Paul D. Dayton
Editor

Evidence-Based Bunion Surgery

A Critical Examination of Current and Emerging Concepts and Techniques

Springer

13 Tarsal-Metatarsal Joint Arthrodesis

Lawrence A. DiDomenico, Danielle N. Butto, Paul D. Dayton, Daniel J. Hatch, Bret Smith, and Robert Santrock

Background

The procedure was first described by Albrecht et al. [1] in 1911 and later popularized by Lapidus in 1934. Lapidus proposed a first metatarsal–cuneiform arthrodesis paired with arthrodesis of the second metatarsal, resection of the dorsomedial eminence of the first metatarsal head, and distal soft tissue repositioning. He believed that metatarsus primus varus was the result of an underdeveloped atavistic foot type resulting in increased intermetatarsal angle (metatarsus primus varus) and that hypermobility of the first metatarsal–cuneiform joint was a component of the pathology. Lapidus concluded that the apex of the deformity, the first metatarsal–cuneiform joint, needed to be addressed or a "bayonet-shaped" deformity would result [2]. To date, numerous modifications have been made to the original Lapidus procedure; however, all include arthrodesis of the metatarsal–cuneiform joint [3–10].

The first metatarsal–cuneiform joint combined with its surrounding ligaments form a stable segment. The base of the first metatarsal has a lateral joint surface, a medial joint surface, and an inferior joint surface. A mediodorsal and lateroplantar protuberance is commonly found, which adds rotational stability to the joint [11]. In an anatomic cadaveric study by Mason and Tanaka, it was found that the lateral plantar prominence is constantly found on the metatarsal base. The size of the prominence differs greatly and is sometimes referred to as the "lateral flange" [12]. This and other details of the anatomic structure of the first ray have a direct impact on the understanding of resultant deformities and necessary components of correction. New information related to the triplane positions on the segments and the effect that these relationships have on function are beginning to change our understanding of the

L.A. DiDomenico, DPM, FACFAS (✉)
Ankle and Foot Care Centers, KSU College of Podiatric Medicine, Independence, OH, USA

Department of Surgery, Northside Hospital, Youngstown, OH, USA
e-mail: LD5353@aol. com

D.N. Butto, DPM
Saint Francis Hospital & Medical Center, Hartford, CT, USA

P.D. Dayton, DPM, MS, FACFAS
College of Podiatric Medicine and Surgery, Des Moines University, Des Moines, Iowa, USA

UnityPoint Clinic, Trinity Regional Medical Center, Fort Dodge, Iowa, USA

D.J. Hatch, DPM, FACFAS
Foot & Ankle Center of Northern Colorado, Greeley, Co., Medical Center of the Rockies, Loveland, CO, USA

B. Smith, DO
Foot & Ankle Division, Moore Center for Orthopedics, Lexington, SC, USA

R. Santrock, MD
Foot & Ankle Surgery, West Virginia School of Medicine, Morgan Town, WV, USA

P.D. Dayton (ed.), *Evidence-Based Bunion Surgery*, DOI 10.1007/978-3-319-60315-5_13

basis and needs for correction of HAV. These anatomic and functional concepts are discussed in detail in Chaps. 2 and 6 and will be referred to in the following procedural overview.

Indications

The first metatarsal–cuneiform arthrodesis has been traditionally performed in patients with a hypermobile first ray as a prime indication. This indication has been challenged recently due to controversy regarding the location of instability, the difficulty in determining the degree of mobility, and the inconsistency of clinical assessment. Root described normal first ray range of motion as equal dorsiflexion and plantarflexion with hypermobility defined as anything beyond equal motion in the sagittal plane. To assess this, he placed the ankle and subtalar joint in neutral position then stabilized metatarsal heads two through five with one hand and the first metatarsal head in the other hand while taking the first ray through range of motion [13, 14]. Roukis et al. described the "dynamic Hicks test" to assess first ray range of motion. They described the placement of the foot and examiner's hands as described by Root. The hallux is fully dorsiflexed at the first metatarsophalangeal joint, and dorsal and plantar pressures are applied to the first metatarsal head. They believe true hypermobility exists when both tests are positive for hypermobility [15].

Further evidence suggesting the presence of first ray hypermobility has been reported based on radiographic findings according to some surgeons on anterior–posterior (AP) X-ray. Cortical thickening of the second is thought to occur secondary to overload [16]. Also diastasis between the base of the first metatarsal and/or the medial cuneiform and the base of the second metatarsal, elevated first metatarsal relative to the lesser metatarsals and painful synovitis at the second metatarsal phalangeal joint, and/or hyperkeratotic lesions under the lesser metatarsals have been identified as possible signs of hypermobility (Figs. 13.1a–d and 13.2).

In reality there is no consensus or consistency in the clinical measurement or definition of first ray hypermobility, and that is why we question the utility of this measure as a primary indication for tarsometatarsal level of correction for HAV. As discussed in Chaps. 2 and 6, the main site of mobility of the first ray is at the naviculocuneiform and talonavicular joints with a minority of motion at the TMTJ. The first metatarsocuneiform arthrodesis in reality is indicated to treat moderate to severe hallux abducto valgus as well as high levels of deformity with or without the presence of hypermobility. The main utility of the procedure is that it has the advantage of providing correction at the apex of the deformity [17, 18]. In addition, TMTJ is a convenient location to address all planes of the deformity concurrently including the transverse, the sagittal, and the frontal plane resulting in complete anatomic correction. Patients with small IMA may have significant frontal plane deformity which is why, like with hypermobility, the degree of IMA is not used as a prime indication. Sesamoid axial radiographs are recommended to assess the overall position of the first metatarsal in the frontal plane. Dayton et al. found in a case study of 25 patients that all patients had a component of frontal plane deformity. Correcting the frontal plane resulted in change in the IMA of 10.1°, hallux abduction angle (HAA) of 17.8°, and proximal articular set angle (PASA) of 18.7° [19]. Dayton et al. reviewed the data on 35 consecutive patients who underwent triplane bunion correction including derotation of the metatarsal. They found the mean amount of varus (supination) rotation performed during correction was 22.1 ± 5.2°. The mean amount of intermetatarsal angle reduction achieved was 6.9 ± 3.0°. The tibial sesamoid position changed by a mean of 3.3 ± 1.2° [20]. DiDomenico et al. evaluated the correction of the IMA and sesamoid position with frontal plane derotation and found by derotating the metatarsal that there is a significant improvement in both IMA and sesamoid position [21]. Other indications for first metatarsal–cuneiform arthrodesis include pes planus correction, treatment of degenerative joint disease (DJD), and revision HAV procedures [10, 16, 22, 23] (Fig. 13.3a–c).

Contraindications include a short first ray, because some degree of shortening is inevitable with resection of the joint, therefore further shortening an already short ray. Additionally, the

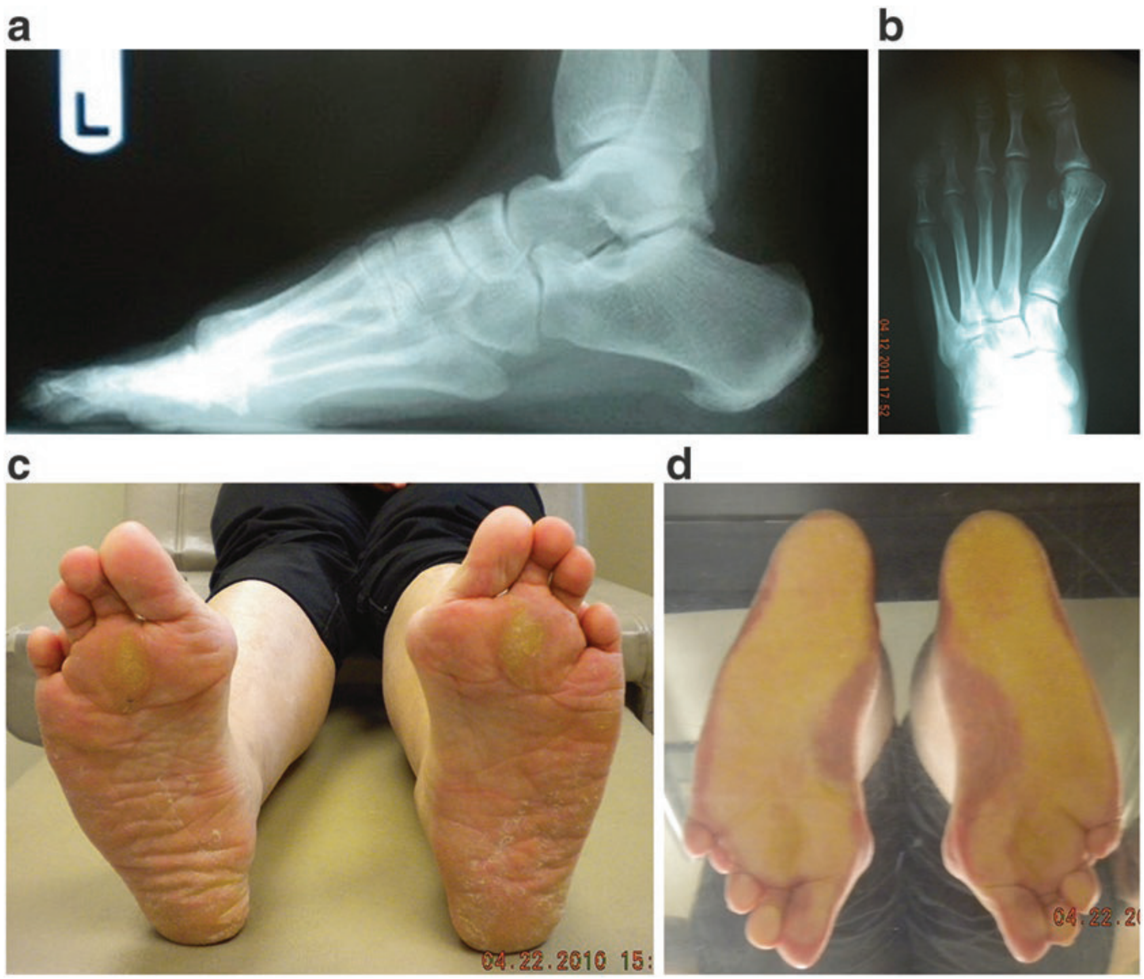

Fig. 13.1 (**a**) A lateral radiograph projection demonstrating a patient who suffers from TMT-1 hypermobility/instability. Note the dorsal cortex of the first metatarsal in comparison to the second metatarsal leading to an elevated first metatarsal. (**b**) An appearance of a "long first metatarsal" on a AP radiograph secondary to the hyper mobility. (**c**) Patient who presents with a HAV deformity bilaterally as well as a sub two callus lesion on both feet. (**d**) Note the lack of weight bearing under the first metatarsal causing the increased pressure to the sub-second metatarsal. The increase in sub-second metatarsal is secondary to the increase in the intermetatarsal (IM) angle, the elevatus of the first metatarsal (the first ray is not bearing the needed weight) along with a tight posterior muscle group increasing the forefoot load to the second metatarsal

procedure should be avoided in individuals with open growth plates.

The authors want to point out that a short first ray is very unusual in feet that have not been affected with trauma or previous surgery. Oftentimes what may appear to be a short first ray on a "single snap shot projection" more likely than not is not truly a short ray. Considerations that must be addressed when evaluating radiographs are what was the patient's position of their foot and was it fully loaded at the time of the X-ray? What was the angle of the beam relative to the foot at the time of the X-ray? Does the patient have more of a flatfoot or a high-arched foot? If a patient has more of a flatfoot, the radiograph projection will more likely than not appear long, and if patient presents with more of a high-arched foot, the first metatarsal will be more plantarflexed and appear relatively short. The surgeon needs to take this into consideration and rely on clinical evaluation as much as the radiographic evaluation.

Fig. 13.2 This is an AP radiograph from a patient who presents with a recurrent hallux abducto valgus deformity who had a previous distal metaphysical osteotomy performed. Note the diastasis of the base of the metatarsals and cuneiforms, a valgus rotation of the hallux and sesamoid complex, a previous stress fracture experienced by this patient from second metatarsal overload because of the increase in intermetatarsal angle (increasing the load to the second metatarsal as the first is not bearing the weight), and hypermobility/instability of the first ray

Technique #1

Preferred Technique: Lawrence A. DiDomenico and Daniell N. Butto

An incision is made over the metatarsal–cuneiform joint approximately 4–6 cm in length. There is no incision at the level of the first metatarsophalangeal joint or in the IM joint space. The tarsal–metatarsal incision is deepened in the same plane using sharp and blunt dissection. All bleeders are identified and ligated as necessary. The incision is carried down exposing the metatarsal–cuneiform joint. The tarsal–metatarsal ligaments are resected using a rongeur exposing the joint. Two mini Hohman retractors are used for the soft tissue retraction. Next the articular cartilage of the metatarsal and cuneiform sides of the joint are resected. The initial joint resection is performed on the first metatarsal articular surface. The first metatarsal articular surface is denuded first as this is the most distal and the most unstable segment. This resection is made perpendicular to the long axis of the first metatarsal and parallel to the existing metatarsal base. There is no correction made within the first metatarsal segment, as there is no deformity in the first metatarsal in typical HAV deformity. Thus, the articular joint resection needs to be kept consistent and parallel with the natural-occurring anatomy. The base of the first metatarsal is concave; therefore, the amount of cartilaginous resection on the base of the first metatarsal will need to be slightly greater than the amount on the convexity of the natural-occurring articular surface of the cuneiform. The corrective articular resection is made at the distal aspect of the convex-shaped cuneiform. The correction is made with a slight change in angular resection in the transverse plane. The frontal and sagittal planes are later corrected via reduction and appropriate positioning of the tarsal–metatarsal joint (Fig. 13.4).

Prior to reducing the joint into the appropriate desired position, a significant amount of time should be spent with joint preparation to ensure good bony healing. The metatarsal base and distal cuneiform as well as the medial aspect of the second metatarsal base are prepared. The authors use a laminar spreader for distraction between the first metatarsal and cuneiform. A pituitary rongeur is used to debride the cortex of the medial wall of the second metatarsal. It is imperative that the surgeon is diligent to ensure that the subchondral plate is penetrated demonstrating good bleeding at both the metatarsal and cuneiform. The joint preparation is extremely important in efforts to obtain a bony union and to avoid a delayed and nonunion (Fig. 13.5).

Next, the frontal plane is addressed. The surgeon derotates the hallux out of valgus (in a varus direction to a neutral anatomic position) in order to get the nail plate to be parallel with the ground. This derotation allows for the entire hallux, sesamoid, and first metatarsal complex to be rotated from a position of valgus and into a neutral

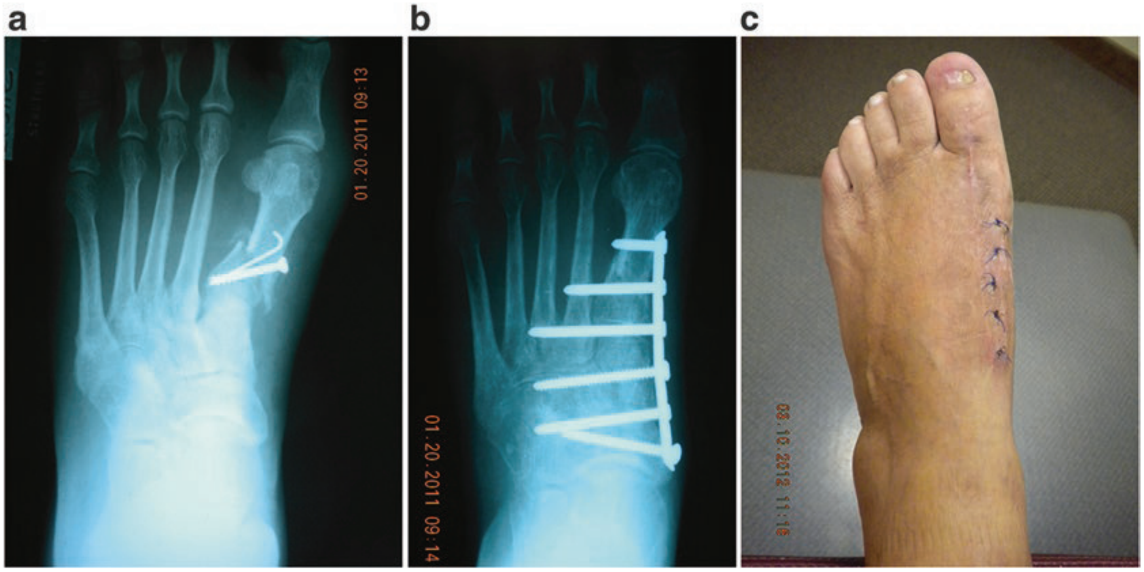

Fig. 13.3 (**a**) This is an AP radiograph of a patient who underwent a closing base wedge osteotomy of the first metatarsal with K-wire and screw fixation. The patient experienced a fracture and displacement of the osteotomy site with malalignment. (**b**) This is an AP radiograph of correction of photo 12 A who underwent a revision Lapidus procedure to correct the malalignment and displacement of the closing base wedge osteotomy. (**c**) A clinical photo demonstrating good anatomical alignment of the recurrent HAV deformity. Note the previous scars from the previous surgeries. There is only an incision at the tarsal-metatarsal joint which obtained good anatomical alignment and reduction of the deformity in all three planes. No dissection (lateral release) or medial eminence resection was performed

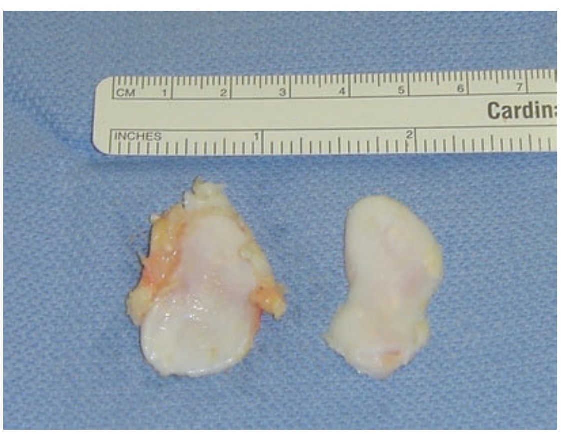

Fig. 13.4 These are the articular surfaces of the base of the first metatarsal and cuneiform following joint resection in preparation of performing a Lapidus procedure

Fig. 13.5 An intraoperative view demonstrating bone debridement of the medial base of the second metatarsal in preparation for fixation of a Lapidus procedure

position as one unit. This results in the sesamoid complex repositioned under the first metatarsal; the hallux is taken out of a valgus position into a anatomic neutral position. This rotation will be clinically evident at the tarsal–metatarsal joint as well as under fluoroscopy. Because there is no dissection at the first metatarsophalangeal joint (medial eminence resection or sesamoidal dissection), the maintenance of the soft tissues allows for the integrity of the hallux, sesamoids, and metatarsal to function as one unit. By maintaining the integrity of the soft tissues, the first metatarsal phalangeal joint maintains stability and allows the surgeon to manipulate and reposition the metatarsal phalangeal joint and the first metatarsal into a corrective anatomical alignment. If the soft tissues are dissected (historically know as a "lateral release" and medial eminence resection), this destabilization of the soft tissues will not allow the surgeon the ability to rotate and position the first metatarsal phalangeal joint and first metatarsal into anatomic alignment. The sesamoid correction can be observed under fluoroscopy at this time. The sagittal plane reduction technique is performed by stabilizing the hind foot, while the surgeon dorsiflexes the first metatarsophalangeal joint initiating the windless mechanism. This hind foot stability allows the surgeon to apply retrograde forces to the plantar tarsal–metatarsal joint and allows for the first metatarsal to plantarflex to a natural-occurring level, parallel with the lesser metatarsals. Once the surgeon has the hallux, sesamoid, and metatarsal rotated to a neutral desirable position (frontal plane reduction), and the first metatarsal sagittal plane corrected, the surgeon can use his or her thumb against the first metatarsal to manually reduce the first intermetatarsal angle in the transverse plane. The primary surgeon must ensure that the first metatarsal is in the desired position, which is essentially rotated out of valgus, and parallel with the second metatarsal in both the transverse and sagittal planes. Next a 2 mm smooth K-wire is used to stabilize the reduction and position. The first K-wire is positioned from the central proximal one-third of the first metatarsal into the cuneiform. Because of appropriate positioning of the tarsal–metatarsal joint, it is not unusual to see dorsal gapping at the tarsal–metatarsal joint. Subsequently, while maintaining position in all three planes, a second K-wire is inserted into the medial first metatarsal head and into the lesser metatarsals; this serves to prevent derotation in the frontal plane, maintains reduction in the transverse plane, as well as maintains confirmed desired position of the first metatarsal parallel to the second metatarsal (prevents elevation of the first metatarsal relative to the lesser metatarsals in the sagittal plane). If the surgeon feels a need to obtain more correction in the frontal plane, the temporary fixation K-wires can be backed out, and an additional K-wire can be inserted into the first metatarsal medial and lateral cortex with the K-wire in the direction of inferior medial to superior lateral. Once the K-wire penetrates the far cortex of the first metatarsal, the K-wire can be used as a rotation device and rotate the metatarsal into more of a neutral position (out of valgus and in a varus direction) and insert the K-wire into the lesser metatarsal to stabilize the position. In many cases, a large Weber clamp may be used to assist, increase, or maintain the reduction. When using the large Weber clamp, the surgeon must be sure not to change the sagittal plane relationship between the first and lesser metatarsals. The position is checked both clinically as well as under fluoroscopy to confirm acceptable alignment (Fig. 13.6a, b).

The recommended fixation options for this technique are three solid long cortical interfragmentary compression screws or a solid cortical interfragmentary compression screw along with a medial plate. Regardless of the construct, the first screw is the most important screw; this is often referred to as the "home run screw" [24]. This screw should be a solid long cortical screw with preference size of a 3.5 or 4 mm. A trough is created into the mid-dorsal side of the first metatarsal approximately in the proximal one-third to one-half of the metatarsal [25]. A high-speed bur is used to create a notch in the cortical bone as described by Manoli and Hansen [25]. The notch allows for drilling difficult angles such as the first metatarsal to the first cuneiform. The first metatarsal has a declination making drilling without the notch difficult, and this technique allows the surgeon to control the screw angle and also allows the undersurface of the screw head to fit better at the level of the cortex or slightly below as well as avoid external pressures such as shoes from the thin skin of the dorm of the foot, help prevent stress risers, and avoid fracturing the cortex.

The first drill is either 4.0 mm for a 4.0-mm cortical screw or 3.5 mm for a 3.5-mm cortical screw and is drilled into the first metatarsal and stopped at the cuneiform. The next drill is either 2.9 mm for the 4.0-mm cortical screw or 2.5 mm for the 3.5-mm cortical screw and drilled into the cuneiform. The drill is aimed for the inferior,

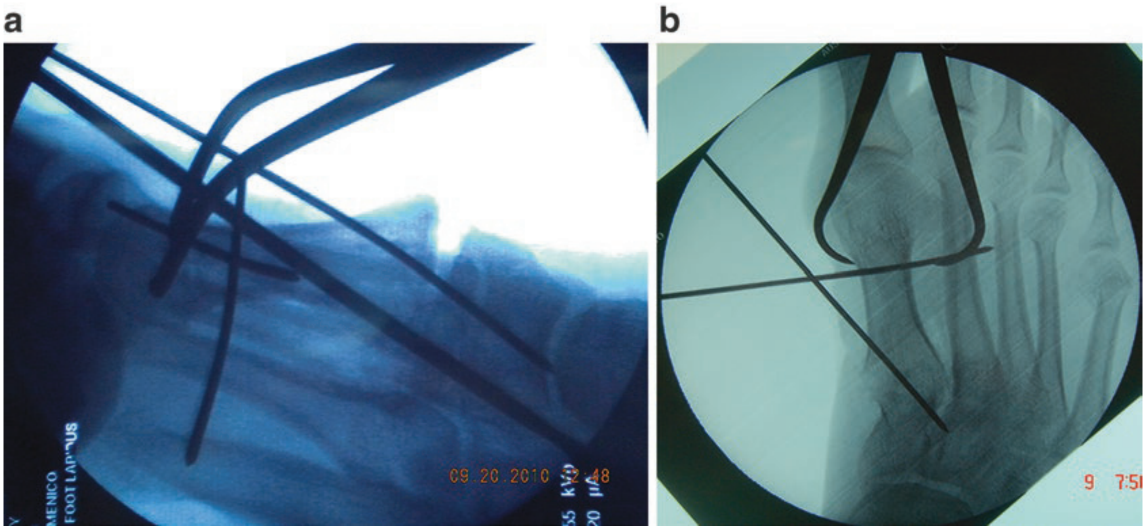

Fig. 13.6 (**a**) An intraoperative lateral radiograph demonstrating temporary K-wire fixation and a large Weber clamp for stabilization and reduction while the surgeon is drilling for the “home run” screw. Note the origin of the drill hole in the first metatarsal is as distal as possible, and it exits at the medial inferior cuneiform inferior to the navicular. The sagittal plane correction is well visualized as there is good bone-to-bone contact at the inferior metatarsal and cuneiform along with dorsal gapping at the metatarsal cuneiform superiorly indicating good sagittal plane correction of the first ray. The dorsal gapping will be backfilled with autogenous calcaneal bone graft. (**b**) An intraoperative AP radiograph demonstrating temporary K-wire fixation and a large Weber clamp for stabilization and reduction of the intermetatarsal angle in the transverse plane

medial aspect of the cuneiform (based on the shape of the cuneiform, the largest cross section of the bone is in the medial cuneiform). This screw should have a bicortical purchase; this screw provides interfragmentary compression at the plantar aspect of the joint or the tension side of the foot, and the long screw provides leverage and resistance to ground reactive forces. This allows for excellent reduction at the base of the tarsal–metatarsal joint most often leaving some dorsal gapping of the tarsal–metatarsal joint. When a three-screw construct is desired, the next screw is inserted from the medial proximal one-third of the first metatarsal into the base of the second metatarsal with the respective drill sizes for a 3.5-mm or a 4.0-mm cortical screw. The initial drill is the oversized drill through the first metatarsal, and the second drill is the undersized drill into the second metatarsal and/or possibly the lesser metatarsals in order to obtain a screw purchase and allow the surgeon to dial in with the desired intermetatarsal angle reduction. Oftentimes a washer will be applied with this screw, which provides greater reduction of the IM angle. The third screw is placed from the most proximal dorsal position of the cuneiform aiming into the medial proximal first metatarsal. This screw also should be as long as possible for obtaining leverage and resistance to ground reactive forces. The longer the interfragmentary screw, the greater the dispersion of forces and more counteraction of the tensile forces. The key to the placement of this screw is to start distally on the metatarsal and aim for the plantar-medial cortex of the medial cuneiform. The construct should be checked under fluoroscopy to confirm adequate reduction. The surgeon should check for intercuneiform instability, and if intercuneiform instability is identified, then intercuneiform joint preparation should be performed, and the medial to lateral screws should be inserted into the intermediate and/or lateral cuneiform for additional stability. It has been the authors’ experience that grossly hypermobile feet and flatfoot deformities often present with intercuneiform instability [26] (Figs. 13.7a, b and 13.8).

When a medial-based plate or locking plate is used in conjunction with an interfragmentary

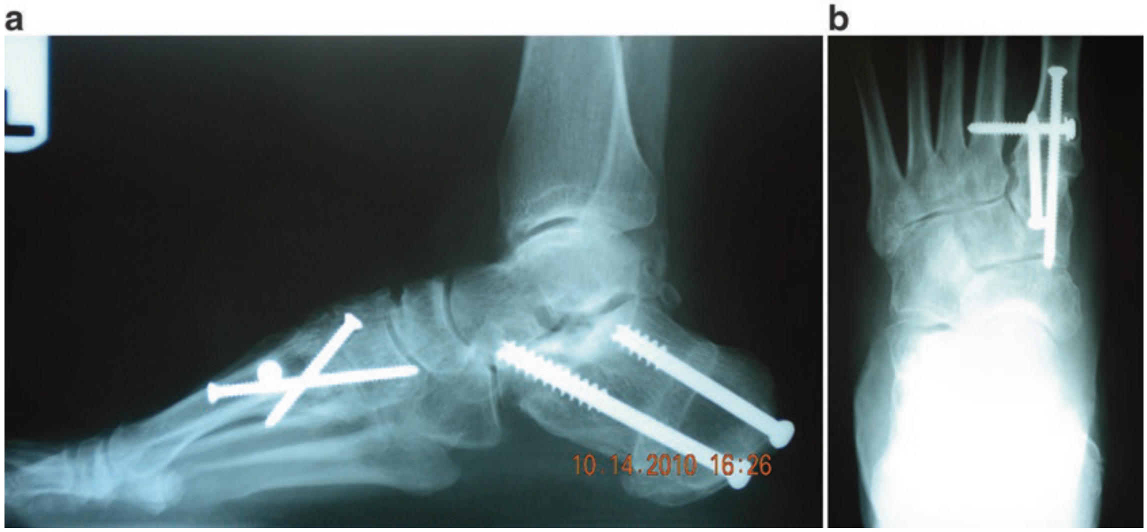

Fig. 13.7 (**a**) This is a postoperative lateral radiographic projection of a patient who had a Lapidus procedure with a three-screw technique and a percutaneous calcaneal displacement osteotomy performed. With respect to the Lapidus fixation, note the "home run" screw is long, it provides interfragmentary compression, and it is parallel to the ground (providing a "beam effect"). The cuneiform to the first metatarsal also is long and provides bicortical interfragmentary compression too, and the medial to lateral screw inserts into the base of the second metatarsal also with bicortical interfragmentary compression. Note the screw heads are countersunk below the cortex because of the thin soft tissue envelop of the skin in the foot and to provide relief from external pressures such as shoes 42. (**b**) This is a postoperative AP radiograph of a patient who had a Lapidus procedure performed with a three-screw technique. Notice the length of the "home run" screw – the authors recommend between 50 and 60 mm of length. The "home run" screws are inserted in the most medial aspect of the inferior cuneiform (area of most bone in the cuneiform). Because of the thin soft tissue envelope of the foot, the transverse screw head is also countersunk to avoid external pressures such as shoe gear. The transverse screw also demonstrates a bicortical purchase. A washer is used with this screw to aid in the reduction of "dialing in" or assisting with the intermetatarsal angle reduction

compression screw, the plate is applied to the medial first metatarsal–cuneiform joint. Following the insertion of the "home run screw," the initial screws are placed proximal in the medial cuneiform of the plate in combination with locking and nonlocking screws. The distal screws are placed into the metatarsal with a combination of locking and nonlocking screws. Similar to the three-screw technique, an interfragmentary compression screw can be applied within the plate from medial to lateral into the second and/or lesser metatarsals. This interfragmentary compression allows the surgeon to reduce the IM angle, and the plate essentially becomes an excellent reduction tool acting similar to a large washer. The plate is placed to span the metatarsal and cuneiform. Screws are placed through the plate and span the cuneiforms proximally, and an intermetatarsal screw is placed at the base of the first and second metatarsals. The medial plate acts as a "large washer" aiding in the reduction of the intermetatarsal angle in the transverse plane. With the proximal portion of the plate anchored well into the cuneiform, the distal portion of the plates mimics a "large washer" as the interfragmentary screws placed at the proximal portion of the first metatarsal allow the surgeon to "dial in" with the reduction of the intermetatarsal angle, and the remaining distal screws lock the reduction in place. Additionally, it provides stability from frontal plane rotation and intercuneiform instability. Often the authors get questioned if the intermetatarsal screw is problematic, painful, or if it breaks/fractures. The authors (unpublished at this time) reviewed 105 cases and found eight cases in which there was a fracture in the screw. Those patients who experienced a fractured screw were clinically/

Fig. 13.8 A hallux varus deformity: this is a patient who had a Lapidus procedure performed with distal soft tissue balancing which lead to a hallux varus deformity. In this chapter, the authors do not recommend distal soft tissue balancing or resection of the medial eminence of the first metatarsal. It has been the authors' experience that this is not needed to obtain an adequate reduction of the hallux valgus deformity and one cannot obtain a hallux varus if the distal soft tissue procedure is not performed

symptomatic insignificant. The construct should be checked under fluoroscopy to confirm adequate reduction (Fig. 13.9a–i).

If supplemental bone grafting is desired, attention is directed to the lateral aspect of the calcaneus where a small stab incision is made in the resting skin line that is posteroinferior to the sural nerve and the peroneal nerves. A Freer elevator is inserted in the incision, freeing the periosteum medially and laterally, exposing the lateral wall of the calcaneus. A 3.5-mm drill was used to penetrate the lateral cortex. With this done, a curette is inserted into the calcaneus, allowing for harvesting of cancellous bone from the lateral aspect of the calcaneus [27]. The dorsal gap of the tarsal–metatarsal is packed tightly with autogenous bone graft and serves as a shear strain-relieved bone graft [24, 28]. The construct is checked under fluoroscopy, and the wound is closed with typical deep and skin wound sutures.

Traditionally a 6–8-week non-weight-bearing period post-modified Lapidus arthrodesis has been recommended [29–31]. With the advent and availability of locking plate constructs that provide more reliable stability and bridging for the fusion, immediate weight bearing is starting to become common [3, 29, 32]. We have allowed immediate, functional weight bearing in a controlled ankle motion (CAM) boot for approximately the past 16 years. A retrospective analysis of the authors' patients identified 376 patients undergoing TMTJ arthrodesis with 74 patients meeting inclusion criteria for immediate weight bearing. Four patients had bilateral procedures performed at separate times for a total of 78 Lapidus procedures. Thirty patients had a three-screw construct, while 48 patients had a medial locking plate with an interfragmentary screw. There were 6 males and 68 females. The average age was 50.2 years old (males 56.7, females 49.7) with a range of 15–86 years. Fifty-five patients had a BMI less than 29, while 16 patients had a BMI greater than 30. BMI information was not available for three patients. Fifteen patients admitted to using nicotine. Additionally, seven patients had type II diabetes mellitus. Autogenous shear-strain relief bone graft was used in 75 of the 78 procedures. Patients who had adjunctive osseous procedures that required a non-weight-bearing post-op course were excluded from the study. Three patients (3.8%) experienced a postoperative nonunion. Interestingly, none of the patients with nonunions were smokers, and only one patient was diabetic.

Technique #2

Preferred Technique: Paul Dayton DPM, MS, Daniel Hatch DPM, Bret Smith DO, and Robert Santrock MD

An alternative procedure for TMTJ level correction is an instrumented system Lapiplasty® procedure (Treace Medical Concepts, Inc., Ponte Vedra Beach, FL) that provides triplane correc-

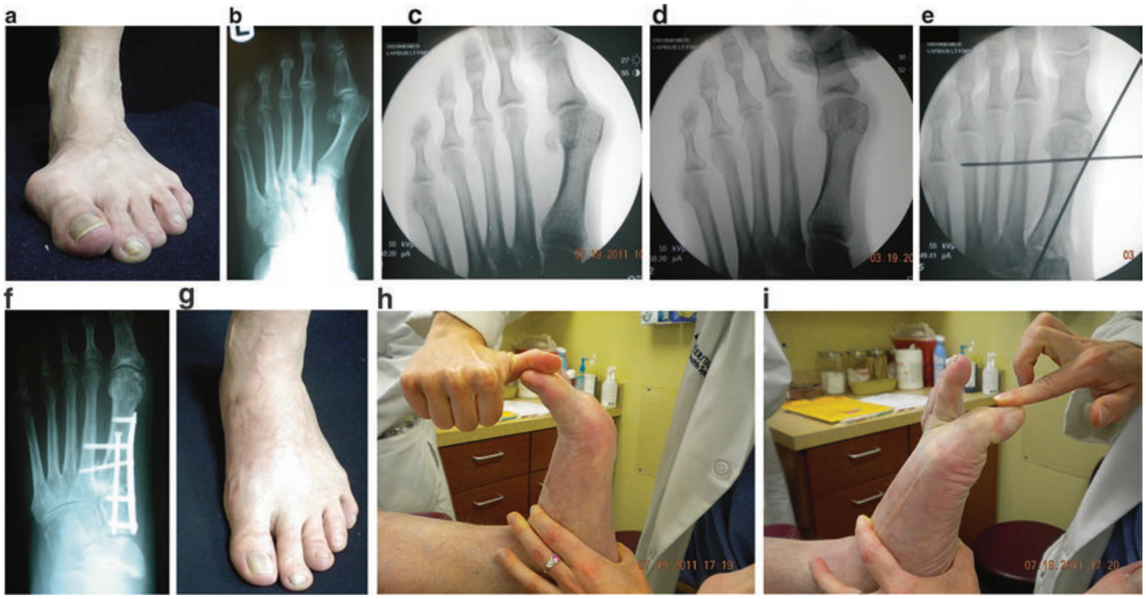

Fig. 13.9 (**a**) A clinical photo of a patient who presents with a painful HAV deformity. Note the valgus rotation of the great toe. (**b**) An AP radiograph of the same patient demonstrating a large IM angle, diastasis of the base of the first and second metatarsal, as well as the cuneiforms. There is a valgus rotation of the great toe, first metatarsal, and subsequently a valgus rotation of the sesamoid complex. (**c**) An intraoperative radiograph of the same patient demonstrating the sesamoid completely in the first interspace and the articular surface of the fibular sesamoid is 90° to the lateral aspect of the first metatarsal. (**d**) An intraoperative radiograph of the same patient demonstrating the great toe in the varus direction to a neutral position rotates the entire first metatarsal, great toe, and sesamoid complex as an entire unit. Note the sesamoid are placed into an anatomic position when a frontal plane rotation is accomplished. This is done without dissection about the first metatarsal phalangeal joint. (**e**) An intraoperative radiograph of the same patient demonstrating temporary fixation following reduction of the IM angle, frontal plane correction, and sagittal plane correction prior to screw fixation. (**f**) A postoperative radiograph of the same patient following reduction of the frontal plane (no dissection about the first metatarsal phalangeal joint), and correction of the transverse and sagittal plane. (**g**) A clinical photo of the same patient with a limited scar at the base of the first metatarsal and cuneiform. Note the reduction of the bunion and anatomical alignment. (**h**, **i**) Demonstration of range of motion of the first metatarsal phalangeal joint following a Lapidus procedure without invasion into the joint

tion at the anatomic apex of the deformity with a stepwise approach. (Note: the authors of this section are consultants and designers for Lapiplasty®.) The system uses a novel surgical sequence, first correcting the deformity with a unique positioning guide before making templated bone cuts and finally fixating with a non-compression biplane plate construct. Indications for this procedure are not based on degree of deformity, presence of hypermobility, or TMTJ angulation. The basic tenants of the procedure are to provide correction in three planes concurrently at the anatomic apex of the deformity and fixate with a construct that tolerates early weight bearing. The technique can be employed in the vast majority of hallux abducto valgus deformities but should not be used when clinically significant first MTPJ arthritis is present. Since this technique relies on the correction of the first metatarsal at the TMTJ and does not employ capsular balancing or distal osteotomies, it is recommended to obtain an anterior-posterior and axial sesamoid views to fully understand the degree of each plane of deformity and to assess whether there is any sesamoid subluxation. The PVB classification system (reviewed in Chap. 5) is used in part to guide decision-making for the need of limited lateral release.

The initial incision is made over the dorsal aspect of the tarsal–metatarsal joint, just medial to the extensor hallucis longus tendon and extends from the proximal pole of the medial

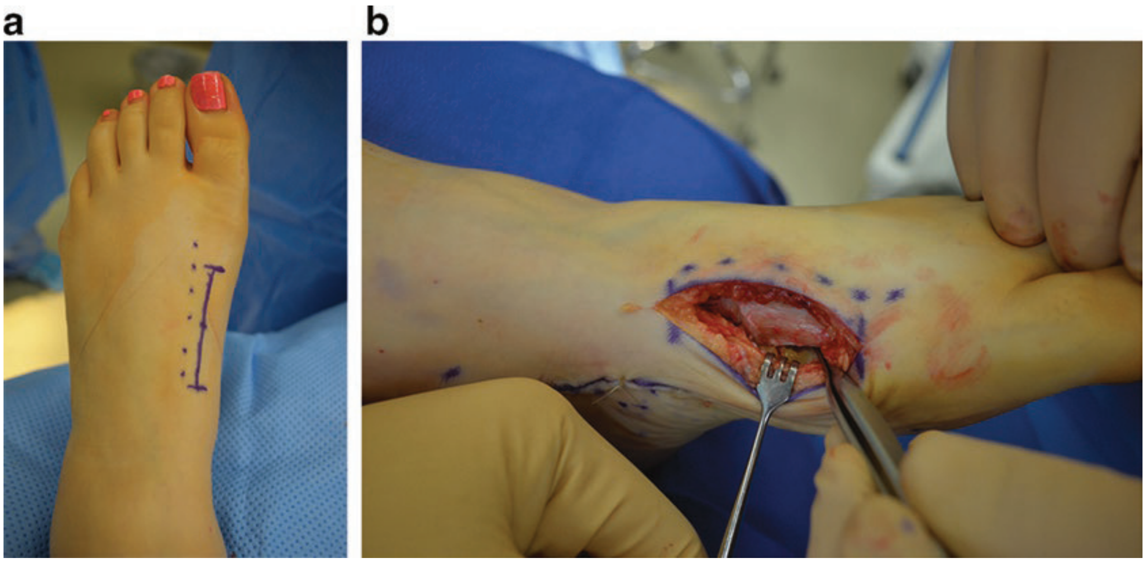

Fig. 13.10 (**a**) Recommended incision place just medial and adjacent to the extensor of the hallux from the proximal pole of the medial cuneiform to mid shaft of the first metatarsal. (**b**) Dissection within intracapsular and subperiosteal pocket exposing the medial ridge of the first metatarsal

cuneiform to the mid shaft of the first metatarsal (Fig. 13.10). It is essential to keep the incision dorsal for this technique to allow the guidance system to work properly. An intracapsular and subperiosteal pocket are developed without subcutaneous undermining to preserve the neurovascular anatomy. Dissection should be carried far enough medial to expose the medial ridge on the first metatarsal.

The TMTJ is released to allow for triplane mobilization of the first metatarsal using a combination of oscillating saw and/or osteotome. Using the oscillating saw technique has the added benefit of plaining any irregularities from the cartilaginous surfaces of the joint making frontal plane rotation more seamless (Fig. 13.11). The fulcrum device is then placed into the space between the proximal first and second metatarsals seating it proximally adjacent to the medial cuneiform (Fig. 13.12). Transverse plane flexibility of the first metatarsal phalangeal joint is evaluated, and if significant soft tissue tightness is noted, a small dorsal first interspace incision is made, and the tight lateral structures at the MTPJ are released until the joint is mobilized out of the abducted position. This step is only necessary if ankylosis is present and preventing correction of the hallux as the positioner device is engaged. A small stab incision is made over the second metatarsal approximately 1.5–2.0 cm distal from the first TMTJ, and the positioner device is inserted over the second metatarsal and onto the medial ridge of the first metatarsal (Fig. 13.13). Engaging the positioner with the fulcrum in place concurrently corrects the metatarsal in all three planes which is confirmed with fluoroscopy. A cut guide alignment tool (termed the “joint seeker”) is placed dorsally in the TMTJ; this assures that the cuts are made correctly in the sagittal plane when the cutting guide is then placed and temporarily fixed in place (Fig. 13.14). The joint seeker is then removed, and the cuts on the base of the metatarsal and cuneiform can be completed. Once all of the cut bone has been removed, the joint is prepared for arthrodesis by aggressive metaphysis drilling on both sides of the joint using a 2-mm drill bit not a K-wire. The joint is axially compressed and held in the corrected position and pre-compressed with a terminally threaded olive wire (Fig. 13.15). When satisfactory triplane correction is obtained, final fixation can be applied with a biplanar mini-plate construct (Control 360® System, Treace Medical Concepts, Inc., Ponte Vedra Beach, FL) that

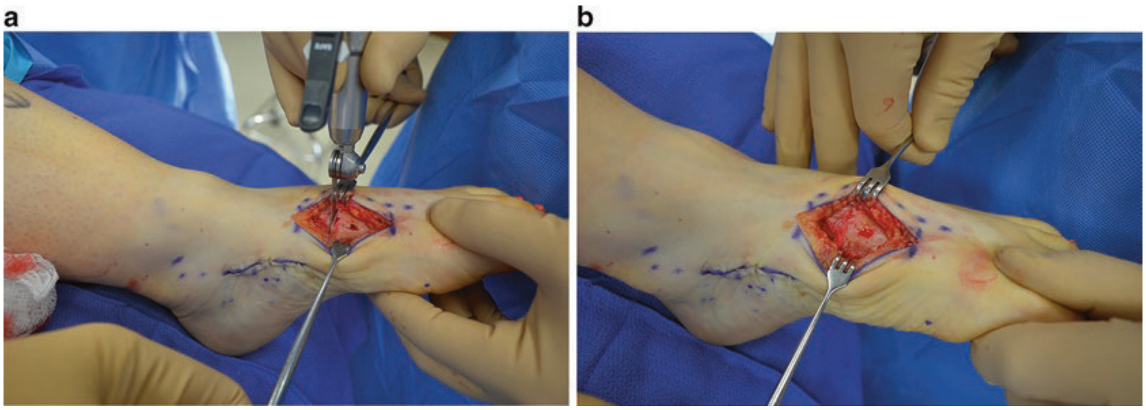

Fig. 13.11 (**a**) Use of the sagittal saw for release of the TMTJ and concurrent planning of the irregular cartilaginous surface to allow for free frontal plane rotation. This step is not aimed at joint preparation for fusion, just mobilization. (**b**) Manual testing of inversion component of frontal plane rotation required for correction

Fig. 13.12 Placement of the fulcrum device between the first and second metatarsal bases (Note the proximal position adjacent to the medial cuneiform)

offers stability and allows for physiologic micromotion to promote callus healing. This fixation design was found to be biomechanically stable in cantilever bending mechanical tests up to 250,000 cycles of bending underload [33]. The initial plate is applied dorsal across the first TMTJ with the screw angle purely sagittal. A second plate is applied medially with the screw angle 90° to the dorsal plate (Fig. 13.16). When complete triplane correction has been obtained, it is generally not necessary to use any fixation from the first metatarsal into the lesser metatarsal or cuneiforms. Anatomic and rotational alignment prevents deforming forces to pull the hallux lateral and buckle the first metatarsal medially. Further incision and dissection at the first MTPJ is generally not needed as the eminence is normalized through rotation (the effects of frontal plane rotation are reviewed in detail in Chap. 6).

The priority for this technique is complete triplane correction and maintenance of normal medial column kinematics. Because we have noted the importance of maintaining the windlass mechanism of the medial column for normal function, we do not advocate transfixation of the first and second metatarsals with additional screws. Similarly, we do not prepare the interval between the bases of the first and second metatarsals for fusion. Fixation of the first and second metatarsals severely curtails sagittal plane motion of the medial column and prevents the normal windlass mechanism for plantarflexion of the first metatarsal during gait. Decreased weight bearing of the first ray can in many cases lead to lateral weight transfer and lesser sub-metatarsal pain. It is not intuitive to many surgeons that medial column motion is maintained after TMTJ fixation because of the prevailing thought that robust motion occurs at the TMTJ and that blocking this motion prevents sagittal plane mobility. As discussed in Chap. 6, the majority of medial column motion occurs at the naviculocuneiform and intercuneiform joints and to some degree at the talonavicular joint. Medial column mobility is maintained in all three planes after TMTJ fusion. Using transfixation to prevent recurrence is not necessary with this technique since the deformity forces that produce recurrence are removed with derotation and complete angular correction.

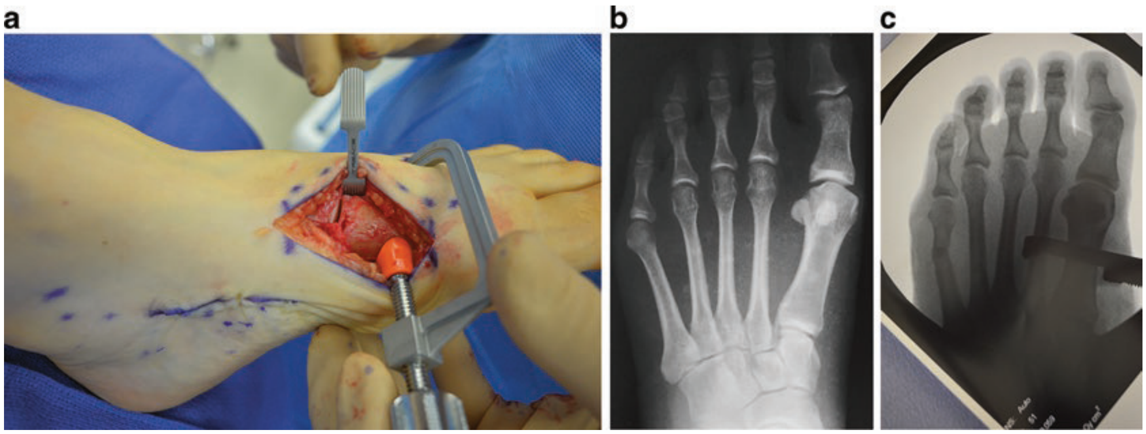

Fig. 13.13 (**a**) Placement of the positioner device. (**b**) Deformity before engaging the device. (**c**) Correction of deformity after engaging the action of the positioner device

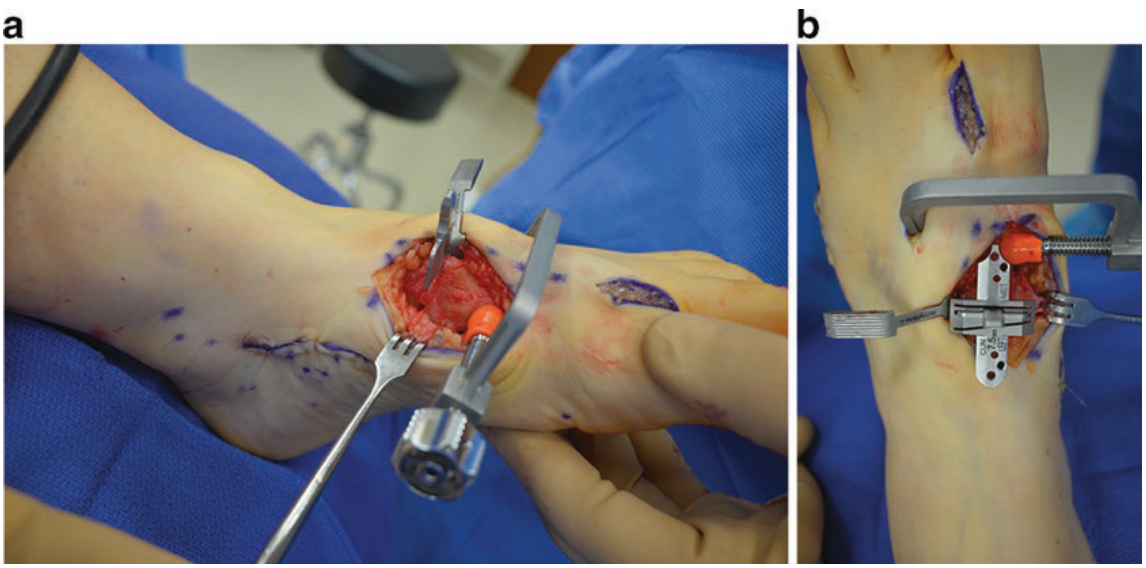

Fig. 13.14 (**a**) Placement of joint seeker device to align cut guide properly with the sagittal plane of the joint. (**b**) Cutting guide placed of the joint seeker device allowing accurate triplane cuts

It has become common to include lesser metatarsal osteotomy procedures with TMTJ fusion because of the concern for lesser metatarsal pain. We find this to be unnecessary when complete correction of metatarsal eversion is carried out and sagittal plain mechanics are normalized. Additionally, maintaining the medial column motion improves first MTPJ mechanics and offsets the slight shortening effect of resection of the TMTJ joints surfaces for fusion. Despite the small amount of shortening of the first ray with this procedure, we rarely see patients develop lateral metatarsal overload. In other words, accurate triplane alignment at the TMTJ improves medial column function thereby making associated procedures unnecessary. As discussed in Chap. 6, complete correction makes recurrence much less likely because the deforming forces on the first ray are removed.

The recommended postoperative course for this technique is protected weight bearing in a tall cast boot with avoidance of any high-impact activity starting several days after the procedure. Initial bandages are removed at 4 days, and no

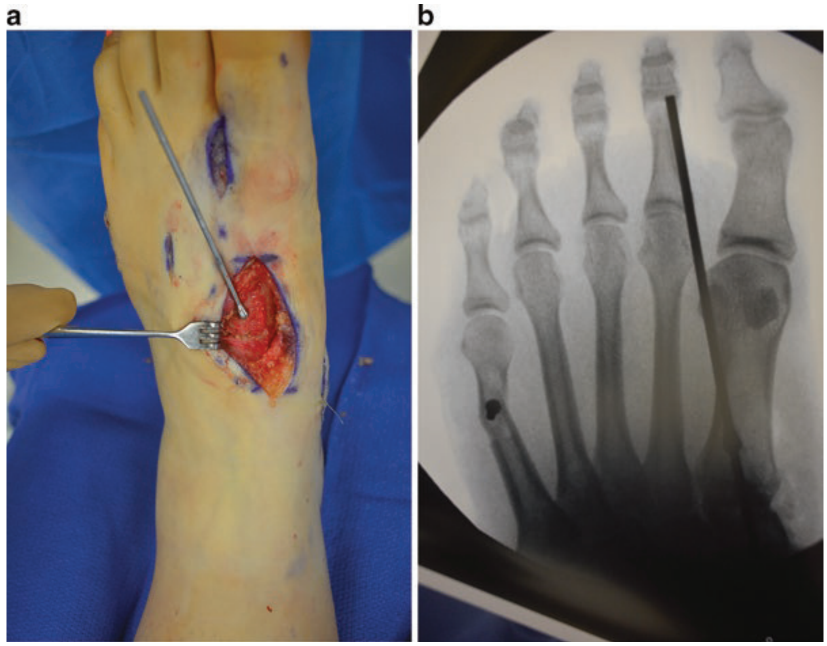

Fig. 13.15 (**a**) Corrected position maintained and compressed joint surface apposition maintained with a terminally threaded olive wire inserted into the lateral flare of the metatarsal based into the medial cuneiform (Note incision for lateral capsulotomy of the first MTPJ. Note MTPJ and hallux position is anatomic without the need for capsulorrhaphy, distal metatarsal or hallux procedures). (**b**) Radiographic evaluation of the corrected position

further digital splinting or bandaging is needed; showering is also allowed at this time. The range of motion activities are allowed for the foot and ankle when the initial pain subsides and are encouraged several times daily. Patients are returned to normal shoe gear around 6–8 weeks and are allowed to pursue high-impact activity when the fusion is consolidated around 3 months.

The traditional Lapidus procedure has undergone a progressive evolution to now include a new understanding of the 3D deformity anatomy. Currently we use the term triplane tarsometatarsal corrective arthrodesis as a more complete description for this procedure. Additionally, traditional indications which limit the procedure have been abandoned by the authors. That is, we do not require the presence of hypermobility, high IMA, or TMTJ arthrosis to select the procedure. As has been discussed throughout this textbook, our traditionally held ideas regarding the anatomy and function of the first ray both with and without HAV deformity may not be entirely accurate. The thought process for selection of TMTJ triplane arthrodesis also includes the identification of an intrinsically straight first metatarsal and the anatomic apex of the deformity at the TMTJ. Using this definition metatarsal osteotomies are not desirable. Although the initial results are extremely promising for 3D correction, this is an extremely new philosophy and technique which requires further study of patient outcomes.

As discussed in other chapters in this book, there is a lack of quality outcome studies reporting on validated PROM for bunion surgeries of all types, including the traditional Lapidus procedure. Review of the literature reveals mostly comparison studies for fixation techniques and evaluation of the safety of weight bearing in the early postoperative period. Recurrence rates have been discussed in Chap. 7. MacMahon et al. [34] assessed return to sports and physical activity following a modified Lapidus procedure in 48 patients with a mean age of 37.3 years old at 2.8 years mean. Patients completed a sports-specific, patient-administered questionnaire and had FAOS scores, and these were compared to sports outcomes. Postoperatively patients rated 29% of activities as less difficult, 52% as the same, and 19% as more difficult and rated participation levels as improved in 40%, the same in 41%, and impaired in 19% compared to

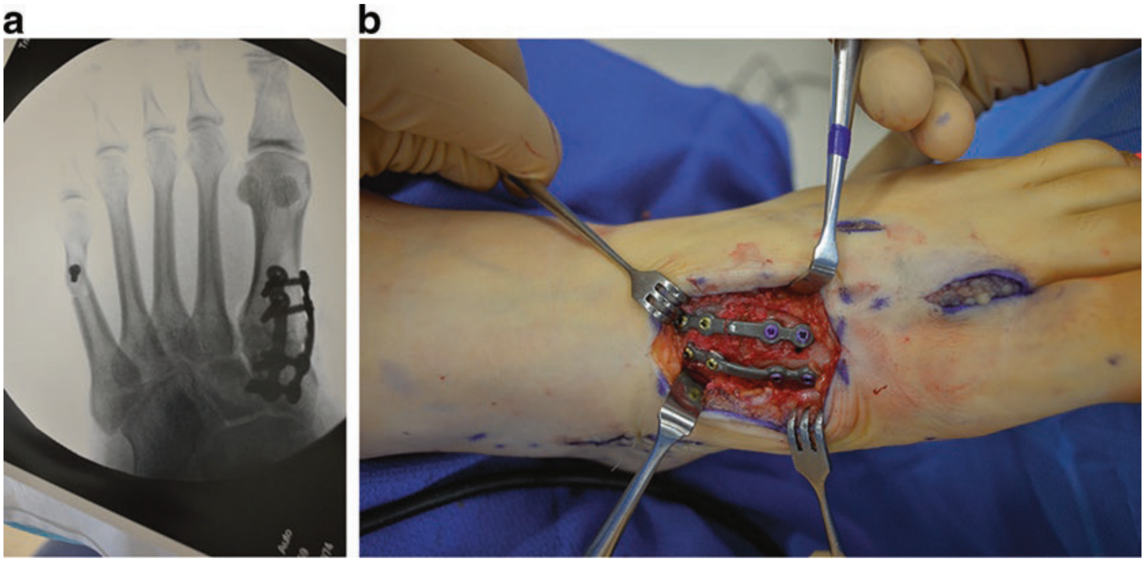

Fig. 13.16 (**a**) Final correction after fixation applied. (**b**) Biplane construct with two small flexible locking plates at 90° angles to each other

preoperatively. Eighty-one percent of patients were pleased with the outcome of their surgery in terms of physical activity. FAOS score improvements were highly associated with improvements in physical activity. Their conclusion was that 80% of patients were able to participate in their previous sports/physical activities at a similar or better level than before surgery. Robinson et al. [35] looked at footwear modifications after the Lapidus procedure footwear-specific questionnaire 18.5 months after surgery in 65 patients. Eighty-six percent of patients were able to wear comfortable footwear postoperatively, and 62% were able to wear fashion heels 21.4 weeks after surgery. Of the patients returning to heels, 77% were able to tolerate wearing heels better than before surgery. No change of foot size was noted following surgery. Taylor et al. [36] reviewed surgical outcomes of 18 modified Lapidus patients using the validated Foot Health Status Questionnaire (FHSQ). All FHSQ domains improved, with the greatest change coming in the category of foot pain. All 18 patients had union with one having poor pain control and another having postoperative bleeding. IMA improved by 7.8°, and HAV improved by 22.9°.

Other Considerations

Concomitant deformities and biomechanical abnormalities such as equinus [37] need to be addressed when performing this procedure. If other deformities are not corrected, biomechanical compensations may occur that hinder the primary surgical correction [38]. As we have highlighted here and discussed in other chapters, the bunion deformity is triplanar, and we feel that reduction of all three planes is a priority. Some surgeons suggest plantarflexing the metatarsal by sliding the metatarsal plantar which we recommend against. This practice decreases the bone surface area and changes the axis relationships within the first ray which we feel reduces the predictability of the procedure. Not only does metatarsal derotation from an everted position results in complete and consistent correction, it also gives the surgeon greater bone-to-bone contact and surface area for fusion which affects mechanical characteristics such as stress and strain at the fusion site. Stress to an area is calculated by dividing force by area ($\sigma = F/A$). Having the metatarsal derotated provides a larger area and therefore a larger denominator resulting in decreased stress per unit area of the surface. The load the construct can withstand is calculated by multiplying stress and area ($F = \sigma A$). Again, the larger the area, the more force that the area can withstand. A larger surface area allows for dispersion of ground reactive forces hence not concentrating force in one area [39]. When the metatarsal is in a neutrally rotated or anatomic position, there is a more uniform transmission of force from the metatarsal to the cuneiform. Further, stiffness is dependent on area. Stiffness (k) is how a material resists deformation in response to an applied force. It is found by multiplying the area (A) times the Young's modulus (E) of the bone and dividing that by the length ($k = A\mathrm{E}/L$). It is advantageous to have uniform stiffness across the fusion site [39].

Surgeons have also discussed resection of the lateral flange of the first metatarsal base to aid in reduction of the intermetatarsal angle. In an anatomic cadaveric study by Mason and Tanaka, it was found that there was a constant lateral plantar prominence found on the metatarsal base. The size of the prominence differed greatly between specimens [12]. We believe this plantar prominence is what surgeons refer to as the "lateral flange." In many cases this flange appears lateral only because the metatarsal is in an everted position. We argue that this bony block is eliminated once the metatarsal is adequately inverted during correction and does not need to be resected. Once this frontal plane is reduced, the lateral flange is now plantar and provides increased bone contact with the medial cuneiform rather than a hindrance to reduction.

Complications

Shortening of the first metatarsal is a potential complication of the Lapidus procedure which can lead to transfer lesions plantar to the second metatarsal head along with decreased hallux purchase. As we noted previously, a plantarflexed first metatarsal can give the appearance of a short ray and must be considered in evaluation. The goal is to achieve a natural plantarflexion angle of the first metatarsal parallel to the second metatarsal, and we recommend against offsetting the first metatarsal by sliding it in a plantar direction because it alters the axis relationship of the first ray. Excessive plantarflexion of the first metatarsal can cause sesamoid pain as well as a joint contracture at the first metatarsal phalangeal joint**.** Also as discussed in Chap. 6, when the first ray is corrected in all three planes, the normal windlass mechanism of the first ray is restored fully, and this improves the weight-bearing function of the MTPJ and medial column reducing the tendency for lateral transfer symptoms. In our experience this normalization of the first ray mechanics protects against lateral weight transfer.

Delayed unions and nonunions are certainly a consideration for this procedure, with delayed unions occurring more frequently in literature [40]. A review of the literature reports nonunion rates between 5% and 33% after modified Lapidus with 6–8 weeks of non-weight bearing [29, 32, 41]. The diversity of joint preparation techniques, fixation techniques, and postoperative protocols makes it difficult to draw accurate conclusions regarding healing rates. The advent of more stable techniques and grafting are an advantage, and we are seeing many reports of excellent healing and low complications even with early weight bearing. The authors' combined experiences highlight a very low healing complication rate with the techniques presented. Malunions associated with the procedure can be avoided with intraoperative radiographs to establish correct positioning in all three planes of the deformity. Malunion of the first ray in an elevated position may give rise to a dorsal bunion, decreased range of motion, and decreased purchase of the first ray, which could lead to transfer metatarsalgia [16]. Likewise, care must be taken to not overly plantarflex the first ray as sesamoiditis could result. Neuritis, while uncommon, can be encountered with the close proximity of the medial dorsal cutaneous nerve to the surgical site. Depending upon dissection techniques and incision planning, the saphenous nerve may be involved as well as the deep peroneal nerve of the first interspace [16, 42, 43]. Cases of complex regional pain syndrome have been reported [40].

Summary

Despite our enthusiasm with this procedure, especially with the triplane modifications, we are fully aware that further outcome studies must be done to understand the overall benefits to the patient and comparison to other procedures. All of the authors perform modifications of the Lapidus with high frequency, and we are rarely performing metatarsal osteotomy procedures due to our analysis of the observed power of the anatomic correction and our empiric results. We are actively collecting data and analyzing results to add to the body of knowledge of this subject.

Reference

1. Albrecht GH. The pathology and treatment of hallux valgus. Russk Vrach. 1910;10:14–9.
2. Lapidus PW. The operative correction of metatarsus varus primus in hallux valgus. Surg Gynecol Obstet. 1934;58:183–91.
3. Chang T, Ruch J. Lapidus arthrodesis. A different perspective. J Am Podiatr Med Assoc. 1994;6:281–8.
4. Hofbauer M, Grossman J. The Lapidus procedure. Clin Podiatr Med Surg. 1996;3:485–96.
5. Sangeorzan B, Hansen S. Modified Lapidus procedure for hallux valgus. Foot Ankle. 1989;6:262–6.
6. Butson ARC. A modification of the Lapidus operation for hallux valgus. J Bone Joint Surg. 1980;62B:350–2.
7. Bacardi BE, Boysen TJ. Considerations for the Lapidus operation. J Foot Surg. 1986;25:138.
8. Hernandez A, Hernandez PA. Lapidus: when and why? Clin Podiatr Med Surg. 1989;6:197.
9. Mauldin DM, Sanders M, Whitmer WW. Correction of hallux valgus with metatarsocuneiform stabilization. Foot Ankle. 1990;11:57.
10. Myerson M. Metatarsocuneiform arthrodesis for treatment of hallux valgus and metatarsus primus varus. Orthopedics. 1990;13:1050.
11. Glasoe WM, Yack HJ. Saltzman. Anatomy and biomechanics of the first ray. Phys Ther. 1999;79(9):854–9.
12. Mason LW, Tanaka H. The first tarsal–metatarsal joint and its association with hallux valgus. Bone Joint Res. 2012;1:99–103.
13. Root ML, Orien WP, Weed JH. Muscle function of the foot during locomotion. In: Root ML, O'Rien WOP, Weed JH, editors. Clinical biomechanics, vol. 2. Los Angeles: Clinical Biomechanics Corporation; 1977.
14. Root ML, Orien WP, Weed JH, et al. Technique for the examination of the first ray. In: Root SA, editor. Biomechanical examination of the foot, vol. 1. Los Angeles: Clinical Biomechanics; 1971. p. 80–7.
15. Roukis TS, Landsman AS. Hypermobility of the first ray: a critical review of the literature. J Foot Ankle Surg. 2003;6:377–90.
16. Myerson M, Allon S, McGarvey W. Metatarsocuneiform arthrodesis for management of hallux valgus and metatarsus primus varus. Foot Ankle. 1992;13:107–15.
17. Goldner JL, Gaines R. Adult and juvenile hallux valgus: analysis and treatment. Orthop Clin. 1976;7:863–87.
18. Saffo G, Desnoyers R, Wooster M, et al. First metatarsal–cuneiform joint arthrodesis: a five year retrospective analysis. J Foot Surg. 1989;5:459–65.
19. Dayton P, Feilmeier M, Kauwe M, Hirschi J. Relationship of frontal plane rotation of first metatarsal to proximal articular set angle and hallux alignment in patients undergoing tarsometatarsal arthrodesis for hallux abducto valgus: a case series and critical review of the literature. J Foot Ankle Surg. 2013;52(3):348–54.
20. Dayton P, Kauwe M, DiDomenico LA, Feilmeier M, Reimer R. Quantitative analysis of the degree of frontal rotation required to anatomically align the first metatarsal phalangeal joint during modified tarsal-metatarsal arthrodesis without capsular balancing. J Foot Ankle Surg. 2016;55:220–5.
21. DiDomenico LA, Fahim R, Rollandini J, Thomas Z. Correction of frontal plane rotation of sesamoid apparatus during the Lapidus procedure: a novel approach. J Foot Ankle Surg. 2014;53:248–51.
22. Bierman RA, Christensen JC, Johnson CH. Biomechanics of the first ray. Part III. Consequences of Lapidus arthrodesis on peroneus longus function: a three-dimensional kinematic analysis in a cadaver model. J Foot Ankle Surg. 2001;3:125–31.
23. Catanzariti AR. Modified medial column arthrodesis. J Foot Ankle Surg. 1993;2:180–8.
24. Hansen S. Functional reconstruction of the foot and ankle. 1st ed. Philadelphia: Lippincott Williams & Wilkins; 2000.
25. Manoli A, Hansen ST. Screw hole preparation in foot surgery. Foot Ankle Int. 1990;11:105–6.
26. Fleming J, Kwaadu K, Brinkley J, Ozuzu Y. Intraoperative evaluation of medial intercuneiform instability after Lapidus arthrodesis: intercuneiform hook test. J Foot Ankle Surg. 2015;54(3):464–72.
27. DiDomenico LA, Hara A. Percutaneous harvest of calcaneal bone graft. J Foot Ankle Surg. 2006;45(2) 131–133.
28. Perren SM. Physical and biological aspects of fracture healing with special reference to internal fixation. Clin Orthop Relat Res. 1979;138:175–96.
29. Patel S, et al. Modified Lapidus arthrodesis: rate of nonunion in 227 cases. J Foot Ankle Surg. 2004;43(1):37–42.

30. Catanzariti AR, et al. The modified Lapidus arthrodesis: a retrospective analysis. J Foot Ankle Surg. 1999;38:322.
31. Mendicino R, et al. The modified Lapidus arthrodesis: technical maneuvers and pearls. J Foot Ankle Surg. 2000;39:258.
32. Menke, et al. Lapidus arthrodesis with a single lag screw and a locking H-plate. J Foot Ankle Surg. 2011;50:377–82.
33. Dayton P, Hatch D, Scanlan S, Ferguson J, Smith B, Santrock B. Comparison of the mechanical characteristics of small bi-planar plating technique to single plate and screw models. J Foot Ankle Surg. 2016;55(3):567–71.
34. MacMahon A, Karbassi J, Burket JC, et al. Return to sports and physical activities after the modified lapidus procedure for hallux valgus in young patients. Foot Ankle Int. 2016;37(4):378–85.
35. Robinson C, Bhosale A, Pillai A. Footwear modification following hallux valgus surgery: the all-or-none phenomenon. World J Methodol. 2016;6(2):171–80.
36. Taylor NG, Metcalfe SA. A review of surgical outcomes of the lapidus procedure for treatment of hallux abductovalgus and degenerative joint disease of the first MCJ. Foot (Edinb). 2008;18(4):206–10.
37. Barvarian B, Briskin GB, Burns P. Lapidus bunionectomy: arthrodesis of the first metatarsal–cuneiform joint. Clin Podiatr Med Surg. 2004;21:97–111.
38. DiDomenico LA, Adams HB, Garchar D. Gastrocnemius recession for the treatment of gastrocnemius recession. J Am Podiatr Med Assoc. 2005;95(4):410–3.
39. The Materials Information Society. Stress-strain behavior. In: Davis JR, editor. Tensile testing. Ohio: Materials Park; 2004. p. 36.
40. Rink-Brune O. Lapidus arthrodesis for management of hallux valgus—a retrospective review of 106 cases. J Foot Ankle Surg. 2004;43(5):290–5.
41. Saxena A, Nguyen A, Nelsen E. Lapidus bunionectomy: early evaluation of crossed lag screws versus locking plate with plantar lag screw. J Foot Ankle Surg. 2009;48(2):70–179.
42. Clarke HR, Veith RG, Hansen ST. Adolescent bunions treated by the modified Lapidus procedure. Bull Hosp Jt Dis Orthop Inst. 1987;47:109–22.
43. Catanzariti AR, Blitch EL. Metatarsal cuneiform procedures. In: Banks AS, Downey MS, Martin DE, et al., editors. McGlamry's comprehensive textbook of foot and ankle surgery. 3rd ed. Philadelphia: Lippincott Williams & Wilkins; 2001. p. 544–56.