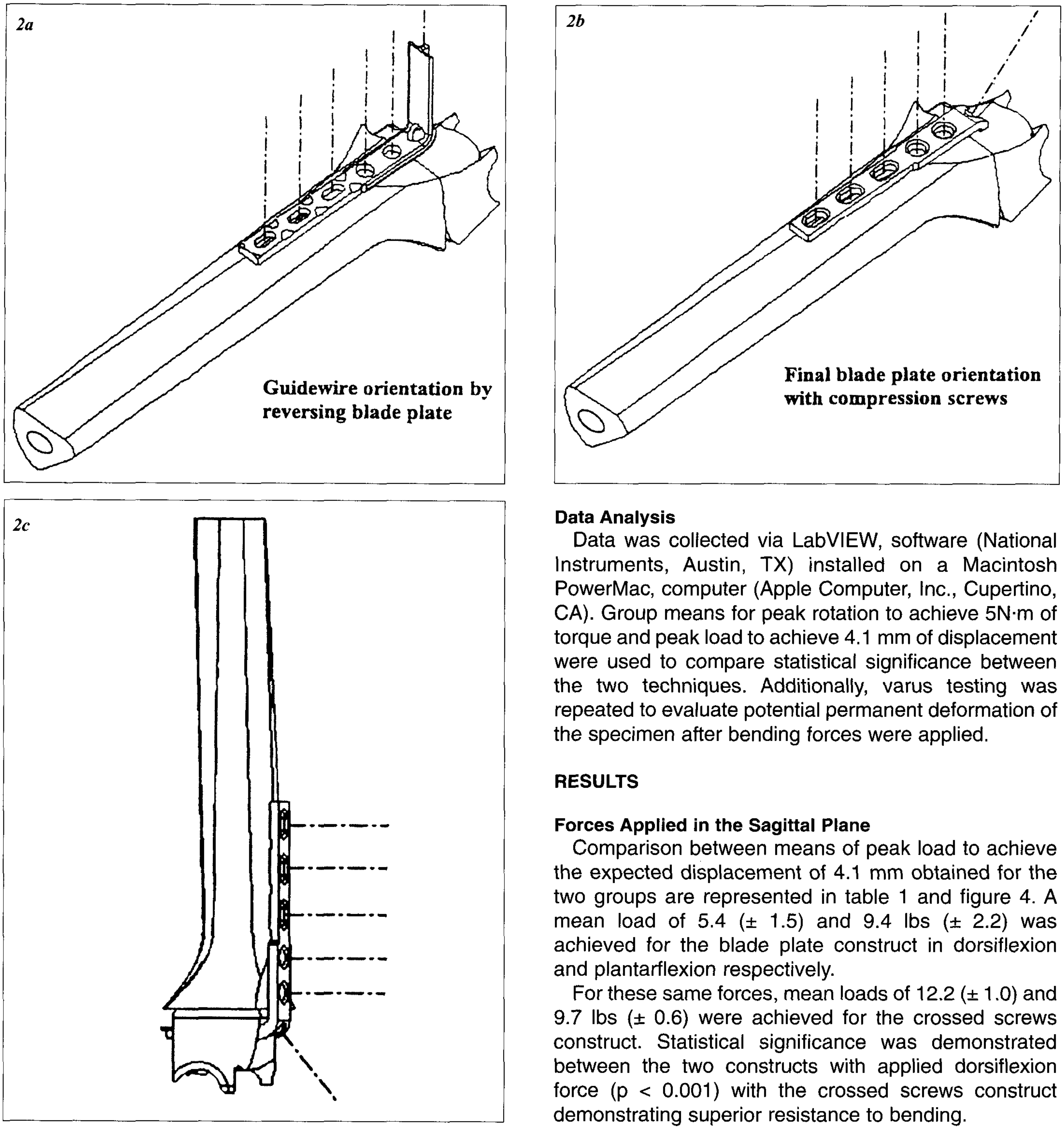

Fig. 2: Schematic representation of specimen fixation using the blade plate construct.

at 90° intervals (initially with varus). Bending rates were achieved at 1.0 mm/s, totaled 4.19 mm of displacement and transcribed an arc of 2°. Fixation stability was confirmed between each run via individual screw inspection.

Data Analysis

Data was collected via LabVIEW, software (National Instruments, Austin, TX) installed on a Macintosh PowerMac, computer (Apple Computer, Inc., Cupertino, CA). Group means for peak rotation to achieve 5N·m of torque and peak load to achieve 4.1 mm of displacement were used to compare statistical significance between the two techniques. Additionally, varus testing was repeated to evaluate potential permanent deformation of the specimen after bending forces were applied.

RESULTS

Forces Applied in the Sagittal Plane

Comparison between means of peak load to achieve the expected displacement of 4.1 mm obtained for the two groups are represented in table 1 and figure 4. A mean load of 5.4 (± 1.5) and 9.4 lbs (± 2.2) was achieved for the blade plate construct in dorsiflexion and plantarflexion respectively.

For these same forces, mean loads of 12.2 (± 1.0) and 9.7 lbs (± 0.6) were achieved for the crossed screws construct. Statistical significance was demonstrated between the two constructs with applied dorsiflexion force ($p < 0.001$) with the crossed screws construct demonstrating superior resistance to bending.

Forces Applied in the Frontal Plane

Table 1 represents the comparison of mean force obtained for the two constructs in applied varus and valgus directions. Mean load to achieve peak displacement for the blade plate construct was 10.6 (± 2.1) and 6.1 (± 0.9) pounds in respective varus and valgus directions.

The crossed screws construct demonstrated a representative mean of 12.9 (± 2.6) and 13.1 (± 2.1) lbs in these same directions. Statistical significance was demonstrated between the two constructs with applied valgus force ($p < 0.001$) with the crossed screws construct demonstrating superior stiffness.

Forces Applied in Rotation

Internal and external rotation forces were applied to achieve an end torque of 5·m. The mean degree of internal rotation to reach this end torque for the blade plate construct was 6.2° (± 1.1), while external rotation force required a mean of 6.1° (± 0.6) to reach the same value.

The crossed screws construct required a mean of 7.0° (± 1.2) to achieve our preset torque requirement for internal rotation. External rotation force achieved the set value at 6.1° (± 1.2). No statistically significant difference between the constructs could be detected for internal and external rotation forces ($p = 0.37$ and 0.96, respectively). These results are demonstrated in table 1.

Evaluation of Potential Permanent Deformation

After testing was completed in all sagittal and frontal planes, each construct underwent repeat varus testing to rule out the possibility of permanent deformation, which could alter the material properties of the fusion constructs. Mean values in varus for the blade plate construct were 10.6 (± 2.1) and 10.6 lbs (± 2.5) for initial and repeat tests, respectively. The crossed screws construct values for varus were 12.9 (± 2.6) and 12.7 (± 2.7) pounds for initial and repeat tests, respectively.

Average peak load to achieve the set displacement did not vary statistically between the initial varus run and the repeat situation for either construct ($p = 0.991$ and 0.918), therefore the stresses previously applied to a specific fusion construct had no adverse effect on the subsequent mechanical measurements.

DISCUSSION

Contrary to our hypothesis, crossed screws proved to make a stronger ankle fusion construct than the compression blade plate in valgus and dorsiflexion testing. An orthopedic surgeon's choice of crossed screws arthrodesis is thereby supported by our biomechanical data that demonstrate that this is the more stable construct to resist conventional post-operative deformation forces.

These results comparing internal fixation constructs of angled blade plate design and crossed screws have not been previously described. Our statistically significant findings of superiority of the crossed screws construct in resisting valgus and dorsiflexion forces are important from a physiologic standpoint because:

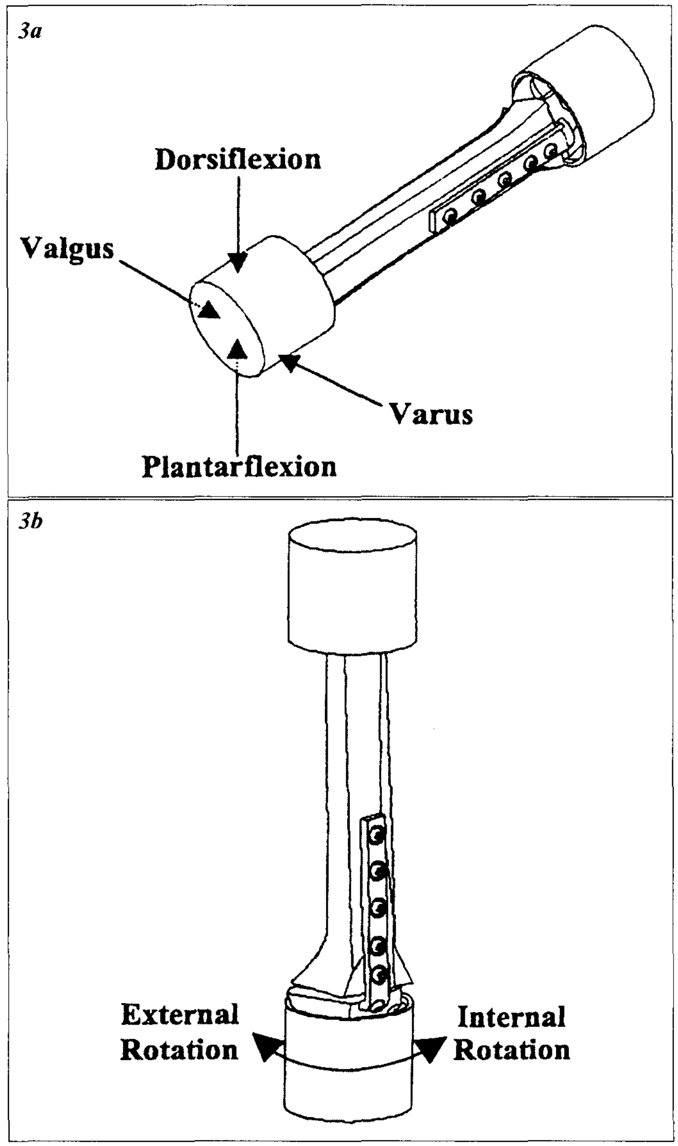

Fig. 3: Diagram of specimens undergoing stress testing.

	Bending (lb_f)		Rotation (degrees)	
	Plantarflexion	Varus	Internal	External
BP	9.4	10.6	6.2	6.1
CS	9.7	12.9	7.0	6.1

BP - Blade Plate   CS - Crossed Screws

Table 1: Comparison of bending forces required to achieve a set displacement and rotational force to achieve a set torque of the two types of constructs. Data represented as a mean standard deviation. No significant differences were detected for these four modes of testing.

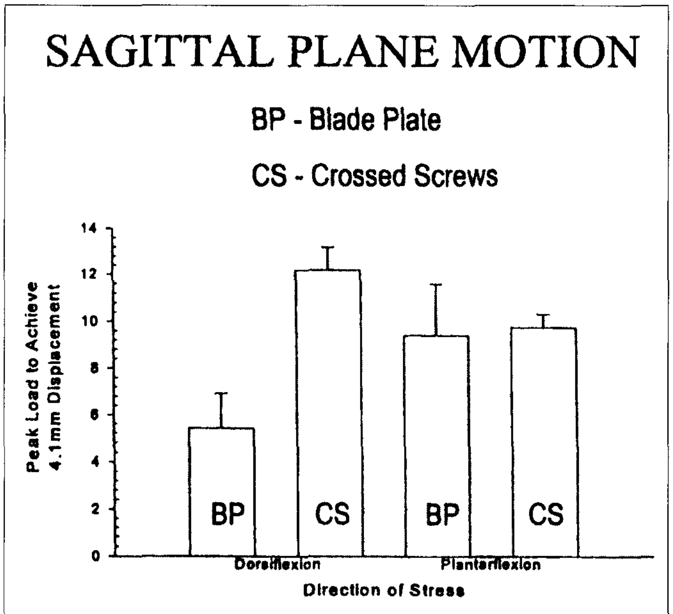

Fig. 4: Graphic representations of statistically significant differences between blade plate and crossed screws constructs in sagittal plane bending (N = applied Newton).

1) a neutral to slight valgus fusion position is preferred and,
2) dorsiflexion is the major stressor imparted to the fused ankle during normal gait.[15]

The evaluation of only four pairs of specimens used to achieve these findings may appear few in number. We believe the small sample size is negated by the significantly small p value identified in dorsiflexion and valgus positions. Furthermore, the powers of these results were 99% and 100% respectively, thereby virtually eliminating the possibility of performing both type I and type II errors in these directions. For the four remaining directions of force not found to be statistically different, a trend existed to further suggest crossed screws superiority. To establish statistical differences in these four directions would have required additional tests unrealistic in number which would simply have lent further support and not detracted from conclusions already reached. Namely, that the crossed screws construct is a stronger fixation technique for ankle arthrodesis.

We alluded to a protocol previously described by Friedman et al.[6] We modified their protocol in the following manner. First, our equipment required the rigid fixation of the talus in the testing device and a corresponding load applied to the diaphyseal region of the tibia 12 cm from the arthrodesis site versus fixation of the tibia with corresponding stress on the talus in their protocol. Our difference in the loading distance was due to the blade plate's length on the lateral tibia. Second, although Friedman et al. did not specifically delineate the screw orientation in their article, measurement of the crossed screws depicted in figure 1 of that study reveals angles of 45° and 55° in the coronal plane.[6] In theory, angles of 45° to the horizontal will produce the strongest construct; however, in order to maintain an effective margin (1 cm) of bone in the talus, this angle was increased to 60°. Another variation of our protocol entailed removal of the medial malleolus which allowed proper fitting into the pvc pipe section.

We elected to use two instead of three crossed screws because we believe readers with an interest in this area will find it easier to make comparisons with the study by Friedman et al. with the fewest number of variables possible introduced. The proximal to distal orientation of the crossed screws was chosen to, again, maintain consistency with Friedman's protocol when possible. Finally, in contrast to the Friedman et al. study, we chose sawbones in an attempt to minimize interspecimen fixation variability.

Before reaching final conclusions based on the data in this study, the following limitations must be considered. First, the biomechanical properties of sawbones are not the same as live bone or even cadaveric bone; sawbones are more brittle. However, they do present a uniform manner to evaluate fixation techniques. Support for the use of sawbones in the orthopedic research community was supplied by Flahiff et al. with their use of sawbones femora testing the pullout strength of screws.[5] Despite sawbones representing osteoporotic bone, our testing protocol was limited to the elastic region of the stress-strain curve and the material integrity of our specimens was confirmed visually throughout our study. Therefore, we believe that the use of sawbones enhanced the consistency of our results.

The second important limitation of our study is that the experimental methods do not accurately mimic the in vivo ankle as it is stressed either to failure acutely or in fatigue, nor do we account for the remodeling capacity of live bone. The removal of the medial malleolus and the absence of soft tissues make our model less stable than an actual live ankle fusion. We do believe, however, that our protocol at least approaches the ideal acute fixation scenario which is under the control of the orthopedic surgeon.

SUMMARY

Considerations in the selection of ankle fusion technique include patient factors and risks of complication, including anatomical characteristics of the ankle joint, systemic disease such as diabetes mellitus or rheumatoid arthritis that may increase the likelihood of wound healing problems. Our results indicate that the crossed cannulated screws construct provides increased

resistance to forces applied in valgus and dorsiflexion while the compression blade plate and crossed screws were equal in varus, plantarflexion and internal and external rotation. Bearing this in mind, we recommend the use of crossed screws for their strength, simplicity, speed and minimal tissue dissection. However, there will be instances in which the blade plate has obvious advantages, such as significant distal tibial bone loss, and these justify the inclusion of the compression blade plate in the orthopedic surgeon's arsenal.

ACKNOWLEDGEMENTS

Funding for this project was provided by a grant from the Medical College of Virginia Trauma Care Fund. The advice of James Kilpatrick, PhD of the Department of Biostatistics, Medical College of Virginia, is greatly appreciated. Synthes (USA) and DePuy ACE each donated the hardware used in their respective ankle fusion constructs.

REFERENCES

1. **Adams, J.C.**: Arthrodesis of the ankle joint. Experiences with the transfibular approach. J. Bone Joint Surg., **30B:** 506-511, 1948.
2. **Braly, W.G.; Baker, J.K.; Tullos H. S.**: Arthrodesis of the ankle with lateral plating. Foot Ankle Int. 1994 Dec; **15 (12):** 649-53.
3. **Buck, P., Morrey, B.F., and Chao, E.Y.**: The optimum position of arthrodesis of the ankle. J. Bone Joint Surg., **69A:** 1052-1062, 1987.
4. **Dennis, D.A., Clayton, M.L., Wong, D.A., and Susman, M.H.**: Internal fixation compression arthrodesis of the ankle. Clin. Orthop., **253:** 212-220, 1990.
5. **Flahiff, C.M., Gober, G.A., and Nicholas, R.W.**: Pullout strength of fixation screws from polymethylmethacrylate bone cement. Biomaterials., 533-536, 1995.
6. **Friedman, R.L., Glisson, R.R, and Nunley, J.A., II.**: A biomechanical comparative analysis of two techniques for tibiotalar arthrodesis. Foot Ankle International, **15:** 301-305, 1994.
7. **Hagen, R.J.**: Ankle arthrodesis: Problems and pitfalls. Clin. Orthop., **202:** 152-162, 1986.
8. **Helm, R.**: The results of ankle arthrodesis. J. Bone Joint Surg., **72B:** 141-143, 1990.
9. **Holt, E.S., Hansen, S.T., Mayo, K.A., and Sangeorzan, B.J.**: Ankle arthrodesis using internal fixation. Clin. Orthop., **268:** 44-48, 1991.
10. **Lynch, A.F. , Bourne, R.B., and Rorabeck, C.H.**: The long-term results of ankle arthrodesis. J. Bone Joint Surg., **70B:** 113-116, 1988.
11. **Mann, R.A., Van Manen, J.W., Wapner, K., and Martin, J.**: Ankle fusion. Clin. Orthop., **268:** 49-55, 1991.
12. **Mazur, J.M., Schwartz, E., and Simon, S.R.**: Ankle arthrodesis. Long-term follow-up with gait analysis. J. Bone Joint Surg., **61A:** 964-975, 1979.
13. **Moeckel, B.H., Patterson, B.M., Inglis,A.E., and Sculco, T.P.**: A comparison of internal and external fixation. Clin. Orthop., **268:** 78-83, 1991.
14. **Morrey, B.F., and Weideman, G.P., Jr.**: Complications and long term results of ankle arthrodesis following trauma. J. Bone Joint Surg.. **72A:** 777-784, 1980.
15. **Simon, S.R.**: Biomechanics. Orthopaedic Basic Sciences. 408-409, 1994.
16. **Scranton, P.E., Jr., Fu, F.H., and Brown, T.D.**: Ankle arthrodesis: a comparative clinical and biomechanical evaluation. Clin. Orthop., **151:** 234-243, 1980.
17. **Sowa, D.T., and Krackow, K.A.**: Ankle fusion: a new technique of internal fixation using a compression blade plate. Foot Ankle, **9:** 232-240, 1989.
18. **Thordarson, D.B., Markolf, K.L., and Cracchiolo, A., III.**: Stability of an ankle arthrodesis fixed by cancellous-bone screws compared with that by an external fixator.. J. Bone Joint Surg., **74A:** 1050-1055, 1992.
19. **Weltmer, J.B., Choi, S.H., Shenoy, A., and Schwartsman, V.**: Wolf blade plate ankle arthrodesis. Clin. Orthop., **268:** 107-111, 1991.