CHAPTER **25**

Staple Fixation for First Metatarsal Transverse Closing Base Wedge Osteotomy: A Cadaver Study

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PURPOSE

As a follow up to the comparative analysis of fixation for proximal closing base wedge osteotomy for the first metatarsal, I propose using the staple fixation method in patients for fixation of the osteotomy. We hypothesize fixation of the osteotomy with a dorsal and plantar compression staple is a viable fixation method when compared to a more oblique osteotomy and screw fixation.

BACKGROUND

Hallux abducto valgus is a common deformity found in the lower extremity and in many cases leads to severe and debilitating discomfort. Many conservative modalities have been developed to accommodate for this deformity, however, once they have all been exhausted with little to no relief surgical intervention is a viable next step.

With a long list of procedures for treatment of hallux abducto valgus, often times surgeons do what works best in their hands. There are considerations, however, that must be evaluated before deciding on one particular osteotomy and form of fixation. The closing base wedge osteotomy was first introduced in 1901 by Loison and initially was not fixated, relying on the intact medial hinge for stability (1). The problem with proximal first metatarsal osteotomies is they are difficult to fixate, and thus Juvara modified the procedure to include a more oblique osteotomy allowing for a screw to be placed (2). In 1977, the Podiatry Institute introduced a long-arm oblique osteotomy to allow for 2 screws to be placed across the osteotomy site (3,4).

The benefit of performing an osteotomy in the metaphyseal portion of the bone is that it consists of mesenchymal stem cells allowing new bone formation, which is stronger than what occurs in the diaphysis (5,6). Also, the blood supply to the metaphyseal portion of the bone is more extensive compared to diaphyseal bone (7). Due to these factors, one could assume that a transverse osteotomy in the metaphyseal portion of the first metatarsal would encourage faster healing and greater likelihood of union if a stable fixation technique was developed for this osteotomy location. The difficulty in performing a transverse osteotomy in the proximal end of the first metatarsal is the inability to utilize screw fixation due to its transverse nature and proximity to the first tarsometatarsal joint.

Staples provide a dynamic fixation method optimal for a transverse osteotomy at the proximal portion of the first metatarsal. (8) By placing a staple dorsal and lateral, the osteotomy is able to be closed down laterally and provide compression (9,10,11). Next, a plantar medial staple can be placed to stabilize the osteotomy in a tension band fashion. Since weight bearing is a dorsal force from the reactive force of gravity, this force will tend to cause gapping of the osteotomy on the plantar aspect. If the transverse staple is placed in the lower half of the metatarsal, this will resist distraction. Therefore, using the tension band principle the ground reactive force of gravity will be converted into a compressive force across the osteotomy site, thus adding an additional factor to the healing condition.

In this cadaver study we perform a transverse closing base wedge osteotomy in the metaphyseal portion of the bone fixated with nitinol staples. We believe a transverse closing base wedge osteotomy with plantar and dorsal fixation facilitates correction of moderate to severe hallux valgus and is a viable surgical method in respect to bony union and patient satisfaction. Performing this in vivo study will demonstrate the elastic recovery and dynamic compression capability.

METHODOLOGY

This study was made possible by a grant provided by the Scripps Coastal Medical Group. A total of 15 unpaired specimens were used from 11 male and 4 female with ages ranging from 47 to 75 (mean 59.6 years). Specimens were divided into 3 groups to undergo transverse closing base wedge osteotomy in the metaphyseal portion of the bone and receive either single or dual staple fixation and oblique closing base wedge osteotomy with screw fixation.

The specimens undergoing transverse closing base wedge osteotomy underwent osteotomy 1.2cm from the first tarsometatarsal joint and perpendicular to the weight-bearing surface. A 1-2mm wedge was removed with care to keep the medial cortical hinge intact utilizing a sagittal bone saw. The osteotomy was then fixated with either a

single staple dorsal and lateral utilizing a nitinol staple oriented dorsal to plantar. The group fixated with two staples also received an additional staple oriented plantar and medial to plantar lateral on the tension side of the bone (Figure 1).

A third group underwent an osteotomy oriented more oblique in the metaphyseal and diaphyseal portion of the bone with the medial hinge left intact approximately 1.2cm distal to the first tarsometatarsal joint. This osteotomy was then fixated utilizing standard AO technique utilizing 2 2.7mm fully threaded solid stainless steel screws.

During dissection and while performing the osteotomy and fixation, all surrounding tissue was left intact for testing. The specimens then underwent amputation at choparts joint to allow for fixation to the biomechanical testing machine. First ray range of motion was measured before and after the procedure was performed as well as after amputation at choparts joint.

After amputation, screws were installed in the cuneiform and navicular to aid in cement fixation. The specimen was mounted in cement at the proximal end with the distal end pointed upward. A threaded pin was inserted to the distal plantar shaft of the first metatarsal.

The specimen was mounted in the VIVO test machine (AMTI), as follows (Figure 2). The cemented proximal mount was fixed to the lower plate. The metatarsal pin was fixed to the upper rotation arm. Rotation of the lower plate was used to align the specimen to the transverse plane. Rotation of the upper rotation arm was used to align the metatarsal pin perpendicular to the plane. This alignment allowed loading to simulate a normal force during standing. The origin of the test environment was placed at the insertion point of the metatarsal pin.

Test load was applied to the plantar surface at the metatarsal pin. Load was cycled from 0 N to 100 N for 2000 cycles. The proximal-distal axis was allowed to move to relieve load, preventing off-axis loading from restricting motion along the axis of interest. Loads and displacements were recorded in the X, Y, and Z directions. Moments and angles or rotation were recorded around the X, Y, and Z axes.

Figure 2. Picture of specimen mounted to Vivo test machine (AMTI).

Stiffness was evaluated as the displacement at 100 N from the neutral starting position. Stiffness was compared between the three restoration conditions. Cycle count at failure was noted when available.

After mechanical testing, specimens were evaluated for fracture or loosening at the restoration site. Dissection was performed to note any fracture or loosening that was not apparent with the soft tissue in place (Figure 3).

Data were processed to evaluate stiffness along the loading axis as a function of total displacement of the mount on the metatarsal and the load applied along the plantar-dorsal direction. The first 3 cycles of data were not included in data processing to account for settling of the specimen and mount in the machine.

Figure 1. Dorsal to plantar and lateral view x-ray of dual staple fixation group.

Figure 3. Example of catastrophic failure seen in screw fixation group.

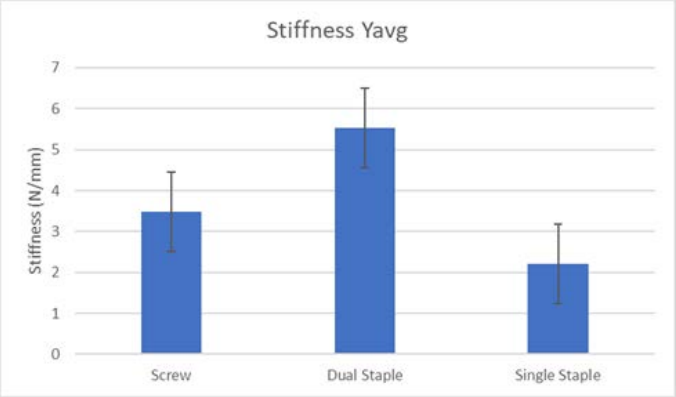

Figure 4: Representation of stiffness of fixation methods for first metatarsal closing base wedge osteotomy.

RESULTS

The average stiffness was greater in the transverse osteotomy with dual staple fixation compared to the single staple fixation and screw fixation groups with a stiffness of 5.53 N/mm compared to 2.21 N/mm for the single staple fixation and 3.48 N/mm for the screw fixation (Figure 4). Additionally, there was an increase in fracture at the osteotomy site for the screw fixation group with catastrophic failure noted in four out of five specimens, while only one fracture was noted in both the single and dual staple fixation groups with fracture of the medial hinge. However, through dissection of the specimens post biomechanical testing, fixations remained intact without catastrophic failure (Table 1). During the surgical procedure in the dual staple fixation group, fracture of the medial hinge was encountered. As a result, stiffness was significantly decreased for this specimen in the dual staple fixation group. When this outlier was removed, the stiffness of the dual fixation group was significantly greater compared to the single staple group ($P< 0.05$).The average width and depth at 0.5 cm from the joint was 20.8mm and 22.06mm respectively. The average width and depth at 0.7 cm from the joint was 22mm and 26.2mm respectively. The average width and depth at 1.5 cm from the first tarsometatarsal joint was 17.7mm and 22.6mm respectively. The average width and depth at 2.5 cm from the first tarsometatarsal joint was 16.2mm and 15.3mm respectively (Table 2).

The treatment of hallux abductovalgus has a myriad of surgical procedures for treatment and correction. The type of fixation employed is also an important factor as the strongest construct that allows for the most correction with least risk of complication is pivotal when selecting the best treatment option. There is no single correct procedure for treatment of hallux valgus, however patients with increased deformity require a proximal metatarsal osteotomy or first tarsometatarsal joint fusion. In our study, we show that a closing base wedge of the first metatarsal is a viable treatment option for treatment of moderate to severe hallux abducto valgus. Furthermore, we demonstrated that a more transverse osteotomy can be performed in the metaphyseal portion of the bone and stably fixated with the use of nitinol staples.

Our study shows dual staple fixation for a closing base wedge osteotomy is comparable in stiffness to dual screw fixation and a single dorsal lateral staple fixation. Furthermore, dual screw fixation resulted in significantly greater catastrophic fractures after cyclical loading of 1500 cycles at 100N of force. This showed that the fatigue limit for the screw fixation group was much lower than the staple fixation groups. Furthermore, no catastrophic failures occurred in the staple fixation groups. There were fractures of the medial hinge in two of the specimens, however, the fixation remained intact. We can infer from the results of our study that staple fixation provides dynamic compression across the osteotomy compared to static compression from the screw fixation group. Furthermore, by placing a staple plantar and medial to the osteotomy on the tension side of the bone the staple

Sample	Fixation Type	Age	Sex	Method of Failure	Failure Cycle
A1	Screw	55	M	Failed at the at the joint proximally	1586
A2	Screw	48	F	Fracture through the osteotomy and plantar screw	1454
A3	Screw	64	F	Fracture through plantar osteotomy and plantar screw	1054
A5	Screw	60	M	Fracture through plantar osteotomy and plantar screw	90
B5	Dual Staple	69	M	Fracture at hinge displaced dorsally with load. Overall osteotomy intact	2000
C3	Single Staple	48	M	Fracture of medial hinge.	2000

Table 1. Type of fixation, age of specimen, and method of failure at specific cycle.

	0.5 cm	0.75 cm	1.2 cm	1.5 cm	2.0 cm	2.5 cm
Depth (mm)	20.8	26.2	22.9	22.6		15.3
Width (mm)	22.1	22.0		17.7	22.6	16.2

Table 2. Measurement of average width and depth at varying portions of the first metatarsal.

prevents distraction forces on the plantar aspect of the bone and converts those forces into compression forces.

During surgical procedure of one of the dual staple fixation specimens (MD19080520) the medial hinge was fractured which significantly compromises the stability of the osteotomy (12). When this specimen was removed from the dual fixation group, the dual fixation group was significantly greater when compared to the single staple fixation group. ($P < 0.05$)

Our study was not without weakness. Firstly, the study was performed on cadaveric specimens and the foot was amputated at Choparts joint to allow for fixation and biomechanical testing. All remaining soft tissue, however, was left intact with the hopes that this would provide us with a more accurate physiological scenario. Secondly, the small sample of specimens led to a lower power study, which made it more difficult to achieve statistical significance. Furthermore, we only measured displacement in the sagittal plane of each specimen. The proximal segment was the portion that was placed through range of motion because in gait the distal segment is fixed to the ground during this portion of gait. But, this is a one-dimensional model, while the first ray range of motion is tri-planar. By amputating at choparts joint and keeping all of the remaining soft tissue intact, we attempted to allow for some of the tri-plane motion of the first ray during testing. None of the specimens demonstrated a hallux abductovalgus deformity.

To our knowledge, this is the first study comparing dual staple and single staple fixation for a transverse closing base wedge osteotomy and screw fixation for an oblique closing base wedge osteotomy of the first metatarsal. Our study is novel because surrounding soft tissue was left intact as we believe this contributes to the overall stability of the osteotomy. With the results of this study we can conclude that a transverse closing base wedge osteotomy of the first metatarsal is a viable and stable fixation option for treatment of hallux abductovalgus compared to the standard closing base wedge osteotomy with dual screw fixation. Screw fixation of the closing base wedge osteotomy showed a lower fatigue limit compared to the staple fixation groups. With a more transverse osteotomy in the base of the first metatarsal, greater healing potential is allowed and with the addition of a plantar medial staple, distraction forces on the plantar aspect of the bone are resisted and thus converted to compression forces across the osteotomy.

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