Arthrodesis of the First Metatarsocuneiform Joint: A Comparative Study of Fixation Methods

Pierce E. Scranton, MD; J. Chris Coetzee, MD; Dominic Carreira, MD
Kirkland, WA

ABSTRACT

Background: The Lapidus bunionectomy is a popular procedure for severe bunion deformity where metatarsus primus varus is equal to or exceeds 15 degrees. We evaluated a new locking compression plate which may improve outcomes with the Lapidus procedure. Methods: Ten matched pairs of cadaver feet were used to compare the standard crossed 4.0-mm compression screw method of fixation to the LPS Lapidus plate. After performing the matched operations the cadaver constructs were stressed to failure using the INSTRON and Wavemaker software. Results: The LPS Lapidus plate load to failure was 108 Nm with a bending moment of 6.0 Nm. The crossed screw technique was inferior at 78 Nm with a bending moment of 4.4 Nm ($p = 0.02$). Conclusion: Unlike other H-plates or locking plates, load to failure was higher with the Lapidus plate constructs. Clinical Relevance: The increased rigidity provided by these plates may help to minimize the risk of nonunion or malunion.

Key Words: Lapidus; Compression Plate; Fusion

INTRODUCTION

Arthrodesis of the first metatarsocuneiform joint (Lapidus fusion) is an effective procedure for the correction of hallux valgus, metatarsus primus varus, and either post-traumatic or end stage arthritis. Several techniques have been used for fixation including Kirschner wires, partially threaded cancellous screws, Steinman pins, 3.5-mm or 4.5-mm cortical screws, and 1/4 tubular plates or so-called “H-plates.” Outcome studies have demonstrated a high satisfaction rate with this procedure, but the reported incidence of nonunion or malunion has ranged from 5% to 15%. Sangeorzan and Hansen reported a revision rate of 13% for mal- or nonunion following Lapidus bunion surgery. A variety of fixation plates have been developed with the intent of improving the biomechanical construct in Lapidus fusions, and by doing so, reduce the non-union rate. However, the gold standard of fixation was one or two compression screws across the arthrodesis. In a study by Cohen et al. the maximum load to failure for screw constructs was significantly stronger than with plate fixation. Marks et al. showed higher resistance to failure, but it was placed on the plantar side of the foot, which would be difficult to do during routine bunion surgery.

Therefore, a new fixation plate (Arthrex Corp, Naples, FL) has been developed which combines the advantages of both locking screw fixation and cross screw arthrodesis compression. This plate is named the LPS Lapidus Plate. We theorized that this new locking compression plate would provide superior load to failure and bending moment than the gold standard of two crossed 4.0-mm compression screws.

MATERIALS AND METHODS

Ten matched pairs of cadaver feet were used. The first and second metatarsal, cuneiform bones, navicular, and their corresponding connective tissue were surgically exposed. One foot from each pair was selected for the Lapidus repair fixed using the LPS Lapidus low-profile plate. The opposite side received the Lapidus repair using two 4.0-mm AO screws. All repairs were performed by the authors on the same day using these fresh cadaveric specimens.
After the surgery the navicular, first ray and second metatarsal were dissected en bloc. When the dissection was completed a 0.096-in hole was drilled through the navicular bone. The specimens were placed in a 1.5-in schedule 40 PVC pipe, and a 0.0945-in shear pin was inserted through the pipe and the navicular. The specimens were then potted with polymethylmethacrylate (PMMA) cement (Figure 1). Potting was done after the repairs were completed so that as much bone as possible was in the cement without interfering with the repair site.

Testing

The repaired feet were fixated to the base of an 8871 Servo hydraulic Materials Testing System (INSTRON, Canton, MA) by securing the PVC pipe in a V-block attached to the base at an angle of 15 degrees from horizontal to simulate anatomic position. A circular marker was placed on the plantar side of the medial cuneiform and proximal first metatarsal for optical tracking of the displacement during loading. The PVC pipe was positioned so that the plantar side was facing up, and the distal end of the first metatarsal was directly beneath the load cell (Figure 2).

A plunger was attached to the 5 kN load cell to apply downward pressure to the distal end of the first metatarsal to simulate dorsiflexion during push-off. The WaveMaker software allowed standardized moment arm measurements. If the force to failure in one construct was 175 N, and in another 163 N, but the lengths of the lever arms differed in a shorter versus longer foot, the software calculated the difference in distance so that the force to failure was similar. During loading, digital video of the specimen was recorded. The digital video and circular markers were used to determine displacement at the plantar aspect of the osteotomy site. The load-displacement curve was used to record failure loads. Mode of failure (failure was either fracture of the bone or failure of the screws attached to the bone) was recorded for each specimen.

Statistical analysis

A statistical analysis was performed with a paired t-test using a significance level of alpha = 0.05.

Surgical Technique

The fresh cadaver foot specimen was placed on the dissecting table and a 6 cm incision was made over the dorsomedial aspect of the foot, medial to the extensor hallucis longus tendon. The entire first metatarsocuneiform joint was exposed by sharp dissection. The medial and lateral aspects of the first metatarsal and cuneiform were well-visualized through this incision. The interval between the first and second metatarsals was exposed to remove any laterally protruding bone which might prevent correction of the first metatarsal alignment.

The articular surface was removed from the opposing surfaces of the first tarsometatarsal joint with either an oscillating saw blade or with small osteotomes and curettes. Several small drill holes penetrating the cancellous bone on either side of the joint were made. If the first metatarsal is relatively long, a laterally-based wedge was removed from the cuneiform to assist in the correction. It could also be angled slightly plantarly to assist in maintaining proper
distribution of weight under the metatarsal heads across the forefoot.

The first metatarsal was then reduced parallel to the second, closing the intermetatarsal gap. It was very important at this time to confirm that the first metatarsal was slightly plantar flexed and was rotated correctly. The joint was reduced and temporarily fixed with crossed Kirschner wires to hold it in the correct position. The Kirschner wires were inserted from the dorsal position so as to not interfere with the low profile plate placement on the medial side of the joint.

The locking plate was then placed over the medial side of the joint. Bony prominences around the joint were removed to create a flat surface for the plate. Provisionally the plate was held in place with the BB-Tak at the slot. Make sure the plate was reduced to the bone, secure, and aligned down the length of the metatarsal. If necessary a second BB-Tak could be used at the distal hole to secure plate conformity and alignment. The locking drill guides were inserted into the proximal holes or were attached to the plate before it was secured to the joint with the BB-Tak. A 3.5-mm appropriately measured locking screw was inserted in a proximal hole (Figure 3). The plate alignment along the medial border of the first metatarsal was confirmed, and then the second hole was drilled. The BB-Tak was removed and the joint compression screw inserted (Figure 4). This screw was introduced from the distal aspect of the plate’s middle slot.

The lag screw was drilled at as steep an angle as possible through the oblong slot hole in the middle of the plate, aiming between the two proximal Locking Screws, using the 2.5-mm drill. This drill went from the first metatarsal proximally into the cuneiform bone. The cancellous compression screw was placed and before it was fully tightened the two crossed Kirschner wires were removed. The final distal locking screw was inserted using the same technique as the proximal screws.

RESULTS

Ten matched cadaver feet had the Lapidus procedure performed, alternating right and left feet with either the LPS Lapidus Plate or the crossed screws. The results are shown in Tables 1 and 2. For the LPS Lapidus Plate, the ultimate load to failure was 108 N with a bending moment of 6.0 Nm. For the crossed 4.0-mm screw technique the ultimate load to failure was 78 N with a bending moment of 4.4 Nm ($p = 0.02$).

DISCUSSION

There are in excess of 130 different bunion reconstructive techniques.24 These surgical corrections are grouped into three basic regions of the first ray: distal metatarsal, mid-shaft, and proximal procedures. Various surgical techniques have evolved due to the real and perceived multiple variations and deformities in human forefoot anatomy. When the first-second intermetatarsal angle exceeds 15 degrees it is generally believed that this degree of deformity cannot be corrected by a distal bunion procedure, but rather by some type of proximal metatarsal osteotomy or more proximal tarsometatarsal arthrodesis.2,5,7,8,11,12,17,21,22 Whether first ray hypermobility exists as an etiological factor still remains controversial2,4,12,13,14 However, in severe bunion deformity wherein there is excessive metatarsus primus varus, successful correction has been well-established in the literature, going back to the original article by Lapidus.16 Lapidus first reported his technique in 1934. In the intervening years there have been many variations reported, predominantly associated with new techniques for fixation. Non-union or mal-union is the predominant cause for failure,
Table 1: Testing to failure data of the lapidus plate specimens

<table>
<thead>
<tr>
<th>Donor</th>
<th>Side</th>
<th>Moment Arm (mm)</th>
<th>Ultimate Load (N)</th>
<th>Bending Moment (N·m)</th>
<th>Mode of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L</td>
<td>55</td>
<td>161</td>
<td>8.9</td>
<td>Cross screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>2</td>
<td>R</td>
<td>55</td>
<td>30</td>
<td>1.7</td>
<td>Cuneiform fractured (repair remained intact)</td>
</tr>
<tr>
<td>3</td>
<td>L</td>
<td>58</td>
<td>75</td>
<td>4.4</td>
<td>Cross screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>4</td>
<td>L</td>
<td>53</td>
<td>187</td>
<td>9.9</td>
<td>Cross screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>5</td>
<td>R</td>
<td>56</td>
<td>83</td>
<td>4.6</td>
<td>Cross screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>6</td>
<td>L</td>
<td>52</td>
<td>101</td>
<td>5.3</td>
<td>Cross screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>7</td>
<td>L</td>
<td>57</td>
<td>172</td>
<td>9.8</td>
<td>Cross screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>8</td>
<td>L</td>
<td>57</td>
<td>118</td>
<td>6.7</td>
<td>Cross screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>9</td>
<td>L</td>
<td>63</td>
<td>55</td>
<td>3.5</td>
<td>Cross screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>10</td>
<td>L</td>
<td>55</td>
<td>98</td>
<td>5.4</td>
<td>Cross screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>108</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td></td>
<td>3.0</td>
<td>2.8</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Testing to failure data of the crossed screw specimens

<table>
<thead>
<tr>
<th>Donor</th>
<th>Side</th>
<th>Moment Arm (mm)</th>
<th>Ultimate Load (N)</th>
<th>Bending Moment (N·m)</th>
<th>Mode of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R</td>
<td>54</td>
<td>93</td>
<td>5.0</td>
<td>Distal screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>2</td>
<td>L</td>
<td>55</td>
<td>41</td>
<td>2.3</td>
<td>Distal screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>3</td>
<td>R</td>
<td>55</td>
<td>42</td>
<td>2.3</td>
<td>Distal screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>4</td>
<td>R</td>
<td>56</td>
<td>105</td>
<td>5.9</td>
<td>Distal screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>5</td>
<td>R</td>
<td>54</td>
<td>108</td>
<td>5.8</td>
<td>Distal screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>6</td>
<td>R</td>
<td>57</td>
<td>67</td>
<td>3.8</td>
<td>Proximal screw pulled out of distal side or repair</td>
</tr>
<tr>
<td>7</td>
<td>R</td>
<td>56</td>
<td>108</td>
<td>6.0</td>
<td>Distal screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>8</td>
<td>R</td>
<td>57</td>
<td>85</td>
<td>4.8</td>
<td>Distal screw pulled out of proximal side of repair</td>
</tr>
<tr>
<td>9</td>
<td>R</td>
<td>54</td>
<td>51</td>
<td>2.8</td>
<td>Cuneiform fractured (repair remained intact)</td>
</tr>
<tr>
<td>10</td>
<td>R</td>
<td>58</td>
<td>83</td>
<td>4.8</td>
<td>Proximal screw pulled out of distal side or repair</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>55.6</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td></td>
<td>1.4</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

and the evolution in fixation technique has been aimed at correcting this problem.9,22 Crossed Kirschner wires and screws have been available for decades as fixation devices.3,9,25 A variety of new fixation devices such as locked or unlocked H-plates were shown to be unsuccessful in providing greater stability for the construct.6,9,10,13,19 However, the LPS Lapidus Plate presented in this paper combines the advantages of the locking construct, combined with the cross compression screw for greater stability. It is important that the surgeon insert this compression screw as distal as possible in the plate’s middle slot, as this will allow for more stability at the base of the screw and will also allow for a more perpendicular screw angle across the arthrodesis, increasing the compression force. Its low-profile design when carefully applied by the surgeon can minimize excessive prominence which will create secondary pressure points necessitating later removal (Figure 5).

When there has been traumatic disruption associated with a medial column Lisfranc injury, instability due to ligamentous disruption or a comminuted fracture of the medial column has the main pathology.1,18,19 Failure to stabilize this injury can lead to catastrophic forefoot collapse. We believe the LPS
or the LPS Lapidus plate. This will be a longer term, multi-
dure will have either crossed 4.0-mm screws used for fixation
wherein patients who are candidates for the Lapidus proce-
creating a randomized prospective study with IRB approval
treatment of patients.
extrapolate to clinical results one might expect during the
to failure studies. We believe the results are reasonable to
the experimental constructs of previously published load
to-failure characteristics. Nevertheless it follows carefully
column Lisfranc arthrodeses.

Fig. 5: Shown is a postoperative anteroposterior radiograph of a successful
Lapidus procedure using the LPS Lapidus plate.

plate could be used for either primary or secondary medial
column Lisfranc arthrodeses.

The limitations of this study are that it is a cadaver study,
and stability in vivo may exhibit different fixation and load-
to-failure characteristics. Nevertheless it follows carefully
the experimental constructs of previously published load to
failure studies. We believe the results are reasonable to
extrapolate to clinical results one might expect during the
treatment of patients.

Further clinical studies will be necessary. We are currently
creating a randomized prospective study with IRB approval
wherein patients who are candidates for the Lapidus proce-
dure will have either crossed 4.0-mm screws used for fixation
or the LPS Lapidus plate. This will be a longer term, multi-
center study which will take at least 5 years to complete.

EDITOR’S NOTE

The authors are to be commended for a good study evaluating first TMT arthrodesis stability in a cadaveric
construct. However, clinical failure usually does not occur
catastrophically such as in the model employed here. A cyclic
loading model would probably more accurately reflect the
usual clinical mode of failure.

REFERENCES

1. Bednarz, PA; Manoli, A: Modified Lapidus Procedure for
the Treatment of Hypermobile Hallux Valgus. Foot Ankle Int.

2. Bozkurt, M: Stability of a Cannulated Screw vs. a Kirschner Wire
for the Proximal Crescentic Osteotomy of the First Metatarsal: A
http://dx.doi.org/10.1053/j.jfas.2004.03.010

3. Carl, A; Ross, S; Evanski, P; Waugh, T: Hypermobility in hallux

4. Catanzariti, A; Mendicino, RW; Lee, MS; Gallina, MR: The
Modified Lapidus Arthrodesis: A Retrospective Analysis. J. Foot Ankle

5. Chow, YC; Lui, TH; Kwok, KW; Chow, YY: Plate Fixation for
Crescentic Metatarsal Osteotomy in the Treatment of Hallux Valgus:
An Eight-Year Followup Study, Foot Ankle Int. 29: 29–33, 2008.
http://dx.doi.org/10.3113/FAI.2008.0029

6. Clark, HR; Veith, RG; Hansen, ST: Adolescent Bunions Treated

7. Coetzee, JC; Wickum, D: The Lapidus Procedure: A Prospective

8. Cohen, DA; Parks, BG; Schon, LC: Screw Fixation Compared to
H-Locking Plate Fixation for first Metatarsocuneiform Arthrodesis: A
Biomechanical Study, Foot Ankle Int. 26: 984–989, 2005.

9. Ego, KA; Kubiak, EN; Fulkerson, E; Kummer, FJ; Koval, KJ:
Biomechanics of Locked Plates and Screws. Orth. Trauma, 18:488–493,

10. Goldner, JL; Gaines, RW: Adult and Juvenile Hallux Valgus: Analysis


12. Horton, GA; Olney, BW: Deformity Correction and Arthrodesis of the

13. Johnson, KA; Kile, TA: Hallux Valgus Due to Cuneiform Metatarsal

14. Komenda, GA; Myerson, MS; Biddingger, KR: Results of arthrodesis
for Management of Hallux Valgus and Metatarsus Primus Varus. J. bone

15. Lapidus, PW: The Operative correction of the Metatarsus Varus Primus


17. Mann, RA; Priekskorn, D; Sobel, M: Mid-tarsal and Tarsometatarsal
Arthrodesis for Primary Degenerative Osteoarthrosis or Osteoarthritis

18. McInnes, BD; Bouche, RT: Critical Evaluation of the Modified

19. Myerson, M; Allon, S; McGarvey, W: Metatarsus-cuneiform
Arthrodesis for Management of Hallux Valgus and Metatarsus Primus

20. Sangeorzan, BJ; Hansen, ST: Modified Lapidus Procedure for Hallux
Valgus. Foot Ankle Int. 9:262–266, 1989.

21. Scranton, PE; Zuckerman, JD: Bunion Surgery in Adolescents:


23. Vienne, P; Favre, P; Meyer, D; et al.: Strength of Fixation of Ludloff
Metatarsal Osteotomy Utilizing Three different Types of Kirschner

24. Vienne, P; Favre, P; Meyer, D; et al.: Comparative Mechanical
Testing of Different Geometric Designs of Distal first Metatarsal

25. Weil, I; Zlottoff, HJ; Couture, SD; et al.: Diagnosis and treatment of
first metatarsophalangeal joint disorders. Section 3: Hallux varus. J