Triple Arthrodesis Stabilization: A Quantitative Analysis of Screw Versus Staple Fixation in Fresh Cadaveric Matched-Pair Specimens

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Qualitative analyses of midfoot stabilization in triple arthrodeses utilizing bone staple versus 4.5-mm cannulated cancellous screw fixation, with and without washers, were performed in fresh cadaveric specimens. Twenty-two trials (11 matched-pair feet) were used for direct comparison. Stiffness, defined as force/displacement, was determined at each talonavicular and calcaneocuboid joint. Ultimate load failure points of each specimen were also calculated. Trial results showed no statistically significant difference in stiffness or ultimate failure between these two forms of midfoot fixation for triple arthrodeses. (The Journal of Foot & Ankle Surgery 37(6):472–480, 1998)

Key words: screw fixation, staple fixation, triple arthrodesis

Triple arthrodesis is a common podiatric and orthopedic procedure which involves fusion of the talocalcaneal, talonavicular, and calcaneocuboid joints. It is typically indicated for intractable pain or deformity of these joints arising from trauma, infection, arthritic conditions, or congenital defects (1–7).

Early in the history of this procedure, the cartilaginous surfaces of these joints were resected and the patients were immobilized in plaster casts with subsequent postoperative manipulation and cast changes in order to maintain appropriate positioning and stabilization (2, 8). Critical reviews of these early procedures revealed poor outcomes resulting from pseudarthrosis, recurrence of deformity, incomplete correction, avascular necrosis of the talus, and degenerative changes in the ankle and midfoot (1, 2, 8, 9). Many authors believe most of these complications are influenced by technical factors such as blood supply of the involved segments and joint alignment (2, 3, 7, 10–13).

Ryerson stated that the position of the foot could be difficult to maintain and recommended chromic suture be passed through the bones to maintain the reduced position. He believed correction was easily lost in the early postoperative period, particularly during the cast change (4). Freidenberg believed that recurrences were the result of insufficient control of the tarsal bones in plaster, which could be detected within the 1 postoperative month (11). The use of internal fixation principles in triple arthrodesis developed from its effective use in the treatment of traumatic disorders and observations from the literature (1). Many authors believe that recurrent deformity and incomplete correction could be influenced by the use of rigid internal fixation (1, 5, 6, 9, 14–18).

In more recent years, with the advent of internal fixation devices, hardware fixation has become more commonplace. However, the specific forms of internal fixation utilized in triple arthrodesis stabilizations varies between individual practitioners. Screw fixation of the subtalar joint seems to be fairly standard; however, the calcaneocuboid and talonavicular joints are often fixated with either screws (1, 9, 19, 20) or staples (5, 7, 9, 19, 21–26). Staples provide rigid fixation but do not, by strict definition, provide compression at the fusion site. Vogler (27), however, stated that rigidity is the key to stability in fixation and that compression is one method of producing rigidity. He also stated that no evidence exists confirming that lag screw fixation shortens the fusion time or improves the fusion rate in triple arthrodesis. The amount of rigidity and overall stabilization that each method provides, despite the compression, is unknown. It is the intent of this study to compare the stability of staple versus screw fixation.

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Materials and Methods

Specimens

Fresh-frozen, unembalmed specimens were utilized for the scientific trials. Eleven matched-pair feet were evaluated in a total of 22 trials. These were stored at −20°C until thawed for dissection, at which point the osteotomy cuts and the articular surfaces were resected from each posterior talocalcaneal, talonavicular, and calcaneocuboid joint. The talocalcaneal joint was then fixated utilizing Synthes 6.5-mm cancellous screws inserted according to the Association for Osteosynthesis (AO)/Association for the Study of Internal Fixation (ASIF) technique. The specimens were then refrozen until the time of the trials. For the first two trials, specimens had to be refrozen because of laboratory scheduling conflicts. After that, all specimens were tested immediately following implant placement with no refreezing. The remaining calcaneocuboid and talonavicular joints were fixated with their respected screws or staples immediately prior to stressing the specimens. Specimen age ranges from 58 to 91 years with no evidence of previous foot surgery or trauma. The mean age was 76 years old, ranging from 58 to 91 years old. Six female and five male specimens were utilized.

Equipment

A computer-integrated Instron materials testing machine[1] (Fig. 1) was utilized to quantify the forces generated to produce ultimate load failure. Two linear variable differential transducers (LVDT)[2] were also used to measure distraction/compression across the talonavicular and calcaneocuboid joints to determine a stiffness measurement of fixation. The resolution of the LVDT is approximately 1 μm with a range of ±5 mm. Computer software consisted of a data translation analog to digital board[3] (Fig. 2).

The specimens were potted for trials in a square metal cup and secured with polymethylmethacrylate bone cement and Steinmann pins surrounding the distal third of the tibia/fibula for attachment to the Instron. The ankle joints were locked into neutral position, 90° with respect to the foot, utilizing two crossed Steinmann pins. The foot was then loaded onto a metal force plate which counteracted the downward weightbearing-simulated forces of the Instron.

Experimental Technique

The triple arthrodeses were performed through a typical two-incision approach. Talonavicular joint access was obtained via a 5.0-cm linear medial incision between the anterior and posterior tibial tendons, while the calcaneocuboid and posterior subtalar joints were accessed through a modified Ollier incision at the lateral ankle joint level and sinus tarsi. The cartilaginous surfaces of the talocalcaneal, talonavicular, and calcaneocuboid joints were resected by osteotomy cuts made with a power bone-cutting saw following the contours of the subchondral bone. All cuts and fixation techniques were done either directly by the senior author or under direct supervision for consistency purposes.

In one of the matched-pair feet, a Synthes 4.5-mm partially threaded cancellous screw was inserted across the talonavicular and calcaneocuboid joints in a dorsal distal to plantar proximal direction, utilizing AO/ASIF cannulated screw system fixation technique (Figs. 3 and 4). After six trials of the specimens fixated with the 4.5-mm screws, it was noted that the screw head appeared to be migrating through the cortical bone. Therefore, washers were introduced for the remaining five screw specimens to

FIGURE 1 Computer-integrated Instron materials testing machine (model 1122) with two linear variable differential transducers (LVDT) (model S5, Ultra Precision, Sensotic, Columbus, OH).

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[1] Instron, Inc., Canton, MA, model 1122.

[2] Sensotic, Columbus, OH, model S5, Ultra Precision.

[3] Marlboro, MA.

FIGURE 2 Computer software with data translation analog to digital board (Marlboro, MA).

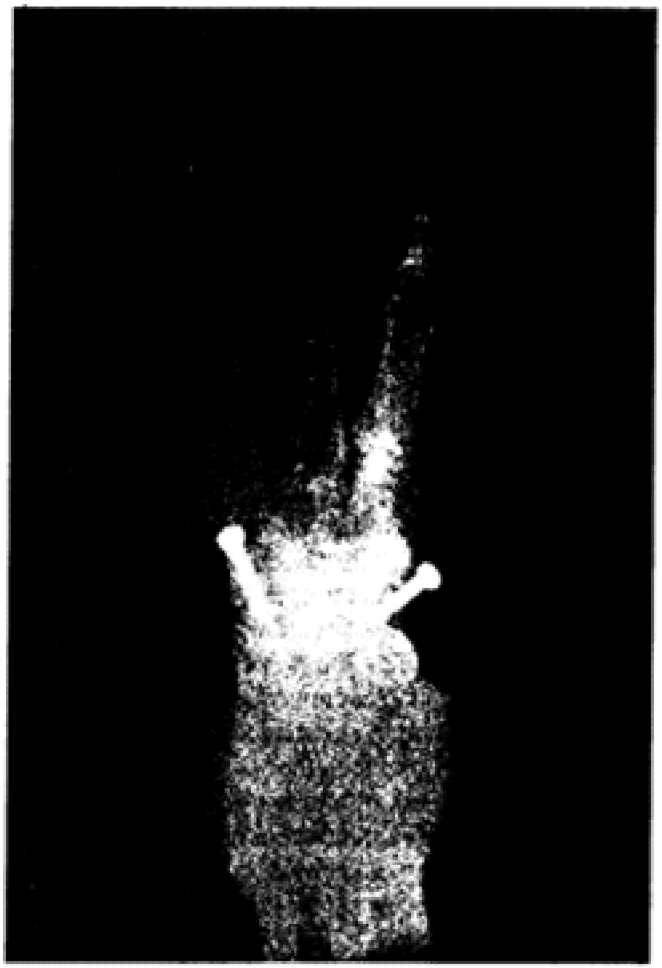

FIGURE 3 Dorsoplantar radiograph of the 4.5-mm screw fixation across talonavicular and calcaneocuboid joints.

FIGURE 4 Lateral radiograph of the 4.5-mm screw fixation across the talonavicular and calcaneocuboid joints, with 6.5-mm screw fixation across the posterior talocalcaneal joint.

evaluate if washers produced any effect on the measured parameters. In the other matched-pair specimen, two large Blount-type barbed bone staples were inserted across the talonavicular and calcaneocuboid joints, as described by Corey et al. (19) (Figs. 5 and 6). The staples measured 22 mm × 19 mm or 16 mm × 19 mm, depending on the size of the foot. The larger sized staples were utilized whenever possible and were oriented 90° to one another as much as possible. The staples were inserted by hand utilizing the appropriate staple holder and mallet.

The posterior talocalcaneal joint of each specimen was fixated with a Synthes 6.5-mm partially threaded cancellous screw, oriented in a dorsal medial to plantar lateral direction, from the talar neck into the body of the calcaneus, utilizing proper AO/ASIF technique. As previously mentioned, the ankle joint of each specimen was fixated with two crossed 4.0-mm Steinmann pins, at 90° to the foot, in order to negate any sagittal plane motion (Fig. 7). These ankle and subtalar joint fixation parameters remained constant in every foot. Each foot was also positioned in approximately 4°–7° of rearfoot valgus, with the forefoot rectus to the rearfoot, preserving a moderate amount of medial longitudinal arch height.

Each specimen was then potted in an aluminum cylinder via cementing the distal tibia and fibula with polymethylmethacrylate. Additional stability was obtained with three

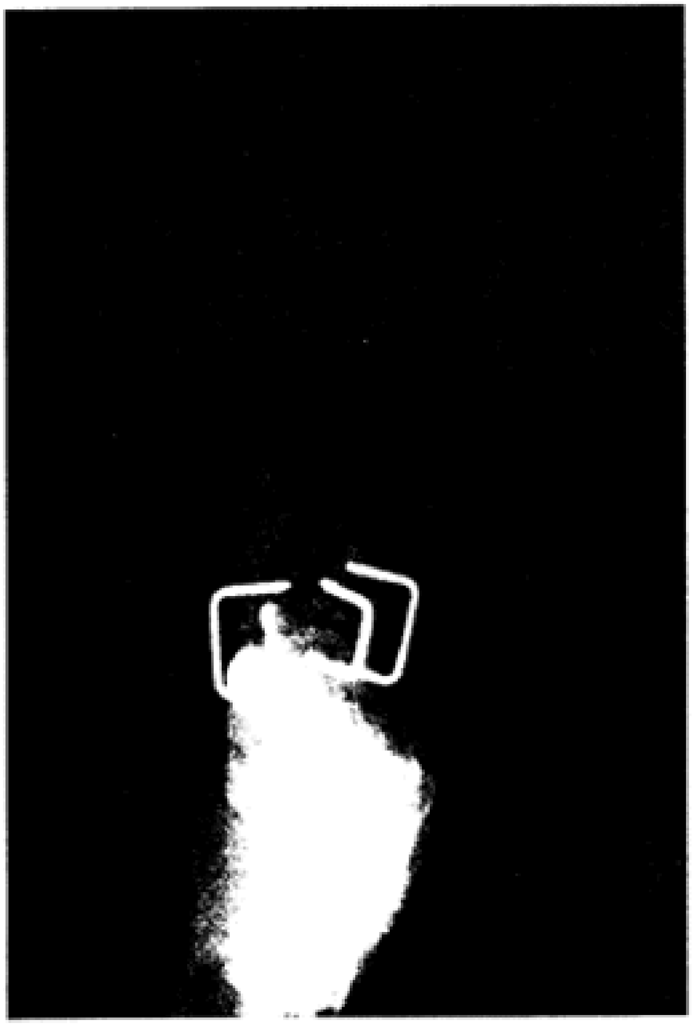

FIGURE 5 Dorsoplantar radiograph of the 22 mm × 19 mm and 16 mm × 19 mm barbed staples across talonavicular and calcaneocuboid joints, with 6.5-mm screw fixation across the posterior talocalcaneal joint.

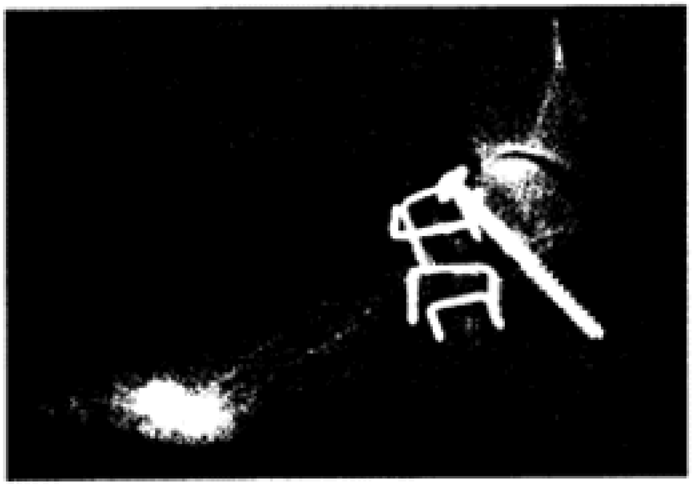

FIGURE 6 Lateral radiograph of the 22 mm × 19 mm and 16 mm × 19 mm barbed staples across talonavicular and calcaneocuboid joints, with 6.5-mm screw fixation across the posterior talocalcaneal joint.

FIGURE 7 Potting of the specimen in the aluminum cylinder with polymethylmethacrylate and three crossed Steinmann pins for stability. Notice the ankle joint is fixated with two crossed 4.0-mm Steinmann pins at 90° to foot and 4° – 7° of rearfoot valgus.

crossed 4.0-mm Steinmann pins through the cylinder (Fig. 7). Variability in specimen age, sex, and bone stock were controlled by utilizing matched-pair specimens.

The aluminum cylinder was bolted to the force arm of the Instron, and the specimen was lowered to the metal force plate until it rested in a flush position (Fig. 8). The specimen was then stressed with a graduated vertical speed/load rate of 5.0-mm/min until ultimate failure of the system (Fig. 8). The point of ultimate failure was determined by the drop off in the constantly applied force (Fig. 9).

The displacement data of the calcaneocuboid and talonavicular joints were collected at 200 Hz (200 samples/sec) by LVDT monitors to an analog to digital board device. The transducer piston mechanism was attached to the navicular and cuboid by a screw mechanism, and the LVDT piston target plates were placed parallel to the osteotomy cuts in the talus and calcaneus utilizing screws (Fig. 10A and B). Stiffness measurements were

FIGURE 8 Stressing of the specimen with the foot resting in a flush position with the metal force plate.

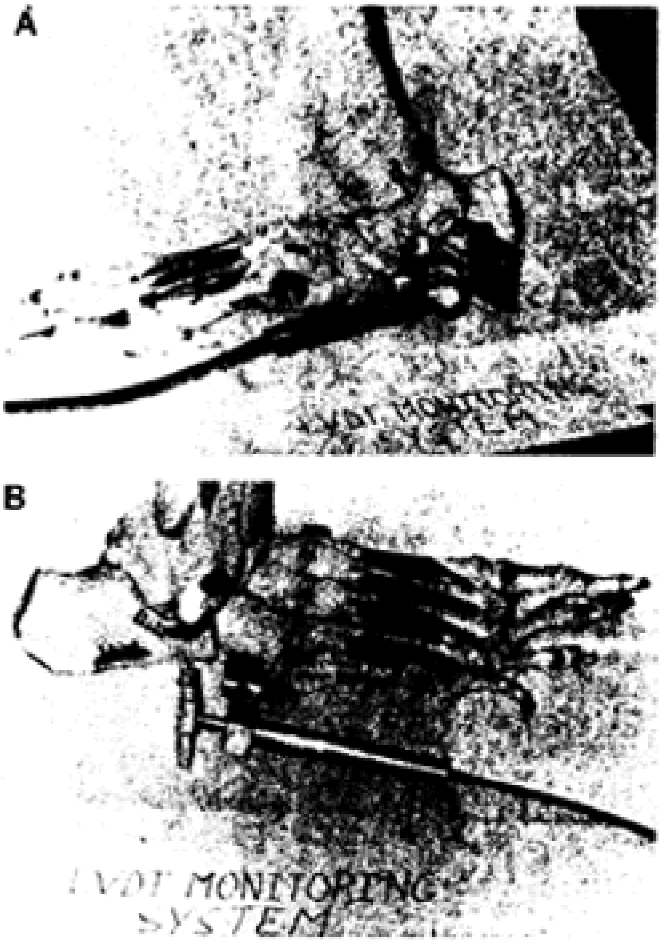

FIGURE 10 *A*, Positioning of the LVDT transducer and target plate for the talonavicular joint. *B*, Positioning of the LVDT transducer and target plate for the calcaneocuboid joint.

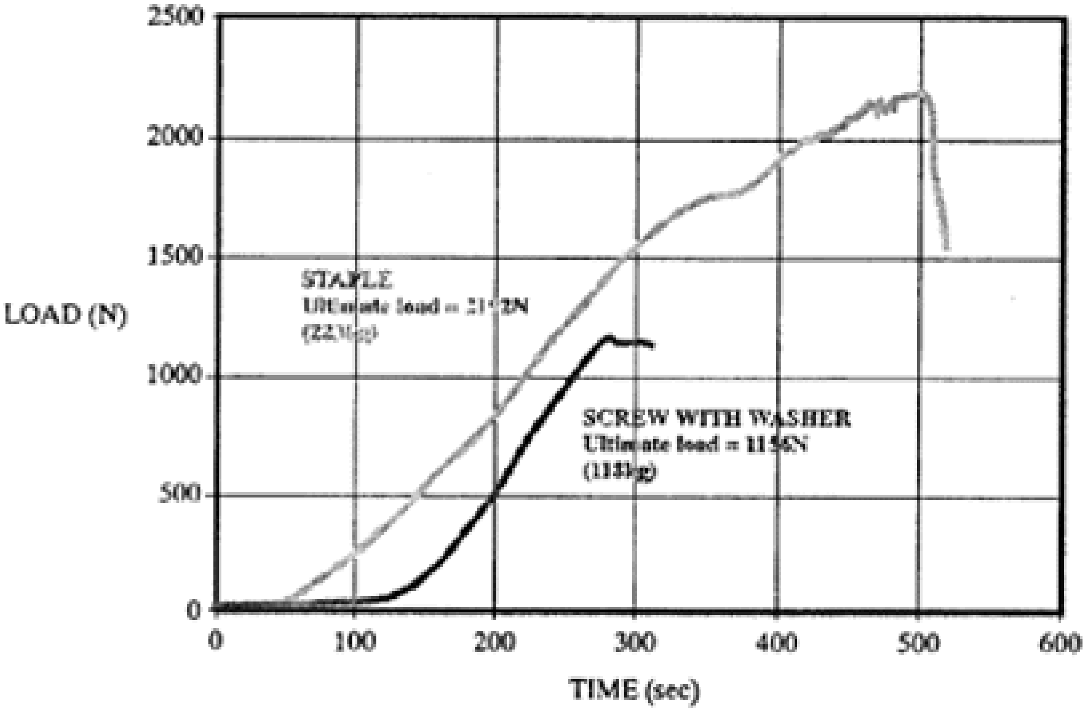

FIGURE 9 Specimen 7: ultimate load of screw with washer and staple.

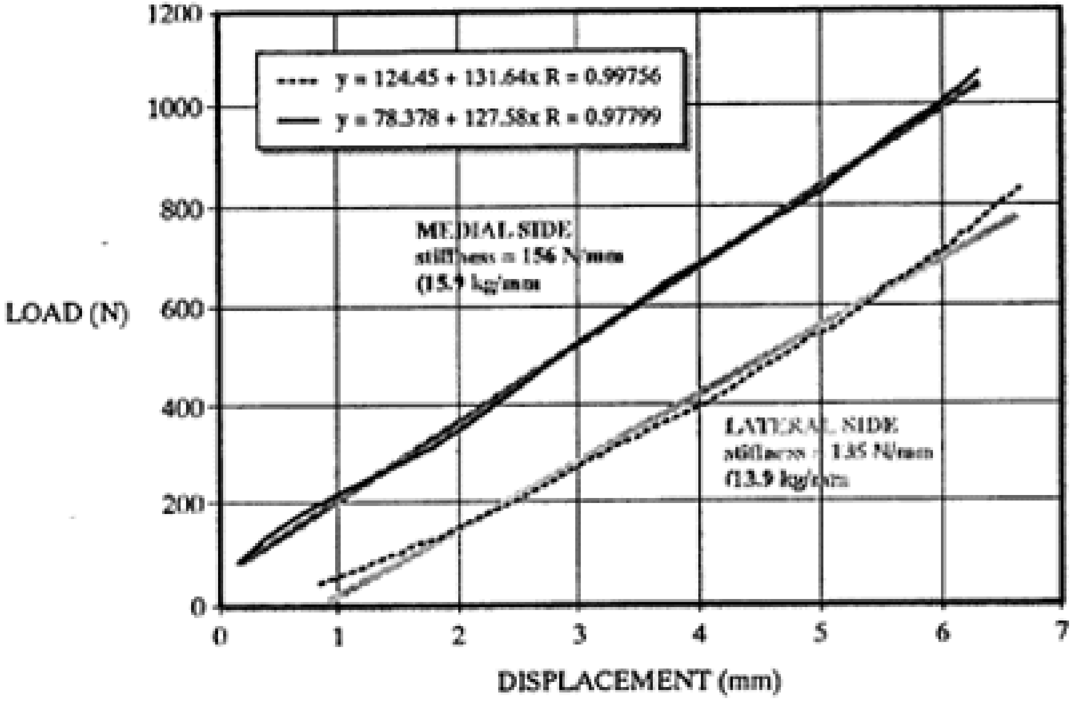

FIGURE 11 Specimen 7: staple medical and lateral stiffness.

then generated by accurately approximating the data via simple fit curves with the appropriate regression coefficient (Fig. 11).

Results

Ultimate Load

Ultimate load measurements (Table 1), analyzed via a paired *T* test, revealed no statistically significant difference between screws and staples ($p = .4531$), or between screws with washers and staples ($p = .8619$). Furthermore, no statistically significant difference was noted between the screws with washers and the screws without washers ($p = .2349$).

Stiffness

Talonavicular and calcaneocuboid stiffness of fixation were analyzed via multivariate analysis of variance (MANOVA), and appropriate assumptions for the multivariate were met (Bartlett-Box $p = .04456$). Overall results of the MANOVA proved to be nonsignificant (W. Lambda $df\,4{,}36$, $F = .92$, $p = .4636$). Protected univariate F tests revealed no significant difference between fixation groups on talonavicular stiffness ($F = .590$, $df\,2{,}19$, $p = .5620$) or calcaneocuboid stiffness ($F = 2.02$, $df\,2{,}19$, $p = .1601$).

The purpose of this project was to identify differences in strength of midfoot fixation between screws and staples in triple arthrodeses. The study demonstrated no statistically significant difference between the stability of these two forms of fixation. However, other differences between the techniques were observed in the course of this project identifying numerous advantages and disadvantages associated with each method.

TABLE 1 Ultimate loads per matched-pair specimen

Specimen	CCJ Stiffness (kg/mm)	TNJ Stiffness (kg/mm)	Ultimate Loads (kg)
1S	10.7	25.1	405.9
1ST	88.9	64.6	425.2
2S	19.2	35.5	203.1
2ST	25.7	43.4	248.3
3S	50.9	55.1	164.6
3ST	15.6	13.8	252.5
4S	20.7	17.4	215.4
4ST	15.7	21.4	209.4
5S	20.5	6.9	365.8
5ST	15.7	19.4	298.3
6S	21.1	20.9	290.3
6ST	29.7	97.9	318.1
7SW	13.4	13.3	117.8
7ST	13.9	15.9	223.4
8Sw	46.2	31.7	500.0
8ST	46.8	35.3	360.4
9SW	15.6	12.2	444.8
9ST	59.8	55.2	313.3
10SW	15.2	22.6	139.8
10ST	12.2	77.6	296.1
11SW	9.6	8.5	229.5
11ST	18.3	11.4	182.3

S, screw; ST, staple; SW, screw/washer

Bone quality has an obvious effect on stability. In this study, staples appeared to hold better in softer bone than screws; however, no data regarding bone density or bone quality were available.

Observations

Screw Fixation

The advantages of screw fixation include compression at the fusion site and fixation in two dimensions (28), resulting in a better opportunity for primary bone healing. Furthermore, no banging or jarring is required during placement.

However, there are many disadvantages to fixating with screws as opposed to staples for triple arthrodesis stabilizations. Screws are technically more difficult and time consuming to insert, as well as relatively more expensive. Furthermore, the correct angle of fixation is difficult to achieve and may jeopardize bone integrity if multiple attempts are required. Also, the navicular and cuboid must be large enough to support screw fixation without sacrificing the integrity of other adjacent joints.

Three main types of failures were noted with screw fixation. First, the screw heads tended to migrate through the cortical bone as the load force increased; thus, washers were utilized to help eliminate this migration. Although the screws with and without the washers did not show any statistically significant difference in strength, the screws with washers were observed to allow less apparent migration through the dorsal cortex.

The second type of failure observed was fracturing of the dorsal cortex. The sharp angle at which the screws need to be placed at the talonavicular and calcaneocuboid joints often caused the dorsal cortex to be extremely thin and susceptible to fracture.

The third type of failure occurred when the screws pulled out of the cancellous bone. One possible reason for no statistical difference in strength between the screws with and without washers may be this loss of screw purchase in cancellous bone.

Another frequent complication noted with screw fixation was the midtarsal screws running into the subtalar screw, thus requiring further drilling at a new site or angle which may have potentially weakened the surrounding bone and fixation.

Staple Fixation

Staples, on the other hand, are less technically demanding, less time consuming, and less expensive than screws. They also require less exposure for placement and rarely interfere with other fixation. An important consideration for triple arthrodesis stabilizations is that they allow for fixation across joints not to be fused, particularly in cases involving a small navicular, with potentially decreased risk of cartilage damage.

On the other hand, staples do not provide true compression and limit motion in only one or two dimensions, making primary bone healing less likely. Furthermore, an assistant is usually required to provide manual compression and counter pressure to ensure proper positioning of the fragments prior to placing the staple. Any movement of the fragment may require pulling the staple and reinserting, which may compromise bone integrity. Also, the banging and jarring of the foot and leg during staple placement may potentially loosen or dislodge the previous fixation. In this study, staples appeared to fail by either pulling out of the bone or fracturing the surrounding bone. This was especially evident in cases where the staples were placed in close alignment with the screw in the talar neck, resulting in stress risers and talar neck fractures. Interestingly, the talonavicular joint fixation remained intact. Unlike the screw fixation, there was little interference with the subtalar screw while inserting the staples.

Discussion

Power analysis was calculated post hoc by a staff biostatsitician, at 26% for lateral stiffness, 24% for medial stiffness, and 42% for ultimate load. This analysis suggests the sample size was small, and may be the explanation for the lack of statistical significance between groups. Further studies with a larger sample size could still reveal greater differences between the techniques.

Although strength of fixation could not be demonstrated to favor screws or staples, several technical recommendations evolved from this study. General considerations in choosing fixation include: surgeon experience and preference, technical skill, cost, equipment availability, and time consumption. Some authors believe that technical considerations, such as joint access and visualization, make it extremely difficult for screw placement at the midtarsal joints (27). Specific grafting procedures and previous use of one type of fixation may also preclude the use of one fixation type versus another.

The mass of bone available for fixation may also dictate which fixation a surgeon will utilize. Occasionally, the navicular and/or cuboid may be small or deformed, thus causing difficulty with fixation. This leads to the consideration of breaching other joints that are not to be fused, such as the naviculocuneiform or metatarsal–cuboid articulations. Breaching these joints with a staple may not damage other articular surfaces and thus allow for the possibility of removing the staple after bony union is achieved.

A literature review of triple arthrodesis stabilizations reveals a wide range of pseudarthroses (2, 3, 11-13, 16, 29). Most agree that the talonavicular appears to be the most frequent joint where non-unions are seen (7, 15, 27), followed by the calcaneocuboid joint and rarely by the talocalcaneal joint (27). There have been many reasons proposed for the high incidence of talonavicular pseudarthrosis. The convex/concave relationship makes the articular surfaces difficult to resect and closely reapproximate. Also, gaining adequate exposure and the proper angle to insert fixation can be technically difficult. These difficulties may lead to poor apposition of the bone edges intraoperatively, which is frequently correlated with postoperative complications (1, 7, 9, 27). Another cause of talonavicular nonunion may be excessive motion at the joint, especially with weightbearing causing distraction and/or rotation.

A technique which may improve the stability/rigidity of fixation at the talonavicular joint might be placement of a screw and a staple across the talus and navicular. The screw provides compression while the staple limits distraction and rotation at the joint, thus preventing the screw head from migrating through the cortex or the screw from pulling out of the cancellous bone. Such a fixation method would require further study to evaluate its efficacy.

Although the utilization of washers on the screws did not prove to be statistically significant, by increasing the surface area at the bone-screw interface, the screw heads clinically appeared to migrate less into the cortex. Therefore, utilization of washers is recommended particularly where decreased bone density is a concern.

Staples should be offset with each other and the talar neck screw, in particular, to prevent stress risers and subsequent fractures. Stress risers in the talar neck region could also be prevented by placement of the talocalcaneal screw from the inferior lateral aspect of the calcaneus in a superomedial direction into the talar body, as described by Sangeorzan et al. (1). This allows more room for hardware placement dorsally at the talonavicular joint.

Furthermore, staple width should be as large as possible. The staple posts should remain at least a few millimeters away from the cut or curetted surfaces in order to prevent the posts from pulling through the thin cortices, as supported by Corey et al. (19).

Although no scientific data were obtained, prestudy trials demonstrated that barbed staples rarely backed out compared to smooth staples. Therefore, barbed staple utilization is also recommended.

Study Limitations

Several areas for additional investigation were identified. First, the specimen number is relatively low, as suggested by the power analysis. Additional work with more specimen may reveal differences in strength not identified in this project. Furthermore, this study did not pinpoint the exact location of failure in the specimen when the ultimate load was determined. Instead, the failure point was determined from the graph when the constantly increasing load fell off. Such graphic evaluation does not identify which joints may have failed or which bones may have fractured. Lastly, this study did not measure shear forces or rotational forces at the talonavicular and calcaneocuboid joints. Evaluation on the effect of such forces individually may lead to development or utilization of fixation techniques which may address the destructive forces most efficiently.

Conclusion

This research project provides basic scientific data which support the notion that staple and screw fixation in triple arthrodesis stabilizations may be used interchangeably in regards to strength or stability of fixation. The research trials revealed no statistically significant difference between screw versus staple fixation in fresh cadaveric matched-pair specimens. However, the study is able to point out many important considerations, advantages, and disadvantages involved with utilizing each type of fixation.

References

1. Sangeorzan, B., Smith, D., Veith, R., Hansen, S., Jr. Triple arthrodesis using internal fixation in treatment of adult foot disorders. Clin. Orthop. 294:299-307, 1993.
2. Angus, P. D., Cowell, H. R. Triple arthrodesis: a critical long-term review. J. Bone Joint Surg. 68-B(2):260-265, 1986.
3. Patterson, R. L., Parrish, F. F., Hathaway, E. N. Stabilizing operations on the foot: the study of the indications, techniques used, end results. J. Bone Joint Surg. 32-A:1, 1950.
4. Ryerson, E. W. Arthrodesis operations on the feet. J. Bone Joint Surg. 5:453, 1923.
5. Bennett, G. L., Graham, C. E., Mauldin, D. M. Triple arthrodesis in adults. Foot Ankle 12(3):138-143, 1991.
6. Graves, S. C., Mann, R. A., Graves, K. O. Triple arthrodesis in older adults. J. Bone Joint Surg. 75-A(3):355-362, 1993.
7. Wilson, F. C. Jr., Fay, G. F., Gardner, F. F., Lamotte, P., Williams, J. C. Triple arthrodesis: a study of the factors affecting fusion after three hundred and one procedures. J. Bone Joint Surg. 47-A(2):340-348, 1965.
8. Johnson, M. K., Kanat, I. O. Complications of triple arthrodesis with comparison to select rearfoot fusions. J. Foot Surg. 26:371-379, 1987.
9. DiStazio, J. J. Triple arthrodesis. Clin. Podiatr. Med. Surg. 8:693-699, 1991.
10. Crego, C. H. Jr., McCarroll, H. R. Recurrent deformities in stabilized paralytic feet: Report of 1100 consecutive stabilizations in poliomyelitis. J. Bone Joint Surg. 20-A:609, 1938.

11. Friedenberg, Z. B. Arthrodesis of the tarsal bones: a study of failure of fusions. Arch. Surg. 57:162, 1948.
12. Marek, F. M., Schein, A. J. Aseptic necrosis of the astragalus following arthrodesis procedures of the tarsus. J. Bone Joint Surg. 27-A:587, 1945.
13. Wetmore, R. S., Drennan, J. C. Long term results of triple arthrodesis in Charcot-Marie-Tooth disease. J. Bone Joint Surg. 71-A:417, 1989.
14. MacKenzie, I. G. Lambrinudi's arthrodesis. J. Bone Joint Surg. 41-B:738-748, 1959.
15. Patterson, R. L., Jr. Various factors involved in triple arthrodesis. Clin. Orthop. 85:59-61, 1972.
16. Southwell, R. B., Sherman, F. C. Triple arthrodesis: a long term study with force plate analysis. Foot Ankle 2:15-24, 1981.
17. Howorth, M. B. Triple subtalar arthrodesis. Clin Orthop. 99: 175-180, 1974.
18. Miller, S. J. End stage flat foot: Diagnosis and conservative and surgical management. J. Am. Podiatr. Med. Assoc. 77:42-45, 1987.
19. Corey, S. V., Zirm, R. J., Chang, T. J. Fixation devices in rearfoot surgery. Clin. Podiatr. Med. Surg. 8:433-447, 1991.
20. Ruch, J. Triple arthrodesis. Doctor's Hospital Symposium on Reconstructive Surgery of the Foot and Leg, Atlanta, Georgia, 1984.
21. Alldredge, R. H., Riordan, D. C. The use of staples and bone-chip grafts for internal fixation in foot-stabilization operations. J. Bone Joint Surg. 35-A:951, 1953.
22. Dekelver, L., Fabry, G., Mulier, J. C. Triple arthrodesis and lambrinudi arthrodesis. A study of the factors effecting fusion after three hundred and one procedures. Literature review and followup study. Arch. Orthop. Trauma Surg. 96:23, 1980.
23. Trott, A. W. Triple arthrodesis. Orthop. Rev. 7:73, 1978.
24. Drew, A. J. The late results of arthrodesis of the foot. J. Bone Joint Surg. 33-B:496, 1951.
25. Marmor, L. *Arthritis Surgery*, pp. 480-485, Lea and Febiger, Philadelphia, 1976.
26. Drennan, J. C. *Orthopedic Management of Neuromuscular Disorders*, pp. 97-104, J.B. Lippincott, Philadelphia, 1983.
27. Vogler, H. W. Triple arthrodesis as a salvage for end-stage flatfoot. Clin. Podiatr. Med. Surg. 6:591-604, 1989.
28. Green, D. R. The hazards of internal fixation in podiatry. Clin. Podiatr. 2:95-119, 1985.
29. Wukich, D. K., Bowen, J. R. Long term study of triple arthrodesis for correction of pes cavovarus in Charcot-Marie-Tooth disease. J. Pediatr. Orthop. 9:433, 1989.