

CHAPTER 12

Proximal Midshaft Osteotomies of the First Metatarsal–The Mau, Ludloff, and Scarf Procedures

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INTRODUCTION

In this chapter, we will focus on three popular midshaft osteotomies: the Mau osteotomy as a standalone procedure or combined with a Reverdin-Laird osteotomy, the Ludloff osteotomy, and separately, the Scarf osteotomy.

DEFINITION

Midshaft osteotomies are mostly centered in the hard cortical bone of the shaft of the first metatarsal. Ludloff in 1913 and 1918 was the first to describe an oblique first metatarsal osteotomy oriented from dorsal proximal to plantar distal.¹ Mau challenged the inherent instability of the Ludloff procedure and described the reverse osteotomy oriented from dorsal distal to proximal plantar, producing an inherent stable and rigid dorsal shelf to resist the ground reactive forces² (Fig. 12.1). As originally published, both of these procedures were not fixated and thus lacked stability. Furthermore, their location within hard cortical mid-diaphyseal bone was a cause for concern for more healing difficulties. These procedures were not popular until the mid-1990s when several authors described modifications of lengthening these osteotomies into the more proximal cancellous region of the metatarsal. This created a more proximal center of rotation and, together with rigid internal fixation, increased stability and ease of healing.³⁻⁶ The Mau and Ludloff osteotomies regained favor since they are easily performed involving only a single cut and are reliably reproducible.

RELEVANT ANATOMIC CONSIDERATIONS FOR MAU AND LUDLOFF

The anatomic topography of the first metatarsal becomes important with shaft osteotomies. The shaft of the first metatarsal is concave plantarly and becomes triangular as it approaches the base of the metatarsal at its articulation with the medial cuneiform. The medial surface is narrow and short, and the lateral surface is longer and flatter. The nutrient foramen is usually found on the lateral surface.^{7,8} The head of the first

metatarsal derives its circulation from the first intermetatarsal artery and medial plantar artery.

Another important anatomic note is the insertion of the peroneus longus tendon on a tubercle on the inferolateral aspect of the base.^{7,8}

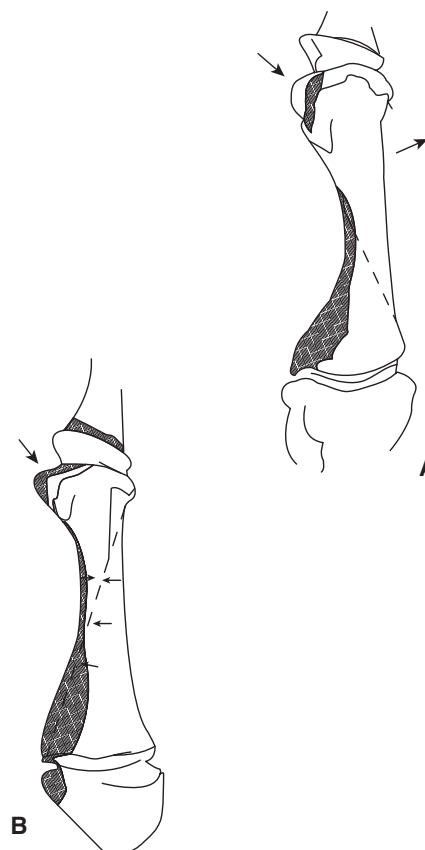


FIGURE 12.1 **A.** Ludloff osteotomy. Ground reactive forces will distract the dorsal fragment containing the head of the metatarsal. **B.** Mau osteotomy. Ground reactive force will not allow distraction of the plantar fragment containing the head of the metatarsal as the dorsal shelf will block the motion.

SURGICAL PEARLS FOR MAU AND LUDLOFF OSTEOTOMIES RELATED TO ANATOMY OF THE FIRST METATARSAL

- Because of the triangular undersurface of the first metatarsal, when fixating these osteotomies, the orientation of the screws should be directed slightly medially and not directly plantar through the center of the plantar triangular surface. Doing so may split the plantar bone and cause a stress fracture along the length of the plantar cut, which will compromise fixation and stability (Fig. 122.2).
- Midshaft osteotomies are always made on the medial surface along the length of the metatarsal and extend to the lateral surface. Care must be taken not to make the dorsal or plantar surface too thin, or this may also cause an increased chance for stress fractures or failed fixation.
- The Mau osteotomy exits in the area of the peroneus longus insertion at the base of the first metatarsal. Therefore, care should be taken to avoid severing the peroneus longus tendon insertion.^{7,8} We recommend not completing the full plantar cut with an oscillating saw. Rather, we start the cut with a saw, and we complete it with an osteotome by distracting the dorsal and plantar fragments from each other. When performing the Mau, we routinely enter the very endpoint of the plantar base to provide the most proximal hinge for axis of rotation, as will be described in the Mau osteotomy technique section later in the chapter.
- Caution should also be used when performing these procedures on a narrow metatarsal, as this may complicate fixation when translated or rotated.

PEARLS FOR THE MAU OSTEOTOMY

- Make a long osteotomy parallel to the weight-bearing surface.
- Position the foot laterally on the operative table when making the osteotomy.
- Most stable construct recommended by the author is with screw and plate fixation.
- First, fixate with a 3.5-mm cortical screw at the point of rotation replacing the K-wire. Follow this with application of 5-6 holes thin compression plate with 2.4-mm locking screws. Insert first two screws proximally at the osteotomy and then apply the screws distal to the osteotomy securing the plate on the metatarsal. Leave the plate hole over the dorsal exit site of the osteotomy open. If have room, add last screw placement to insert again proximally over osteotomy.
- If adding Reverdin-Laird osteotomy, it is fixed with a 3.0-mm headless double-threaded screw. Oriented from medial dorsal shaft to lateral plantar into the metatarsal head.

AXIS AND PLANE OF MOTION AS IT RELATES TO MIDSHAFT OSTEOTOMIES

In wedge osteotomies, the axis of motion is influenced by the orientation of the hinge. For example, in a closing base wedge procedure, the metatarsal may plantar flex or dorsiflex with closure of the wedge depending on the orientation of the hinge axis.

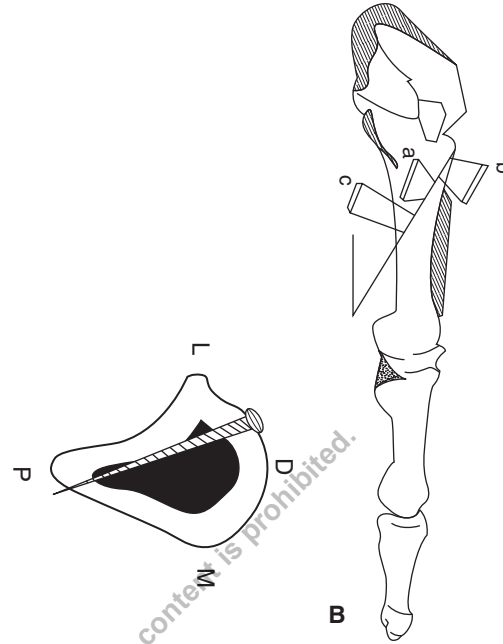


FIGURE 12.2 **A.** Orientation of the screws should be directed slightly medially and not directly plantar through the center of plantar triangular surface, which can cause a stress fracture along the length of the plantar cut compromising fixation and stability. **B.** In plane-of-motion osteotomies such as Mau and Ludloff. The orientation of the hand and saw will influence the direction of motion. Example of Ludloff osteotomy with (a) hand neutral, (b) saw tilted down metatarsal head will declinate—plantar flex, and (c) saw tilted up metatarsal head will elevate—dorsiflex. (Adapted with permission from Nyska M, Trnka H-J, Parks BJ, Myerson MS. The Ludloff metatarsal osteotomy: guidelines for optimal correction based on geometric analysis conducted on a sawbone model. *Foot Ankle Int.* 2003;24(1):34-39.)

In contrast, The Mau, Ludloff, and Scarf are “plane-of-motion” osteotomies, where the orientation of the cut itself will influence the direction of motion. For example, the metatarsal may plantar flex or dorsiflex depending on the position of the saw as the cut is made (see Fig. 12.2). Therefore, care must be taken when creating the osteotomy to have the hand positioned properly so as not to cause an undesired elevation or declination of the metatarsal.

Plane-of-motion osteotomies can be categorized into two types:

1. *Translational:* one segment of bone is slid or transposed over another. The scarf is primarily a transpositional osteotomy but may allow for minimal rotation and some proximal articular set angle (PASA) correction as will be discussed later in the Scarf historical review section.
2. *Rotational:* one segment of bone is rotated over another. Both the Ludloff and Mau are primarily rotational osteotomies. However, they can allow for some transposition as will be described later in the chapter. Care must be taken when translating the bone so not to overtranslate more than 5 mm as this may compromise stability and fixation.⁹ Furthermore, as rotation increases, the first metatarsophalangeal (MTP) joint becomes incongruent, increasing the chance for arthritis. This maneuver also increases the PASA and chance of recurrent bunion deformity¹⁰⁻¹²

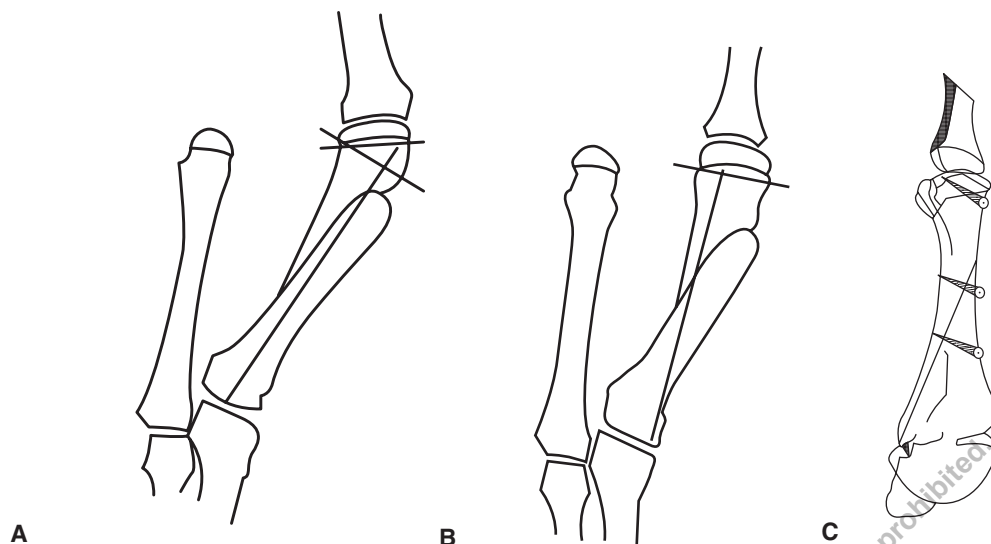


FIGURE 12.3 **A.** As rotation increases, the congruity of the joint is compromised increasing the proximal articular set angle (PASA) and making the joint incongruent. **B.** The Mau as shown or Ludloff can be combined with a Reverdin-Laird osteotomy, which can correct for the increased PASA at the capital fragment. It can also correct some for additional increased intermetatarsal angle by translating the capital fragment laterally after realignment of the PASA. **C.** Mau-Reverdin shown after fixation. (Adapted from Neese DJ, Zelent ME. The modified Mau-Reverdin double osteotomy for correction of hallux valgus: a retrospective study. *J Foot Ankle Surg.* 2009;48(1):22-29.)

(Fig. 12.3A). The Mau and Ludloff can be combined with a distal head osteotomy, such as a Reverdin-Laird,¹³ which can correct for the increased PASA at the capital fragment. It can also correct some for additional increased intermetatarsal angle by translating the capital fragment laterally after realignment of the PASA^{3,9,11,14,15} (Fig. 12.3B and C). This will be discussed in more detail at the end of the fixation section.

INDICATIONS

The Mau, Ludloff, and Scarf midshaft osteotomies are mostly reserved for when distal, capital head procedures are not sufficient to reduce a high intermetatarsal angle. The goal of midshaft osteotomies is to adequately correct a large intermetatarsal angle without the need for a wedge osteotomy and to avoid invasion of the first metatarsal-cuneiform joint.

Midshaft osteotomies are primarily indicated for moderate hallux valgus deformities. The overall radiographic criteria range would be an intermetatarsal (IM) angle of 12-20 degrees and a hallux abductus (HA) angle > 30 degrees.¹² Average IM correction of 9 degrees and HA correction of 22

degrees is relatively similar with the Ludloff^{12,16-19} and Mau osteotomies.^{11,14,15,20-22} Ideally, there should be no arthritis of the first MTP joint. The PASA should not be excessively elevated as this may become worsened with rotation and translation as described above.

SURGICAL TECHNIQUE FOR MAU AND LUDLOFF

CONTRAINDICATIONS

- Arthrosis of first MTP joint
- Poor bone quality

ADVANTAGES OF MAU/LUDLOFF OSTEOTOMIES

- Correction of advanced bunion deformities
- Stable construct maintaining intrinsic stability of the first metatarsal
- Minimal or no shortening of the first metatarsal

SKIN INCISION AND SOFT TISSUE RELEASE

The author's (TBD) midshaft procedure of choice is the Mau osteotomy and is most often combined with a distal Reverdin-Laird procedure for realignment of the PASA and additional IM correction if needed.

The initial incision and release are the same for both the Mau and Ludloff osteotomies. A dorsolateral and slightly medially based skin incision is made over the first MTP joint medial and parallel to the extensor hallucis longus tendon. It extends prox-

INDICATIONS FOR MAU/LUDLOFF OSTEOTOMIES

- IM angle 12-20 degrees
- HA angle >30 degrees
- Short metatarsal
- Desire not to fuse first metatarsal-cuneiform joint



FIGURE 12.4 Skin incision dorsal linear and slightly medial over the first MTP joint medial and parallel to the extensor hallucis longus tendon extending proximally to the base of the first metatarsal just at the cuneiform joint.

imally to the base of the first metatarsal at the cuneiform joint (Fig. 12.4). The incision is deepened to the periosteum and capsule, where an inverted-L capsulotomy is made at the head of the metatarsal with the long arm ending at the proximal edge of the incision. The first MTP joint is then inspected for any

increased PASA (Fig. 12.5A). Next, the medial metatarsal exostoses at the head are resected with a sagittal saw. The capsule and full-thickness periosteum are reflected dorsally and plantarly, exposing the plantar surface of the metatarsal down to the base, where the apex of the triangular base or “flare” will be palpable and visualized (Fig. 12.5B). A soft tissue release of the first interspace is performed by cutting the conjoined adductor hallucis tendon and release of the fibular sesamoid metatarsal suspensory ligament (Fig. 12.6). The hallux is then manipulated in the direction of maximum allowable adduction to release any further adhesions or scarring within the first metatarsal interspace, which may be still maintaining the toe in the abducted position. The fibular sesamoid is palpated to ensure it can be realigned under the metatarsal as the hallux is repositioned medially.

OSTEOTOMY TECHNIQUE

Mau Osteotomy

The foot is repositioned on the table with the lateral aspect against the operative table and the dorsal, medial, and plantar aspect of the first metatarsal exposed and facing dorsally. We minimize lateral and dorsal dissection of the soft tissues surrounding the metatarsal head, thus protecting the blood flow to the head. Adequate protection of the dorsal and plantar soft tissue and neurovascular structures is achieved with Hohmann, malleable, and Senn retractors.

A sagittal saw is then used to create the Mau osteotomy with a single cut starting distally and dorsally and ending proximally and plantarly. The osteotomy is made as close to parallel to the weight-bearing surface as possible. The osteotomy begins approximately 1.5–2.0 cm proximal to the first MTP



FIGURE 12.5 **A.** The first MTP joint is then inspected for any increased PASA. **B.** Capsule and full-thickness periosteum are reflected dorsally and plantarly with exposed plantar surface of the metatarsal down to the base, where the apex of the triangular base or “flare” is palpable and visualized. The medial metatarsal exostoses at the head have been resected with a sagittal saw.

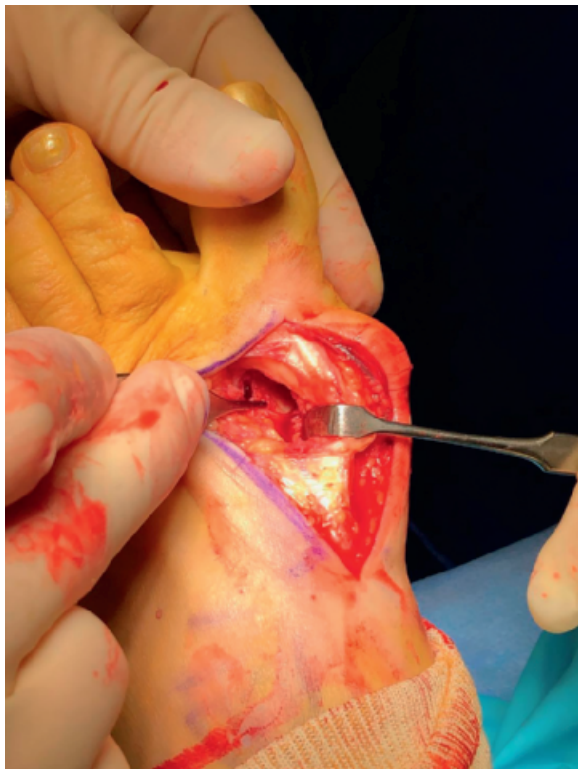


FIGURE 12.6 The first interspace soft tissue release is achieved by releasing of the conjoined adductor hallucis tendon and release of the fibular sesamoid metatarsal suspensory ligament. Note forceps pointing to the dorsal articular surface of the fibular sesamoid visualized in the interspace.

joint, extending into the shaft, and ending approximately 1.0 cm distal to the first metatarsal-cuneiform joint. The cut should be sufficiently long enough to allow for appropriate fixation, and it can extend into the metatarsal base at its flare and, if necessary, to the metatarsal at the edge of the medial cuneiform joint (Fig. 12.7). In both the Mau and Ludloff procedures, rotation of the metatarsal osteotomy occurs around a single axis point. The further proximal the rotational axis point is (ie, the closer the axis of rotation is to the tarsometatarsal joint), the less the angular correction will be distally within the metatarsal itself.²³ When reducing a high IM angle, if the axis is too far distal, the metatarsal will have a “banana-shape” from increased acuity and create an increased PASA and incongruent joint. Sammarco⁹ described modifying the Mau with a second cut made with a smaller, 5-mm blade transversely through the plantar metaphyseal cortex. This allows for extension of the osteotomy more proximally to gain more significant correction, since the axis of rotation will be more proximal. Our experience has not led us to see the need for this second cut. We always enter the proximal cortex and create the rotational axis point close to the metatarsal-cuneiform joint at the apex of the plantar triangular portion of the proximal metatarsal and have not seen complications from this (Fig. 12.8). Hence, at times, the osteotomy ends at the metatarsal-cuneiform joint at the end point of the apex of the plantar flare. Recognizing that we are in the area of the peroneus longus insertion at the metatarsal base, the cut is not completed proximally with the saw, but rather a



FIGURE 12.7 Outline of the Mau osteotomy. Note the cut is made as close to parallel to the weight-bearing surface as possible. The osteotomy begins approximately 1.5-2.0 cm proximal to the first MTP joint, extending into the shaft, and ending distally just shy of the first metatarsal-cuneiform joint. It can extend into the metatarsal base at its flare at the edge of the medial cuneiform joint.

thin osteotome, which is inserted at the proximal $\frac{1}{4}$ of the metatarsal. The osteotome is extended dorsally and plantarly between the fragments, separating them and completing the cut. This protects the peroneal longus tendon insertion point at the base of the first metatarsal. It also creates a fixed, thick dorsal shelf and a plantar segment that includes the metatarsal head (Fig. 12.9). The head of the first metatarsal should be parallel to the weight-bearing surface. Maintaining this position, the osteotomy is stabilized with a bone clamp, and the foot is then repositioned to face dorsally on the opera-

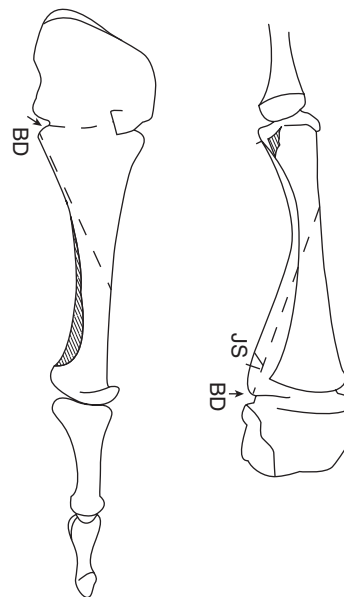


FIGURE 12.8 **A.** Sammarco⁹ described modifying the Mau with a second cut made with a smaller, 5-mm blade transversely through the plantar metaphyseal cortex **B.** The author's (TBD) preferred osteotomy enters the proximal cortex close to the metatarsal-cuneiform joint at the apex of the plantar triangular portion of the proximal metatarsal.



FIGURE 12.9 The cut is completed proximally with a thin osteotome inserted at the proximal quarter and the hand extended dorsally and plantarly between the fragments, thus separating the fragments and completing the cut while protecting the peroneal longus tendon insertion at the base of the first metatarsal. Note the thick dorsal shelf and plantar fragment that includes the metatarsal head.

tive table (Fig. 12.10). A 0.045 K-wire (or a guidewire if using cannulated screws) is inserted at the proximal aspect, perpendicular to the osteotomy from dorsal to plantar, to provide stabilization and a rotational axis (Fig. 12.11). When placing the wire, it is important to maintain the original length of the first metatarsal unless there is a specific need to shorten or lengthen it. The clamp is removed and the plantar shelf, which contains the metatarsal head, is rotated laterally and under the stable dorsal shelf to reduce the IM angle (Fig. 12.12). This is achieved by pulling the plantar fragment medially with a towel or bone clamp and rotating the dorsal shelf either with a bone clamp or with thumb pressure. When necessary, the metatarsal can be slightly lengthened or shortened by sliding the plantar segment on the distal segment prior to inserting the stabilizing axis wire. Using a bone



FIGURE 12.10 The osteotomy is stabilized with a bone clamp, and the foot is then repositioned to face dorsally on the table.



FIGURE 12.11 A 0.45 K-wire, or guidewire if fixating with cannulated screw, is drilled at the proximal aspect, perpendicular to the osteotomy from dorsal to plantar, providing stabilization and a rotational axis point.

clamp, the osteotomy is compressed to stabilize the metatarsal in its corrected position, and a secondary K-wire or guidewire can be inserted to help maintain this corrected position while fixating the osteotomy (Fig. 12.13).

A fluoroscope is used intraoperatively to visualize the correction. If additional IM correction is necessary, it can be

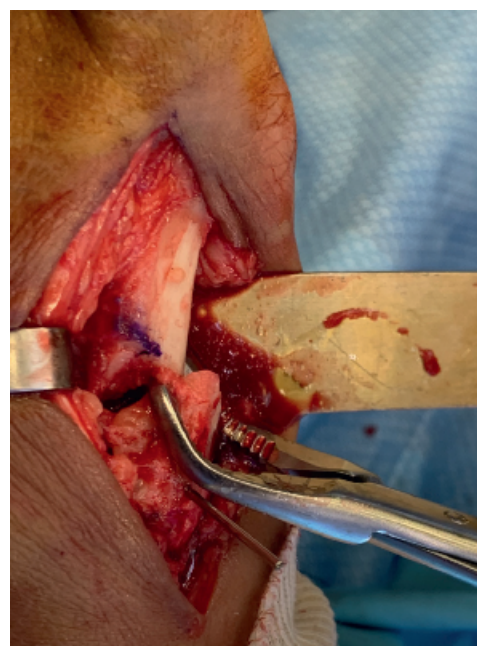


FIGURE 12.12 The plantar shelf, which contains the metatarsal head, is rotated laterally and under the stable dorsal shelf to reduce the IM angle and then clamped in the fixed position.

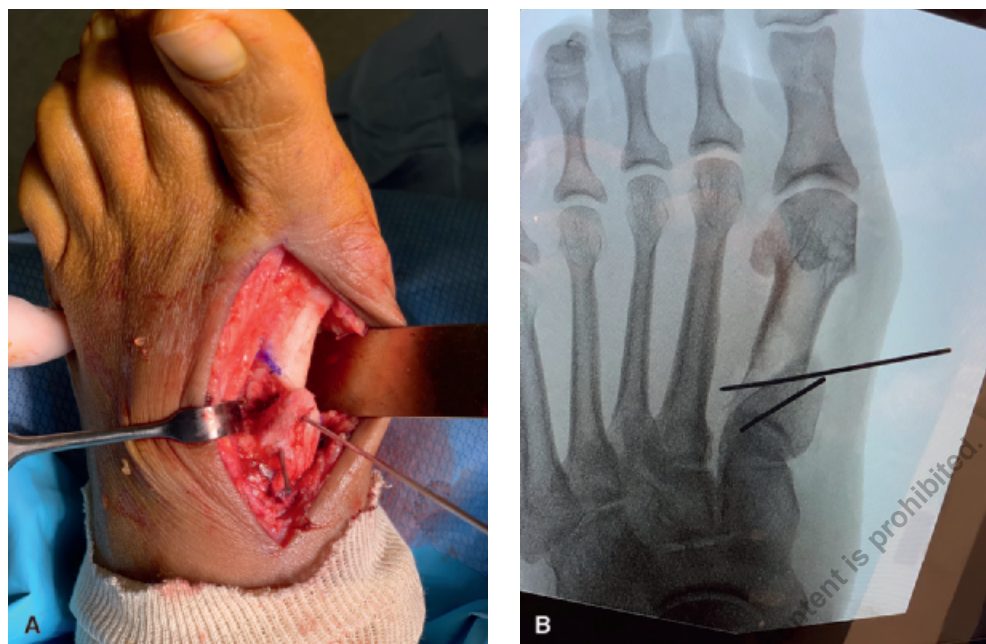


FIGURE 12.13 **A.** A secondary K-wire can be inserted to help maintain the corrected position while fixing the osteotomy. **B.** Intraoperative fluoroscope. Correction of IM deformity with the 0.45 K-wire rotational axis point proximal and secondary distal 0.45 K-wire stabilizing the bone.

achieved by initially sliding the plantar segment on the dorsal segment laterally to a limit of 5 mm before the axis wire is placed and rotational correction achieved.⁹ As explained above, excessive translation of the plantar fragment may compromise stability and fixation. In cases where a distal Reverdin-Laird osteotomy will be required, the distal capital fragment can be translated laterally for additional IM angle correction.

Ludloff Osteotomy

Beischer et al.,²⁴ using three-dimensional computer modeling, found the optimal geometric parameters for the Ludloff osteotomy started at the dorsum of the first metatarsal base just at the joint and extended distally and plantarly to a point just proximal to the sesamoid articulation. Furthermore, a tilt of 10 degrees in the coronal plane of the osteotomy (ie, saw tilted down) was necessary to limit first metatarsal head elevation.^{24,25} The best axis of rotation was within 5 mm of the proximal end of the osteotomy. The most common configuration of the Ludloff osteotomy is an oblique cut starting approximately 5–8 mm anterior to the metatarsal cuneiform joint and continuing toward the plantar-distal diaphysis with about 30 degrees of inclination (Fig. 12.14). This construct permits a broad area of bony contact involving some metaphyseal bone for better stability and healing, and allows for greater IM angle correction by being closer to the apex of the deformity. It is important to place retractors, such as Hohmann or malleable-type retractors, dorsal proximal to protect the extensor hallucis longus tendon and plantar-distal to protect the plantar artery to the metatarsal head.²³ Initially, the dorsal two-thirds of the osteotomy is carried out without completion of the plantar cortex distally.^{17,18,23} A proximal screw, most commonly through a guidewire, is inserted and directed from dorsal to plantar.

This will act as the center of rotation. As stated with the Mau above, the further proximal the osteotomy is performed (ie, the closer the axis of rotation is to the tarsometatarsal joint), the less the angular correction is distally.²³ The osteotomy is then completed, and the distal fragment is rotated around the proximal screw. The second screw is placed about 1 cm distal to the first one to complete the fixation.¹² To rotate the osteotomy, pull the plantar fragment medially either with an instrument and rotate the dorsal fragment laterally either with a bone clamp or by the use of thumb pressure on the shaft or head. The first screw is fully tightened to hold the correction. The second screw is then inserted either from dorsal to plantar or as recommended by some^{12,18,26} from plantar to dorsal, across the distal aspect of the osteotomy and approximately 1 cm distal to the first screw as described below in the fixation technique section.

FIXATION TECHNIQUES

Mau and Ludloff Osteotomies

The Mau and Ludloff midshaft osteotomies are commonly fixed with compression screws. The alignment of the screws is as close to perpendicular to the osteotomy as possible, with supplemental K-wire or plate fixation. Sometimes, correction can be lost when orienting the screws perpendicular due to tension across the osteotomy. In this case, orient the screws in a position that will maintain the greatest correction. Additionally, the screws are placed slightly medial to capture the opposing cortex and not oriented directly plantar. This avoids the screws exiting through the center of the plantar triangular surface and potentially splitting the plantar bone creating a fracture along the length of the plantar cut (Fig. 12.15). When fixing the Mau, multiple screws can be used. The first screw to be inserted

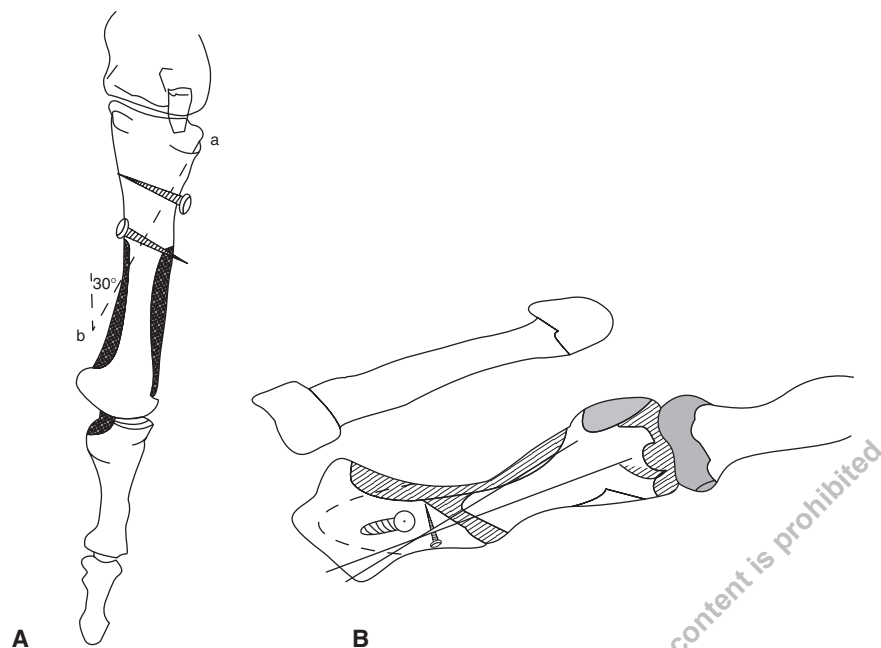


FIGURE 12.14 **A.** The most common configuration of the Ludloff osteotomy is an oblique cut starting dorsally approximately 5-8 mm anterior to the metatarsal cuneiform joint and continuing toward the plantar-distal diaphysis with about 30 degrees of inclination. (Adapted from Bae SY, Schon L. Surgical strategies: Ludloff first metatarsal osteotomy. *Foot Ankle Int.* 2007;28(1):137-144; Schon LC, Dom KJ, Jung H-G. Clinical tip: stabilization of the proximal Ludloff osteotomy. *Foot Ankle Int.* 2005;26(7):579-580.) **B.** Some authors recommend that the second distally oriented screw in the Ludloff be inserted from plantar to dorsal across the distal aspect of the osteotomy and approximately 1 cm distal to the first screw. Two K-wires for supplemental reinforcement for the Ludloff. The wires are oriented from proximal medial and driven distal into the metatarsal head or shaft and oriented parallel to the cut.

is at the proximal axis point. Fixation is then carried distally with one or two more screws inserted distal to the initial screw. Sizes range from 2.7 to 4.0 mm at the proximal apex and as small as 2.0 mm at the distal aspect of the osteotomy. We recommend using headed screws. Robinson et al.¹⁷ compared Scarf and Ludloff osteotomies and determined that headless screws are insufficient to hold the Ludloff osteotomy and may attribute to delayed union and malunion. Countersinking the screws, especially the proximal one, is important to reduce the risk of fracture of the dorsal metatarsal cortex.^{18,23} This is true for both the Mau and Ludloff. Some authors^{12,18,26} recom-

mend that the second distally oriented screw in the Ludloff be inserted from plantar to dorsal across the distal aspect of the osteotomy and approximately 1 cm distal to the first screw (see Fig. 12.14). There is no literature to support inserting the distal screws from plantar to dorsal in the Mau, although this may be beneficial. Schon²⁶ does not use a lag screw here with the Ludloff, as he feels the screw will not be perpendicular when the bones are in the corrected position. Attempting a lag screw in this case may cause loss of correction through tension across the osteotomy.

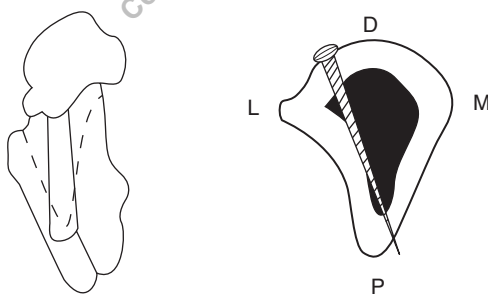


FIGURE 12.15 When fixing the Mau and Ludloff, the screws are oriented slightly medial to capture the opposing cortex and not directly plantar thereby avoiding the center of the plantar triangular surface and a potential stress fracture along the length of the plantar cut compromising fixation and stability. L, lateral; D, dorsal; M, medial; P, plantar.

PERILS and PITFALLS

- “Banana” metatarsal by making a short osteotomy or overrotation of the first metatarsal.
- Beware of compromised peroneal longus tendon insertion.
- Do not translate more than 5 mm if at all. Mau and Ludloff are primarily rotational osteotomies.

To bolster stability in the Ludloff, Bae, and Schon, insert two K-wires for supplemental reinforcement.¹² This is especially helpful when encountering osteoporotic bone. The wires are oriented from proximal medial and driven distal into the metatarsal head or shaft and oriented parallel to the cut. Choi et al.²⁷ showed that insertion of a supplementary K-wire in the Ludloff also reduces the loss of IM correction, which can occur with these osteotomies at the time of immediate fixation or up to 1 year from the surgery¹⁷ (see Fig. 12.14).

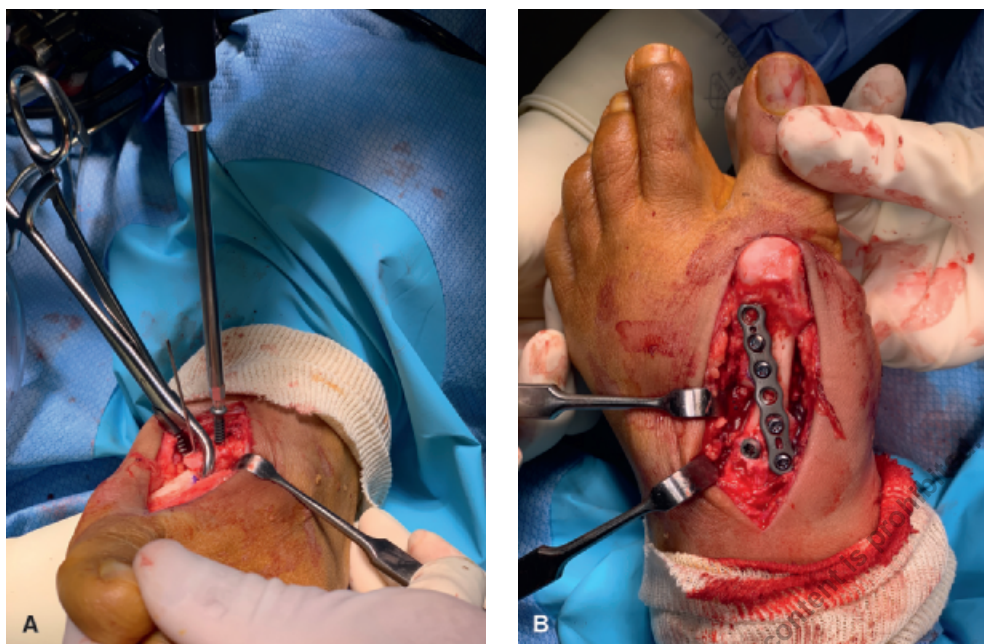


FIGURE 12.16 A. Mau osteotomy fixated with screw and plate construct. Note the proximal 3.5-mm solid cortical compression screw (Stryker Corp) replaced the proximal 0.45 K-wire. **B.** Following this, a plate is aligned medial to the screw and extends dorsal and lateral over the osteotomy. Note 5-hole slim compression plate with 2.4-mm locking screws (Stryker Corp). Authors preferred construct includes 2-3 screws proximal and crossing the osteotomy, thus providing additional fixation to the osteotomy through the plate. The dorsal edge of the osteotomy is aligned with an empty plate hole. Distal to the osteotomy 2 compression screws secure the plate on the bone. Image reprinted with permission from Stryker Corporation. © [2021] Stryker Corporation. All rights reserved.

More recently, there has been a push for fixation utilizing locking plates to add more stability, resistance to fatigue, and loss of fixation.^{23,28-30} Saxena found that fixation of the Ludloff with a locking plate provided superior stabilization to two lag screws.²⁴ A locking plate may also minimize loss of correction.

Reports of supplemental K-wires or using locking plates have not as of now been documented in the literature with the Mau.¹¹ However, we have started to employ plating techniques for the Mau osteotomy. When fixating the Mau with a plate, we recommend fixating the osteotomy proximally with an independent compression screw and then applying the plate distal to this screw. A second screw is placed through the plate (either standard technique or locking) fixating the osteotomy at a second point. The rest of the screws crossing the plate will stabilize the dorsal and plantar fragments against load and shearing forces (Fig. 12.16).

Once full fixation is complete, the osteotomy is tested for stability by attempting to place a slight bending force at the head with one's fingers and observing for distraction of the osteotomy.

When complete, the Mau and Ludloff will have a redundant medial shelf of bone, which is smoothed with a power bur.

At this point, if articular deviation is present or additional IM correction is warranted, a Reverdin-Laird osteotomy¹³ is performed. The authors preferred method of fixating this osteotomy is with a single cannulated headless 3.0-mm-diameter screw oriented from dorsal proximal to distal plantar and directed into the head with avoidance of the articular cartilage of the distal metatarsal (Fig. 12.17A-C).

Alternative fixation techniques include staples or a K-wire (Figs. 12.18A-C and 12.19A-C).

POSTOPERATIVE PROTOCOLS FOR MAU AND LUDLOFF OSTEOTOMIES

The literature does not have a consensus on postoperative protocols for the Mau and Ludloff procedures. There is a wide variation ranging from immediate heel weight bearing in a rigid post-op shoe with an assistive device, immediate walking with a CAM boot walker, to immobilization with a cast for 1-6 weeks prior to full weight bearing.^{11,15,17,18,20-23,27,29,30} Constructs with more rigid fixation, such as locking plates and the presence of better bone quality, may allow for earlier weight bearing.²⁹ Neufeld found that locking plates used with the Ludloff provided ability for immediate weight bearing with no increased recurrence rates compared to other protocols.²⁹ When fixating the Mau with only screws, we recommend 4 weeks of non-weight bearing. With plate fixation, the osteotomy appears much more stable and resistant to shear and distraction; therefore, we are more liberal. In this case, we use a forefoot splint with partial weight bearing on the heel for 3 weeks in a post-op shoe before returning to partial weight bearing in a sneaker. Serial radiographs are taken to ensure healing of the osteotomy before allowing for full weight bearing in a supportive sneaker shoe. Most patients are able to wear casual shoes between 8 and 12 weeks, while full recovery is typically not achieved for 6-9 months.

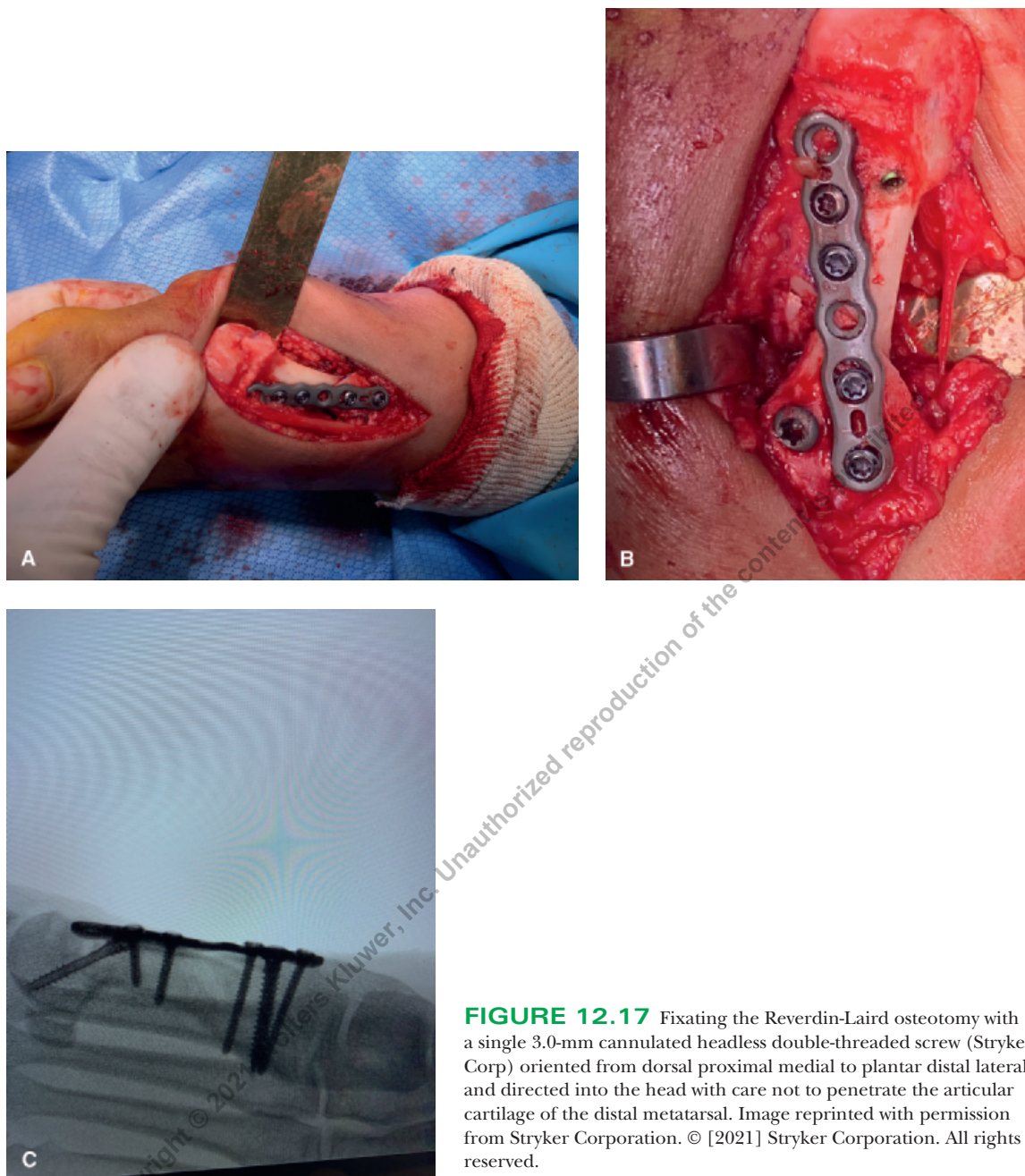


FIGURE 12.17 Fixating the Reverdin-Laird osteotomy with a single 3.0-mm cannulated headless double-threaded screw (Stryker Corp) oriented from dorsal proximal medial to plantar distal lateral and directed into the head with care not to penetrate the articular cartilage of the distal metatarsal. Image reprinted with permission from Stryker Corporation. © [2021] Stryker Corporation. All rights reserved.

COMPLICATIONS OF MAU AND LUDLOFF OSTEOTOMIES

Ludloff osteotomies have been associated with a delayed union rate of 2%-7%, metatarsal shortening, loss of IM correction with recurrent deformity, and a malunion revision rate of 1.5%-5%.²⁸ Delayed union in the Ludloff osteotomy may further lead to dorsiflexory malunion with subsequent elevation and metatarsalgia. Malunion with dorsiflexion of the osteotomy is most common with the Ludloff and least with the Mau osteotomy.^{9,11} Comparing the Scarf and Ludloff procedures, Robinson et al.¹⁷ found the Scarf to have superior outcomes in clinical and radiologic outcomes. Of 57 patients, 5%

of patients had a delayed union with the Ludloff, which may have been attributed to the use of headless screws. Two of the three nonunions in that series went on to develop a dorsiflexory nonunion.¹⁷

In the Ludloff, the load is transferred from the distal fragment to the proximal fragment through the fixation device.²⁸ This can lead to an irritation callus at the osteotomy site with a reported incidence of 16%-27%.²⁸ Gapping and load failure can also occur with the Ludloff as the osteotomy will distract and usually fracture at the proximal screw on the dorsal aspect of the metatarsal.^{31,32} Mechanical cadaveric studies by Trnka³³ and saw bone studies by Acevedo³¹ showed the Mau osteotomy to be more stable than the Ludloff and Scarf



FIGURE 12.18 Preoperative and postprocedure intraoperative fluoroscopy of Mau-Reverdin osteotomy fixed with plate and screws. Note the apex screw proximally is out of the plate. The distal Reverdin screw does not penetrate the articular cartilage at the head. The second proximal screw through the plate is also compressing the osteotomy. The rest of the screws are stabilizing the dorsal and plantar fragments against load and shearing forces.

osteotomies. Saw bone studies by Meric demonstrated failure in the distal screw region with the Ludloff, in the proximal screw region in the Mau, and between the screws with the Scarf.³⁴ Many studies demonstrated failure with the Ludloff in the proximal screw region.^{12,33,35,36} Gapping has not been reported with failure in the Mau due to the inherent strong dorsal shelf. Loss of the intraoperative IM correction can occur with both Mau and Ludloff procedures, which can be minimized by orienting the screws perpendicular to the osteotomy whenever possible.

As with any capital osteotomy, when adding a Reverdin-Laird osteotomy to the Mau, there is low risk of avascular necrosis of the head. The incidence does not seem to be increased with the added osteotomy through the midshaft.^{11,15}

HISTORICAL REVIEW

SCARF OSTEOTOMY

The midshaft Z-osteotomy was initially described by Burutaran³⁷ and Zygmunt and Gudas.³⁸ The “scarf osteotomy” was first coined by Weil Sr. in 1984^{39,40} and describes a carpentry term whereby the two ends of a piece of wood are beveled and secured together so that they create one longer uninterrupted beam⁴¹ (Fig. 11.20). Due to its stability, the scarf construct withstands tension and compression forces along the osteotomy.⁴² Barouk popularized its usage in Europe, supported by the Scarf osteotomy’s inherent stability, versatility, and ease of internal fixation, which allows for early weight bearing.⁴³ Barouk also



FIGURE 12.19 Preoperative and postoperative x-rays of the Mau-Reverdin osteotomy fixed with compression screw, plate, and distal headless screw.

reported that the Scarf osteotomy does not violate the blood supply to the first metatarsal, which is mainly from a plantar origin,⁴⁴ as can be the rare case with distal metatarsal head osteotomies, such as the Chevron (Fig. 12.21).⁴⁵

INDICATIONS FOR SCARF OSTEOTOMY

The indications for a Scarf osteotomy are a moderate to severe hallux valgus deformity with intermetatarsal angles ranging from 12 to 23 degrees.⁴² Proximal articular set angle (PASA) of up to 10 degrees can also be addressed with the osteotomy.⁴⁰ The technique can also be performed safely, simultaneously, bilaterally with early return to full weight bearing in shoes.⁴⁶ Contraindications to the procedure are moderate to severe first MTP joint arthritis, osteoporosis, extremely large intermetatarsal angles >25 degrees, and frank hypermobility of the first ray.⁴⁷

INDICATIONS

- IM angle 12-23 degrees
- Can address elevated first metatarsal with modifications
- Can address increased PASA with modifications
- Can be performed bilaterally simultaneously
- Patients can start protective weight bearing immediately following surgery

CONTRAINDICATIONS

- Arthrosis of first MTP joint
- Poor bone quality

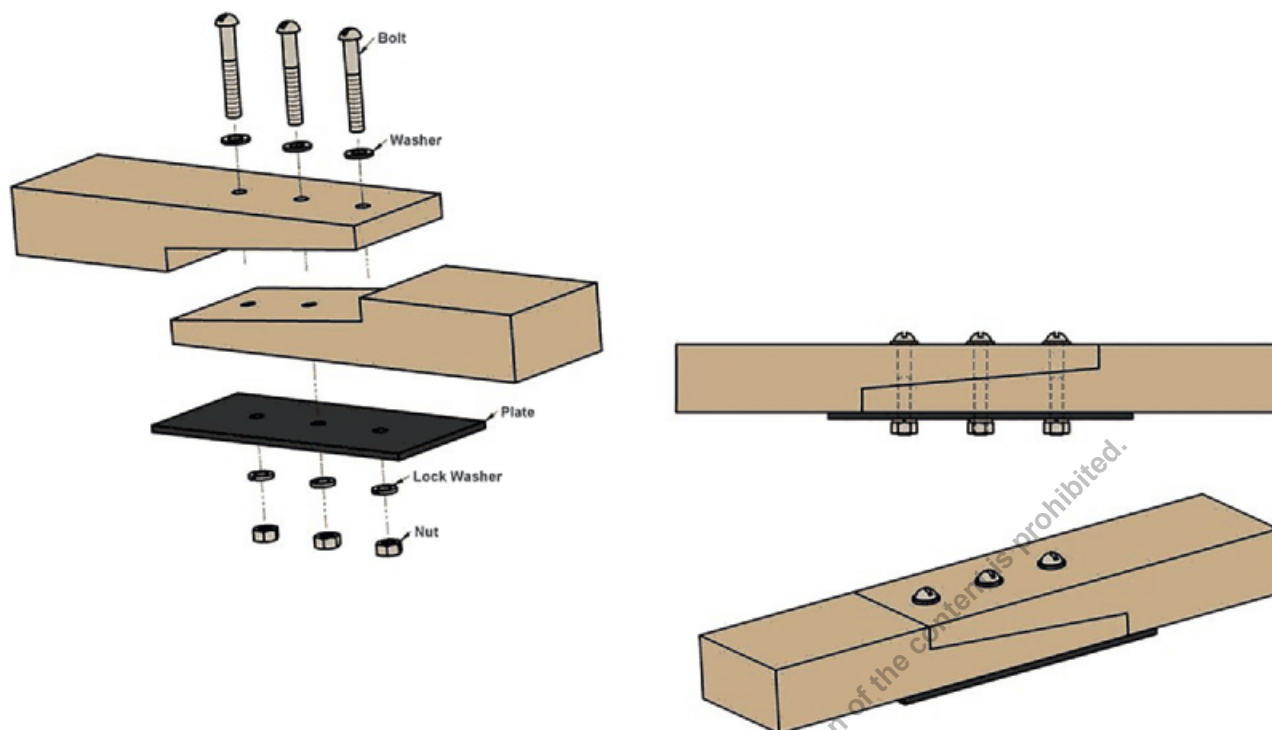


FIGURE 12.20 Illustration of a Scarf carpentry joint. With permission from Barouk LS. *Forefoot Reconstruction*. 2nd ed. Paris, France: Springer-Verlag; 2005.

SURGICAL TECHNIQUE

INCISION

Surgery is performed with the patient in a supine position with a combination of monitored sedation and a local Mayo block⁴⁸ using 15-18 cc bupivacaine 0.5% plain. If bilateral simultaneous surgery is being performed, a mixture of 0.5% bupivacaine plain and 1% lidocaine plain in a 1:1 ratio is used to avoid a potential toxic dose of local anesthetic.⁴⁹ An Esmarch bandage

is used to exsanguinate the foot. An ankle tourniquet set at 250 mm Hg is employed, as it facilitates hemostasis and visibility of the surgical field. The author (RF) prefers to use a medial incision of the first metatarsal as it avoids the dorsomedial neurovascular bundle, allows for better visibility of the osteotomies and fixation, and gives a more cosmetic scar (Fig. 12.22).⁴⁰ The incision measures approximately 5-7 cm and is made just above the junction of the glabrous plantar skin and dorsal skin, from the base of the proximal phalanx to the midshaft of the metatarsal. The incision is deepened to subcutaneous tissue to the level of the joint, and any bleeding veins are ligated or cauterized. At this point, a Metzenbaum scissor is used to free up any attachments at the plantar portion of the incision. In addition, a soft tissue flap inferior to the neurovascular bundle is made dorsally, which envelopes the structures and enables them

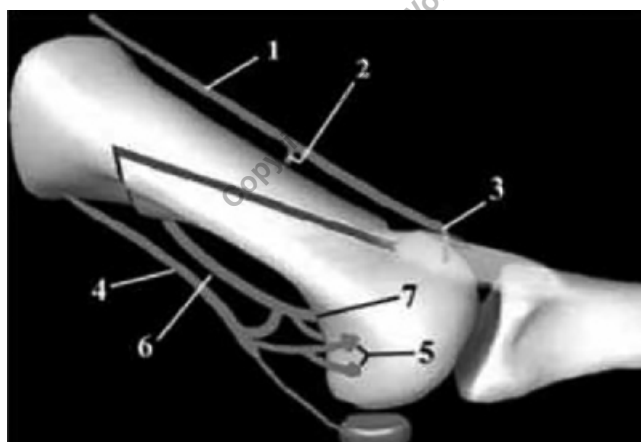


FIGURE 12.21 Blood supply to first metatarsal in relation to Scarf osteotomy. 1. Dorsalis pedis artery; 2. Nutrient artery (variable); 3. Metaphyseal capital dorsal branch; 4. Medial plantar artery; 5. Medial plantar metaphyseal capital branch; 6. First intermetatarsal artery (main artery to the first metatarsal head); and 7. Lateral plantar metaphyseal capital branch. (With permission from Barouk LS. *Forefoot Reconstruction*. 2nd ed. Paris, France: Springer-Verlag; 2005.)



FIGURE 12.22 Skin incision.

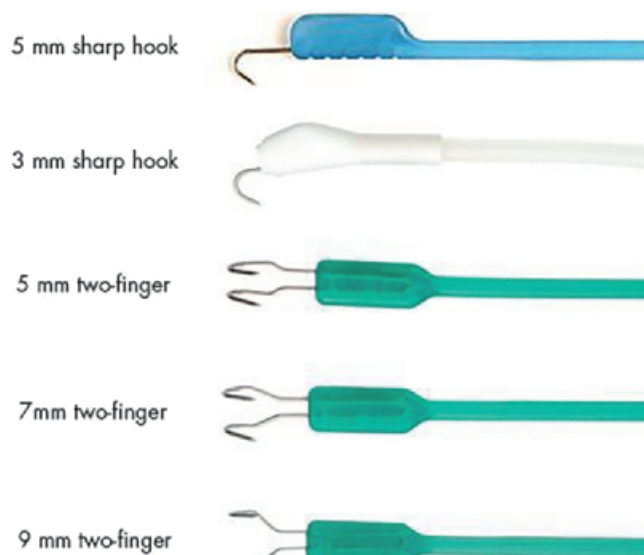


FIGURE 12.23 Flexible skin hooks. (Image provided courtesy of CooperSurgical Inc.)

to be carefully retracted out of the field. Flexible abdominal skin hooks aid in retraction and keep the operative field free of handheld instruments, allowing the procedure to be performed unassisted (Fig. 12.23).

PEARLS

- Use fluoroscopy.
- Use “one-third to two-third” relationship of the metatarsal when planning the osteotomy.
- Make head osteotomy in cancellous metaphyseal bone 4-5 mm proximal to articular cartilage to prevent troughing.
- Use an osteotomy guide to make accurate cuts.
- Make a long osteotomy.
- Use threaded head screws for fixation to provide stability and compression of fragments.

PITFALLS

- Troughing from making osteotomy in cortical bone or having inaccurate cuts
- Stress fracture or fracture from making a short osteotomy
- Malunion
- Metatarsalgia from shortening or elevation

CAPSULOTOMY AND LATERAL RELEASE

Two semielliptical converging incisions are made at the joint, which act as both a capsulotomy and subsequent capsulorrhaphy once the redundant tissue is excised. This gives excellent visualization of the medial aspect of the joint. Blunt dissection of the plantar tissue is achieved using the end of the scalpel handle and is extended distally to the plantar flare of the metatarsal. The dorsal joint tissue and periosteum are reflected sharply off the metatarsal head and shaft, and the skin hooks are reapropriated to encompass the deeper tissues. Through

the same medial incision, a McGlamry elevator is used to free up any adhesions of the lateral joint capsule and to mobilize the sesamoids with care being taken to avoid the plantar blood supply to the sesamoids. A Weitlaner smooth self-retaining retractor is then positioned and expanded between the plantar joint capsule and metatarsal head. This allows intracapsular release of the lateral sesamoid suspensory ligament using a Beaver 6400 blade. Ergonomically, for the right-handed surgeon, the technique is best performed from the base of the operating table on the right foot and overarching the left foot to the surgical area from the lateral aspect. This is the opposite for the left-handed surgeon. The hallux is then extended into a varus position to further relax the lateral joint structures.

OSTEOTOMY

The Scarf osteotomies create a “z-cut,” which is inherently stable and is fixated using rigid internal fixation. Minimal removal of the dorsomedial bump is performed with an oscillating saw to give a flat surface for the osteotomy. As described by Weil Jr. and Bowen, a 0.045 smooth K-wire is placed at the dorsal one-third of the first metatarsal head and driven laterally. The guidewire can be positioned to maintain length, shorten or lengthen the metatarsal, as well as for plantar or dorsal displacement based on axis guide principles.^{40,50,51} In most cases, slight shortening and plantar displacement are desired, so the guidewire is directed approximately 25-30 degrees dorsal-to-plantar with slight shortening by aiming the wire toward the fourth metatarsal head. Slight plantar displacement of the first metatarsal osteotomy decreases the risk of second metatarsal overload.⁴⁷ A Reese osteotomy guide is then placed over the guidewire in order to make predictable and reproducible cuts. It is the authors’ opinion and others^{40,47} that this is one of the most important components in the success of the Scarf osteotomy. A marker is used to draw out the cuts on the bone in preparation for the osteotomy. The dorsal portion of the z-cut is made first. It is angled approximately 60-70 degrees and exits 4-5 mm proximal to the articular cartilage of the first metatarsal head. This cut must be made in the cancellous metaphyseal bone of the metatarsal head to prevent troughing during translation of the osteotomy. Next, the transverse cut is made. A “one-third, two-third” concept is used to orient this portion of the osteotomy; at the distal end, there should be one-third of the bone dorsal to the osteotomy, and two-thirds below the osteotomy. This is reversed at the proximal end where one-third is plantar and two-thirds is dorsal to the cut. The cut is angled toward the base of the first metatarsal near its anatomic flare. The K-wire in the head and guide is then removed, and the plantar proximal cut is made free-handed with the edge of the blade, corresponding to the same angle as the dorsal distal cut (Fig. 12.24). An axis guide is usually not needed for the proximal plantar cut but can be placed if so desired. It is important that this cut be parallel to the dorsal cut so that there is an easily translatable osteotomy. Distal traction on the hallux can help with completing this portion of the cut.

Once the osteotomy is completed and mobilized, it is translated laterally using a push-pull technique (Fig. 12.25).⁴⁷ A small phalangeal clamp attached at the corner of the capital fragment and is used to pull the dorsal fragment medially, while the plantar portion is pushed laterally with a blunt instrument or thumb to close down the intermetatarsal angle.

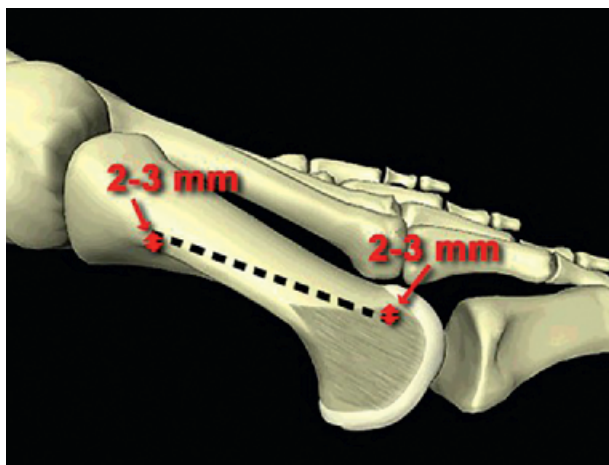


FIGURE 12.24 Scarf osteotomy placement. (With permission from Barouk L.S. *Forefoot Reconstruction*. 2nd ed. Paris, France: Springer-Verlag; 2005.)

Some authors extend the limits of translation to 75% of the width of the metatarsal shaft,¹² but rarely does it go more than 50%. A specialized Scarf clamp is used to hold the osteotomy in place (Fig. 12.26A-C).



FIGURE 12.25 Scarf translation.

The Scarf is primarily a transpositional osteotomy. It prevents rotation since the proximal plantar cut will be blocked by the shelf of bone behind it. The Scarf can be modified to correct for increases in PASA/DMAA of up to 20 degrees. Small increases can be managed by rotating the capital fragment

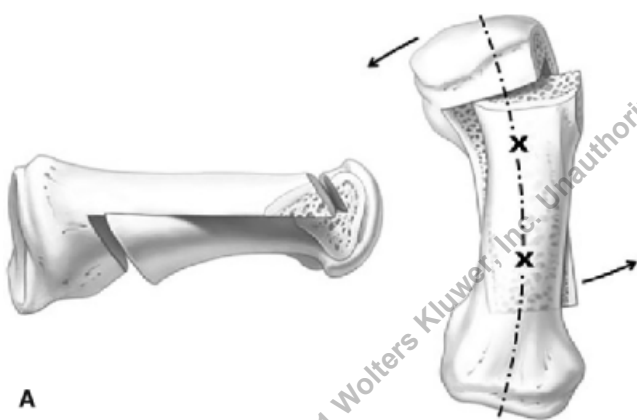


FIGURE 12.26 Scarf stabilization using specialized scarf clamp.

to make the joint congruent. Larger PASA/DMAA correction can be achieved by removing a small mirror-image wedge at the dorsal distal cut and proximal plantar cut, which will now allow for additional rotation to occur (see Fig. 12.26A). However, intermetatarsal angular correction is achieved only by translation.

FIXATION

Fixation is achieved using two cannulated threaded-head compression screws, usually 2.5-3.0 mm in size. Two provisional K-wires are placed to guide the cannulated screws. The first screw is unicortical and is positioned distal and plantar toward the crista of the first metatarsal head (Fig. 12.27A). Care is taken to avoid hitting the sesamoids when advancing the wire. This can be done via visual inspection or with the help of intraoperative fluoroscopy. When using compression screws, a good rule of thumb is to subtract about 4 mm from the length of the wire to get the correct screw size. This will allow appropriate countersinking of the head of the screw without violating the plantar joint space from using an inappropriately long screw. The proximal screw is bicortical and is directed from dorsal medial to plantar lateral to capture the cortex of the plantar shelf (Fig. 12.27B). Once screw fixation is obtained, the Scarf clamp is removed, the screws are finger tightened, and the remaining overhanging bone shelf at the dorsomedial head is resected with a saw. At this point, a fluoroscopic image in multiple planes is performed to ensure maintained correction and appropriate screw length and placement. An assessment for any adjunctive first ray procedures, such as an Akin phalangeal osteotomy, is then made.

TROUGHING

A rare complication of the Scarf osteotomy is troughing, which occurs during translation of the osteotomy.^{40,52} The medial portion of the dorsal shelf falls into the soft medullary canal of the plantar bone and essentially creates a dorsiflexion of the first ray with loss of metatarsal height (Fig. 12.28). The risk may occur with osteopenic bone, multiple passes of the saw blade, and exceeding the recommended amount of lateral translation of the osteotomy.⁵³ Meticulous surgical technique is important to help prevent troughing. By making the proximal and distal cuts in strong cancellous bone, this limits the effect. Using an osteotomy guide eliminates the need for multiple passes of the saw blade. If troughing is encountered intraoperatively, Lee et al advocates inserting a free oscillating saw blade in the longitudinal cut, clamping the bone, inserting the screws, and then removing the saw blade.⁵⁴ A similar technique was described by Saragas using the flat end of the McDonald dissector.⁵⁵ Others have used the resected medial eminence as bone graft to resist troughing.⁵⁶

CLOSURE

The toe is held in a corrected position, and the joint capsule is closed with 2-0 absorbable suture in a running fashion. The closure starts with a pulley suture directed from plantar capsule to dorsal capsule, which help maintain joint alignment. The subcutaneous closure and skin closure are performed as per surgeon's preference. A multilayer compression dressing is used to maintain the correction.

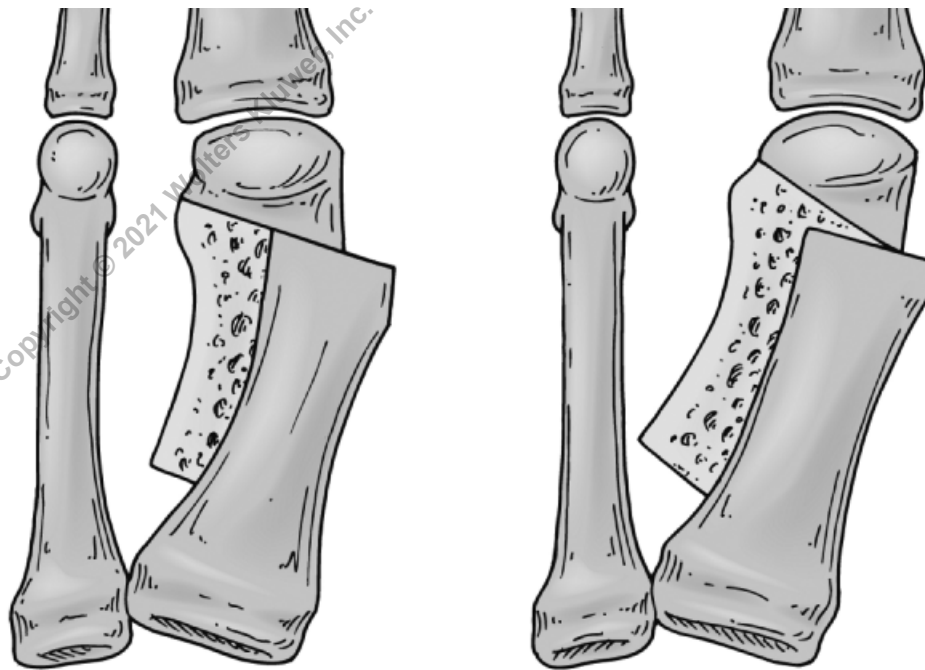


FIGURE 12.27 Scarf correction for PASA/DMAA. On the left, is normal translation without any correction of the cartilage deviation. On the right, the capital fragment is rotated to allow for PASA/DMAA correction. Larger angles are addressed by removing a small, mirroring bone wedges from the dorsal distal metatarsal and the proximal plantar fragment. (Courtesy of the Podiatry Institute.)



FIGURE 12.28 Scarf screw placement. **A.** Note that placement of the distal screw is in the head of the first metatarsal and avoids violating the joint. **B.** Note the placement of the guidewire goes from dorsal proximal medial to plantar distal lateral in order to catch the plantar cortex with the screw. (With permission from Barouk LS. *Forefoot Reconstruction*. 2nd ed. Paris, France: Springer-Verlag; 2005.)

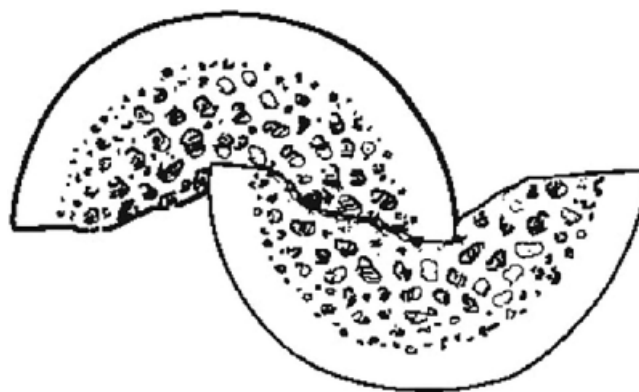


FIGURE 12.29 Troughing.

POSTOPERATIVE PROTOCOL

Guarded weight bearing in a postoperative shoe or CAM walker is started immediately. Advancement to a stable running shoe occurs between 10 and 21 days, depending on the patient's activity level and type of work they perform.⁴⁶ Physical therapy range-of-motion exercises are started at 7-10 days post-op, as evidence has shown that early adoption of therapy increases function and decreases pain after bunion surgery.^{57,58} If appropriate healing is clinically and radiographically apparent at 6 weeks, transition to any type of footwear is allowed, and low-impact exercises, such as elliptical machine and walking, can be started. Full-impact activity, such as running, is permitted at 3 months (Figs. 12.29 and 12.30).



FIGURE 12.30 **A,B.** Pre-operative radiographic and clinical image of foot prior to Scarf bunionectomy. **C,D,E.** 10-year post-operative Scarf bunionectomy clinical and radiographic images.

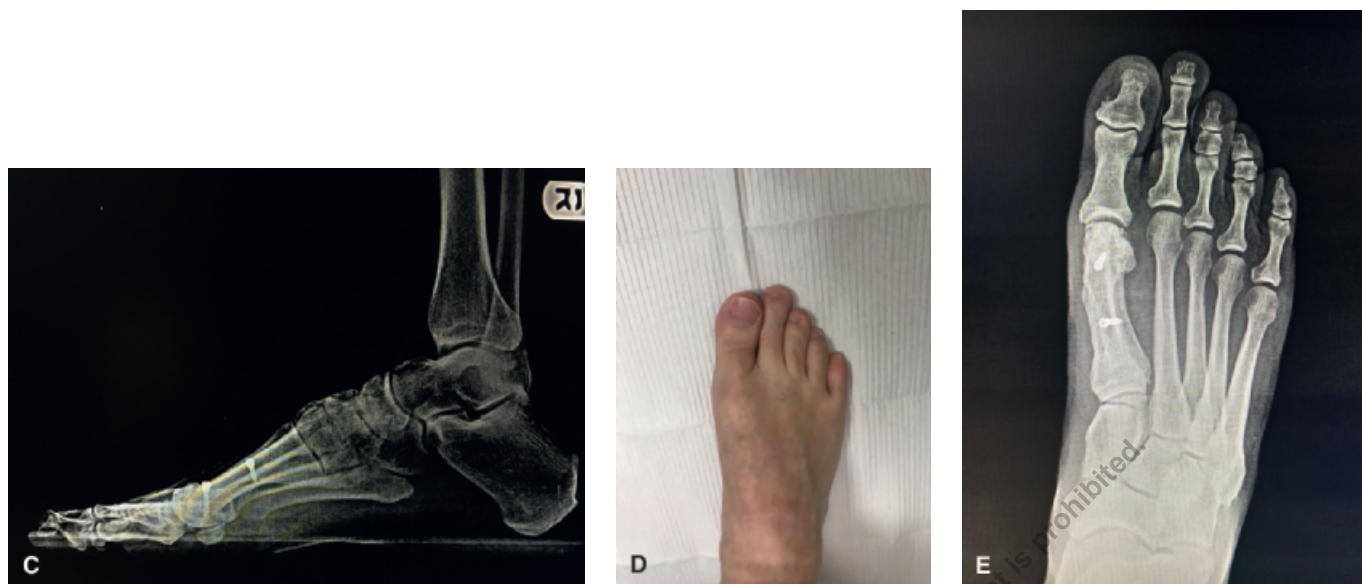


FIGURE 12.30 (Continued)

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