

VOLUME ONE

McGLAMRY'S

Foot and Ankle Surgery

FIFTH EDITION

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PREFACE

We are delighted and honored to write the preface for the fifth edition of *McGlamry's Foot and Ankle Surgery*. E. Dalton McGlamry recognized the need for a complete and well-referenced textbook in foot and ankle surgery and published the first edition in 1987. Through the centuries, physicians and surgeons have been engaged in preservation of normal foot and ankle function. In ancient times, the normal functioning foot was vital to survival. Aristotle (384-322 BC) studied movement and analyzed the degeneration of muscles and the defective development of human beings, and it was believed that individuals possessing these attributes could not survive. In ancient Rome, those with disabilities were treated as objects of scorn. As early as 400 BC, Hippocrates described clubfoot and recommended nonoperative treatments using manipulation and bandaging techniques not dissimilar to the techniques utilized today.

In recent times, an abundance of medical knowledge and innovations have been unveiled and the dynamic nature of medical science continues to evolve. Professionals among the medical disciplines work collectively as interdisciplinary teams and are the cornerstone of medical organizations and health care systems representing the future of medicine. Well-trained, successful, foot and ankle surgeons exert a large influence within

medicine and represent departmental chairs, current and past presidents of major medical associations, journal authors and editors, researchers, and reviewers.

This textbook is intended for use by residents in training with a focus on foot and ankle pathology as well as surgeons with interest in the foot and ankle; both nonoperative and operative techniques are described with quick reference text boxes highlighted as an educational tool for the reader.

The esteemed authors represented in this textbook were carefully selected for their educational, clinical, and surgical acumen, contributions to research and achievements in their selected subject matter. The editorial board endeavored to ensure that the information provided is accurate and current.

It is our hope and expectation that this book will provide an effective learning experience and referenced resource for all foot and ankle specialists and ultimately lead to improved patient care and outcomes.

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CHAPTER 9

Lesser Rays

William D. Fishco

DEFINITION

Metatarsalgia is an all inclusive diagnostic term for pain in the submetatarsal region of the foot.¹ For the purposes of this chapter, the focus will be for the condition of pain under the metatarsal head(s) due to plantar pressures and to address tailor's bunion deformity. Lesser metatarsal surgery is typically performed to address metatarsalgia related to high plantar pressures when nonoperative treatments fail to adequately resolve pain.

ANATOMIC FEATURES AND FUNCTIONAL ANALYSIS

Central metatarsal surgery is typically performed to "adjust" the height or length of a metatarsal head that is causing pain due to pressure overload. It is important to remember that the central metatarsal conditions have mechanical influences that contribute to pathology such as ankle equinus, instability of the medial column, hallux valgus, and hammer toes. The 5th metatarsal is generally associated with more of a structural problem of the metatarsal bone. A tailor's bunion typically has lateral bowing or a wide metatarsal head leading to a lateral and/or plantar lateral prominence of bone. Typically, a higher arched foot or one that oversupinates has trouble under the 5th metatarsal head.

PHYSICAL EXAMINATION

History and physical examination can determine the etiology of the pain and treatment can be initiated based upon those findings. When a patient presents with "pain in the ball of the foot," the physical examination includes a complete radiographic examination, palpation and range of motion examination of the metatarsophalangeal joints, anterior drawer test of the metatarsophalangeal joints, palpation/squeeze test into the intermetatarsal spaces, and a dermatologic examination to assess for associated keratoses. In the elderly, diminished plantar fat pad under the metatarsals may be a factor.

The common clinical findings associated with metatarsalgia that should be evaluated for include ankle equinus and hammer toes,² hallux valgus deformity with first ray insufficiency,^{3,5} and acute inflammatory joints.

When there is pain and/or crepitation with range of motion to a lesser metatarsophalangeal joint, then an inflammatory or degenerative joint condition such as rheumatoid arthritis, Freiberg infraction, or an acute synovitis/capsulitis should be considered. Pain with plantar flexion of the digit and pain with palpation of the plantar plate is consistent with an acute synovitis/capsulitis, which can lead to hammer toe or dislocation deformity. This condition has also been referred to as predisslocation syndrome.⁶ Morton neuroma should be considered when there is pain and clicking noted with palpation and squeezing into the interspace between the metatarsals.

DIAGNOSTIC IMAGING

The commonly accepted "normal" metatarsal length pattern or parabola is $II \geq I > III > IV > V$.⁷ Just how much metatarsal length variation is acceptable and what the length pattern should be is still very much a debate.⁸ A relatively long 2nd metatarsal is still considered to be a leading causation of metatarsalgia and hammer toe development of the 2nd toe.⁹ A complete set of radiographs is necessary to determine whether there is any structural deformity. An anteroposterior radiograph is helpful in determining the metatarsal parabola. An oblique view will assess sagittal plane abnormalities of the central metatarsals and lateral bowing of the 5th metatarsal (Fig. 9.1). The lateral view and sesamoid axial view will allow visualization of sagittal plane positions of the metatarsal heads (Fig. 9.2). Radiographs will also rule out arthritic conditions.

TREATMENT

Treatment

- Designed to resolve high peak pressures causing pain under the metatarsal head

Nonsurgical treatment includes wearing stiff soled shoes with orthotics to reduce high peak plantar pressures to the painful metatarsal head(s). Debridement of any associated hyperkeratotic lesions help reduce pressure. In older patients with fat pad atrophy, cushioned liners with shock absorbing properties can be used.



FIGURE 9.1 Oblique view illustrating lateral bowing of the 5th metatarsal.

INDICATIONS

- Lesser metatarsal surgery is typically performed to treat metatarsalgia
- Lesser metatarsal surgery may be an adjunct to repair complex digital deformities
- 5th metatarsal surgery is commonly performed to correct a tailor's bunion



FIGURE 9.2 Sagittal plane abnormalities can be seen on and axial view. Note elevated 3rd metatarsal.

When surgery is performed to address metatarsalgia, the end goal is to resolve high peak plantar pressure areas, which would lead to pain and dysfunction. There is a combination of four surgical approaches that are typically used, which includes removal of bone, which can be done with a plantar condylectomy or partial/complete metatarsal head resection, shortening/lengthening a metatarsal, raising/lowering a metatarsal head (sagittal plane correction), or medial/lateral translocation (transverse plane correction), which is typically performed when repairing a concomitant transverse plane hammer toe deformity or tailor's bunion deformity.

Surgery of the 5th metatarsal is typically performed for a tailor's bunion. The techniques used typically involve shaving of the lateral bony prominence (exostectomy) and/or osteotomy to move the metatarsal medially and/or dorsally depending on the location of pain.

PERILS and PITFALLS

- Not addressing concomitant hallux valgus and hammer toes.
- Over shortening/raising metatarsals may lead to transfer metatarsalgia.
- Over lengthening metatarsals may lead to stiff joints.
- Osteotomies performed without fixation to allow the bone to "float" increases incidence of nonunion, malunion, and/or excessive bone callus.
- A floating toe may develop after shortening a metatarsal.
- A hammer toe may develop after shortening a metatarsal if the toe floats.
- Use caution with osteotomies and internal fixation in patients with osteoporotic bone.

Metatarsal osteotomies can be performed in the neck, midshaft, or base of the bone. The majority of surgery is performed at the metatarsal neck due to the typical need of minor adjustments of height and/or length, ease of dissection/osteotomy/fixation, and proximity to the digit (which often times is also addressed). Moreover, healing potential is greatest in metaphyseal bone (Figs. 9.3 through 9.5). When larger amounts of correction are needed, then a midshaft osteotomy or base osteotomy is recommended. A midshaft sagittal Z osteotomy is ideal for metatarsals requiring greater amounts of shortening that can be obtained with a distal metatarsal osteotomy or if lengthening of the bone is required (Fig. 9.6A and B). For large amounts of sagittal plane correction, a dorsiflexion or plantarflexion osteotomy of the metatarsal base is recommended as the proximal location leads to greater correction with minimal bone wedging (Fig. 9.7A and B). Osteotomies placed in the metatarsal base have a longer radius arm. The more proximal the osteotomy, the longer the lever arm will be and thus allow for larger amounts of correction. In the cavus foot, for example, a dorsiflexory base osteotomy is often used.

The most common metatarsal osteotomies of the metatarsal head/neck include the Weil osteotomy, a "V" osteotomy, and an oblique osteotomy that can be used as a "tilt-up" or through and through osteotomy with a single or double cut (Figs. 9.8 through 9.10). Certainly any osteotomy that can afford repositioning of bone to the desired location that is amenable for



FIGURE 9.3 Traditional chevron osteotomy.



FIGURE 9.5 Healed osteotomy



FIGURE 9.4 Oblique osteotomy is simple and effective in reducing the deformity.

internal fixation is acceptable. Fixation of a “V” osteotomy can be difficult and as a result has fallen out of favor. One can modify the osteotomy with unequal arms of the chevron to make it easier to fixate (Fig. 9.11). In addition, small plates and screws can be used for traditional chevron osteotomies.¹⁰ With the advent of small superelastic memory staples, a transverse osteotomy can be simple and easy to fixate (Fig. 9.12).



FIGURE 9.6 **A.** Diagram illustrating a “step-down” sagittal Z osteotomy. **B.** Intraoperative view of a sagittal Z osteotomy in a patient with iatrogenic deformities requiring more shortening than could be obtained with a distal metatarsal osteotomy.

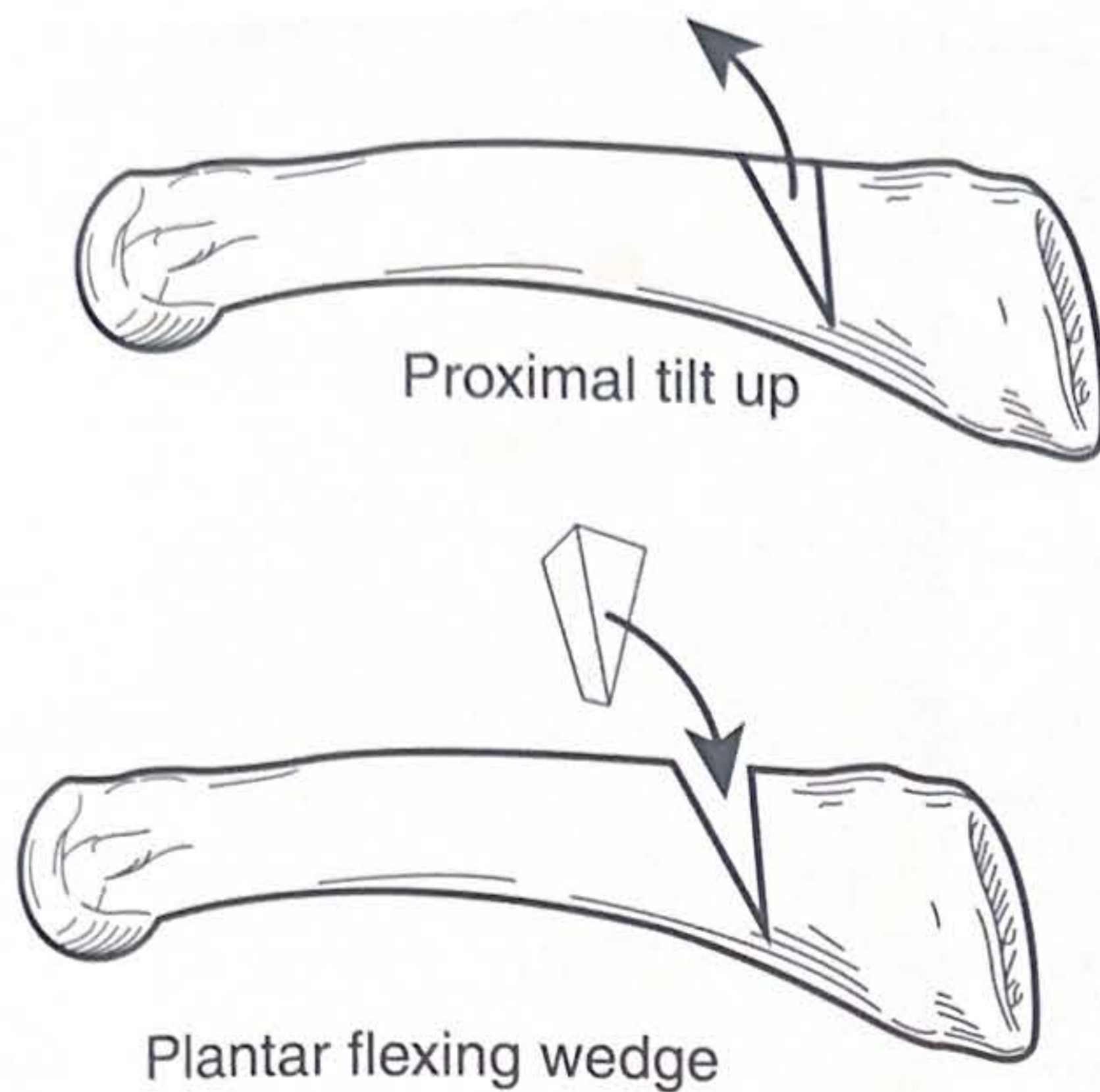


FIGURE 9.7 **A.** Diagram illustrating a dorsiflexing base wedge osteotomy. **B.** Diagram illustrating a plantarflexing base wedge osteotomy using a bone graft.

DISSECTION TECHNIQUE

Surgical exposure for lesser metatarsal surgery includes a mid-line linear skin incision over the affected ray from the base of the phalanx to the metatarsal neck and shaft. Depending on which procedure is being performed will dictate how long the incision should be and whether the metatarsophal-

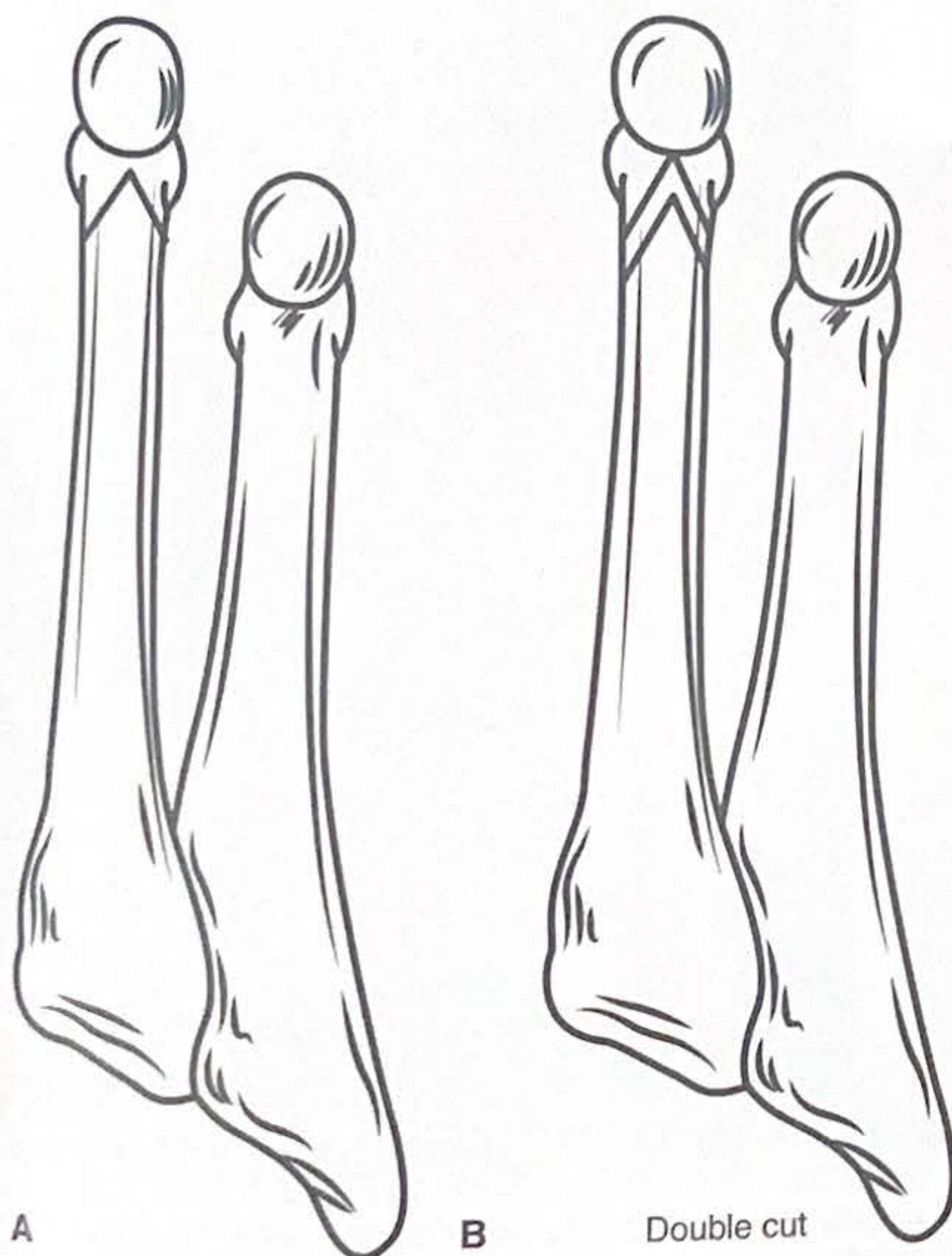


FIGURE 9.8 **A, B.** Diagram illustrating a chevron osteotomy to adjust the height of a metatarsal or a double cut for more shortening.

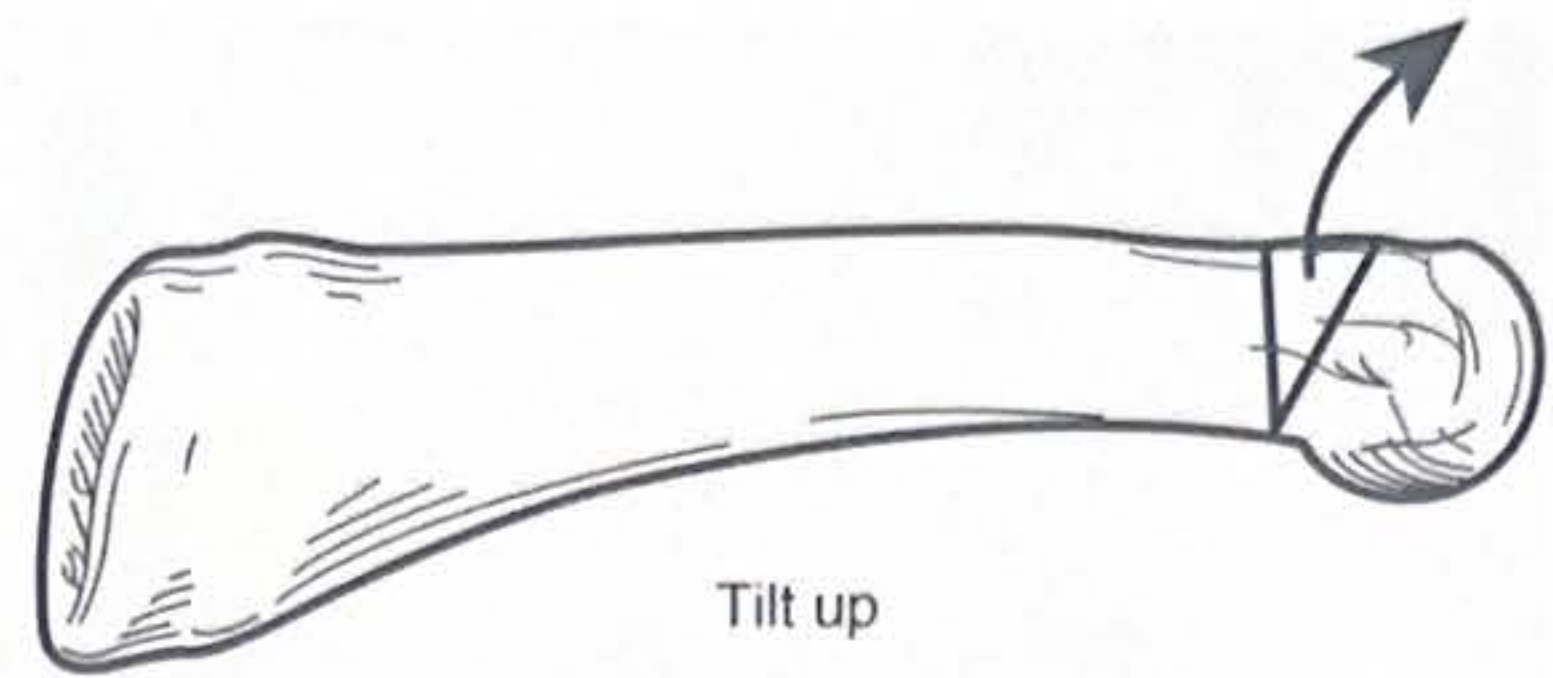


FIGURE 9.9 Diagram illustrating a "tilt up" oblique osteotomy.

angeal joint needs to be opened. When performing a condylectomy, the dissection starts more distally on the toe and ends just proximal to the metatarsophalangeal joint. For extra-articular distal metatarsal osteotomies, the dissection can start just proximal to the metatarsophalangeal joint. If an intra-articular osteotomy, such as a Weil osteotomy is going to be performed, then the incision will need to encompass the base of the toe and extend to the metatarsal neck. Once the skin incision is made, the subcutaneous tissues are dissected and separated from the long extensor tendon. A moist gauze sponge is useful in clearing away the fatty tissue off of the extensor tendon apparatus. The tendon can be reflected by releasing the hood fibers on lateral side and retracting the tendon medially or vice versa. This will expose the joint capsule and periosteum. A transverse capsulotomy of the metatarsophalangeal joint is performed followed by a linear incision on the periosteum of the metatarsal neck. This will have the appearance of a "T." The periosteum is reflected medially and laterally for exposure of the bone and is now ready for the osteotomy. Use intraoperative fluoroscopy to ensure proper amount of correction is obtained (Fig. 9.13). Alternative approaches for the tendon include splitting the tendon in the midline and retract medially and laterally, or finally one can do a z-plasty of the tendon and repair after the bone work is done. For basilar osteotomies, the dissection starts more proximal in midshaft area of the metatarsal and carried toward the base of the bone.

Plantar condylectomies are considered when there is not a significant deformity of the metatarsal, yet there is chronic pain, keratosis, and/or skin breakdown under the metatarsal head (Fig. 9.14). Condylectomies are ideal for patients with osteopenic bone or if they are not good candidates for an osteotomy and internal fixation.

PEARLS

CENTRAL METATARSAL OSTEOTOMIES

- Use fluoroscopy to confirm metatarsal positioning to avoid over shortening.
- Aggressive postoperative ROM of toes helps prevent stiff joints.
- Bandaging toes in excessive plantarflexion and splinting in this position for the first few weeks help prevent floating toes.
- Consider concomitant hammer toe repair when shortening a metatarsal as a digital deformity may worsen or develop due to loss of intrinsic stability of the toe.

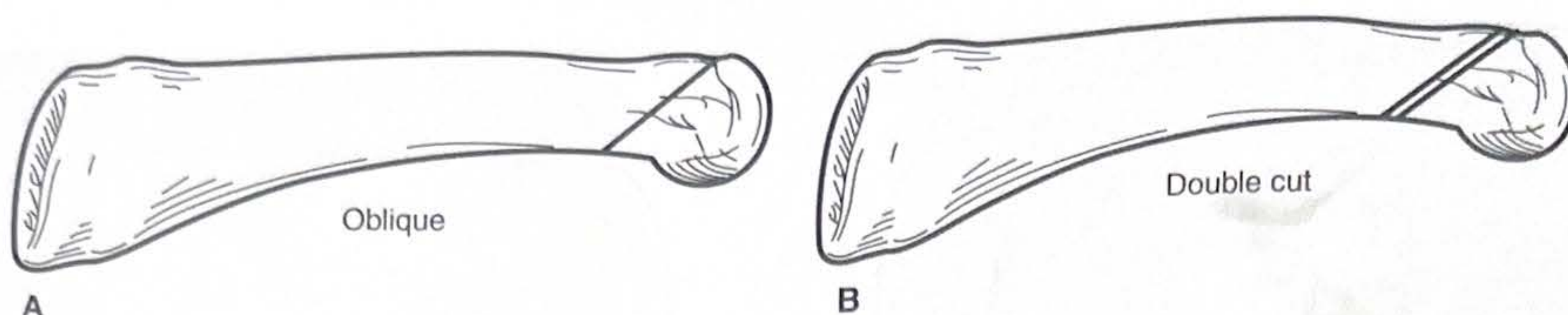


FIGURE 9.10 A, B. Diagram illustrating a single cut oblique osteotomy and a double cut for more shortening.

TAILOR'S BUNION

Tailor's bunion, also known as a bunionette, is a common cause of pain to the lateral or plantar lateral 5th metatarsal head. Radiographic findings associated with tailor's bunions include a large intermetatarsal angle between the 4th and 5th metatarsals, lateral bowing of the 5th metatarsal, and/or a large dumb-bell-shaped metatarsal head¹¹ (Fig. 9.15).

Surgical techniques to address a tailor's bunion include lateral condylectomy, distal neck, midshaft, basilar osteotomies, and on rare occasions a 5th metatarsal head resection.

Lateral condylectomies are selected when there is pain to the lateral aspect of the 5th metatarsal head without any significant radiographic evidence of intermetatarsal splaying or lateral bowing. There may be a wide metatarsal head or prominent lateral condyle. Approximately $\frac{1}{3}$ of the lateral metatarsal can be resected with a power saw or osteotome.

Fifth metatarsal head resections are rarely performed due to inherent complications. The notable exceptions may be in geriatric patients with osteoporosis, a very large deformity, or in a patient with a neurotrophic ulceration

on the lateral or plantar aspect of the 5th metatarsal head. Potential problems that occur with a metatarsal head resection include a retracted/flail 5th toe, transfer metatarsalgia, and in rare cases can trigger Charcot arthropathy in neuro-pathic patients.¹²

Distal metatarsal osteotomies are most commonly performed for tailor's bunion correction just as in central metatarsal osteotomies for same reasons. Various osteotomy designs have been described and used without a clear advantage of one over another. A chevron osteotomy with or without a long dorsal or plantar arm, oblique osteotomies, closing wedge osteotomies, and transverse osteotomies are used (Fig. 9.16). After the osteotomy is complete, a shift of no more than half of the width of the metatarsal head should be performed to avoid instability.



FIGURE 9.11 Diagram illustrating an offset chevron osteotomy, which may be easier to fixate than a traditional chevron osteotomy.



FIGURE 9.12 A transverse osteotomy with superelastic staple may be ideal for minimal shortening and transverse plane correction. This patient had a large hallux valgus deformity with a medially deviated 2nd toe.



FIGURE 9.13 Over shortening of the 3rd metatarsal could have been avoided with the use of intraoperative fluoroscopy.



FIGURE 9.15 Note dumbbell-shaped 5th metatarsal in a patient with a bunion and tailor's bunion.



FIGURE 9.14 Intraoperative view of a condylectomy of the 5th metatarsal for a patient having sub 5 pain without any significant metatarsal deformity.



FIGURE 9.16 Postoperative x-ray of a tailor's bunion repaired with a chevron osteotomy with a long plantar arm fixated with 2.0-mm cortical screws. This is a very stable construct.

For large deformities or in cases where there has already been surgery such as a lateral condylectomy, midshaft or proximal osteotomy is considered. The most common midshaft osteotomy is a SCARF design. Basilar osteotomies typically include a closing wedge osteotomy with a lateral apex and hinge.

SURGICAL TECHNIQUE

A skin incision is made overlying the 5th metatarsal and extended to the base of the 5th toe. The incision should be just lateral to the extensor tendon. The subcutaneous tissues are reflected away from the extensor tendon and hood apparatus. The periosteum of the 5th metatarsal is incised. Use forceps to palpate the bone, this will avoid slipping off the side of the bone where there is intrinsic muscle. As the periosteum is incised lateral to the extensor tendon, it is extended to the base of the proximal phalanx. Now the joint is visualized. The 5th toe can be distracted and that will lead to puckering of the lateral capsule, which will leave a pouch to the lateral side of the joint where the scalpel blade can be inserted to detach the capsule from the lateral aspect of the metatarsal head. Depending on the type of osteotomy to be performed will determine how much periosteum will need to be reflected for bone access. The lateral eminence can be removed with a sagittal saw or osteotome. Avoid removing too much bone as you will only be able to move the metatarsal head $\frac{1}{3}$ to $\frac{1}{2}$ of the width of the head. The desired osteotomy can now be performed (Fig. 9.17A–E). An alternative method involves removing the eminence and overhang of bone after the osteotomy is made and fixated so that there is more metatarsal head available for shifting.

PEARLS

TAILOR'S BUNIONECTOMY

- A traditional chevron osteotomy can be difficult to fixate. Modifying the osteotomy with a long plantar arm allows for easier and more stable fixation with two 2.0-mm cortical screws.
- Do not medially translocate the metatarsal head more than half the width of the metatarsal head.
- When performing a distal metatarsal osteotomy, do not remove too much of the lateral eminence so that you have greater ability to shift the head.
- Avoid plantar and lateral condylectomy as this will weaken the bone.
- Avoid basilar osteotomies unless the deformity cannot be fixed with a distal osteotomy.
- Use caution with 5th metatarsal head resections. In the cavovarus foot type, a new lesion will occur at the stump of the metatarsal. In neuropathic patients, it may trigger a Charcot event.

POSTOPERATIVE CARE

Distal metatarsal osteotomies can be managed with weight bearing to tolerance in a fracture boot or surgical shoe. Base wedge osteotomies will require 4–6 weeks of non-weight bearing followed by protected weight bearing in a fracture boot for an additional 2–4 weeks based upon radiographic signs of bone healing. Stiff and floating toes are common with these procedures; therefore, aggressive range of motion exercises of toes, bandaging toes in plantar flexion, and the use of splints after surgery can help mitigate those problems.

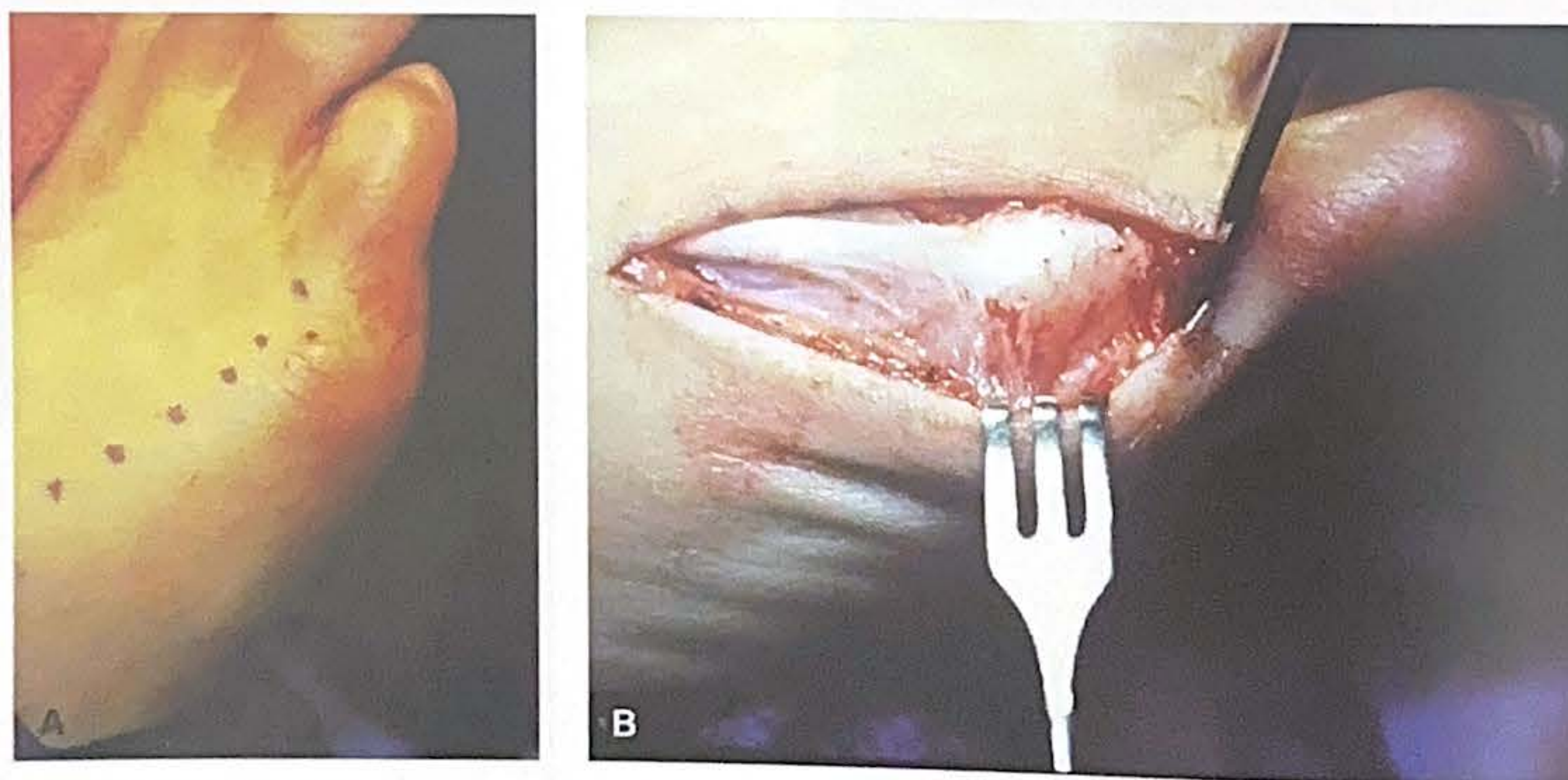


FIGURE 9.17 **A.** Skin incision is dorsolateral from the base of the 5th toe to the metatarsal shaft. **B.** The subcutaneous tissues are dissected off of the joint capsule and extensor tendon apparatus.

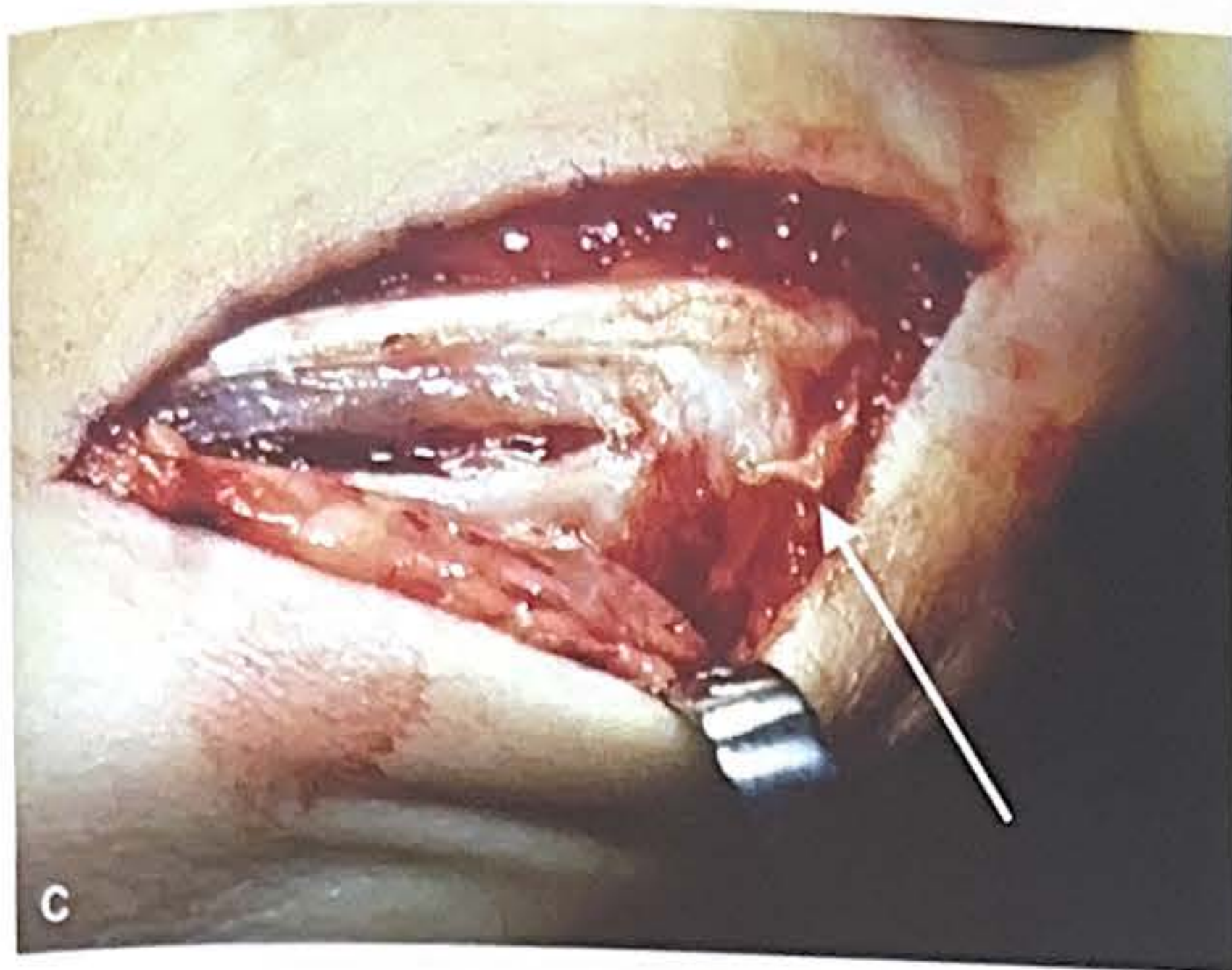
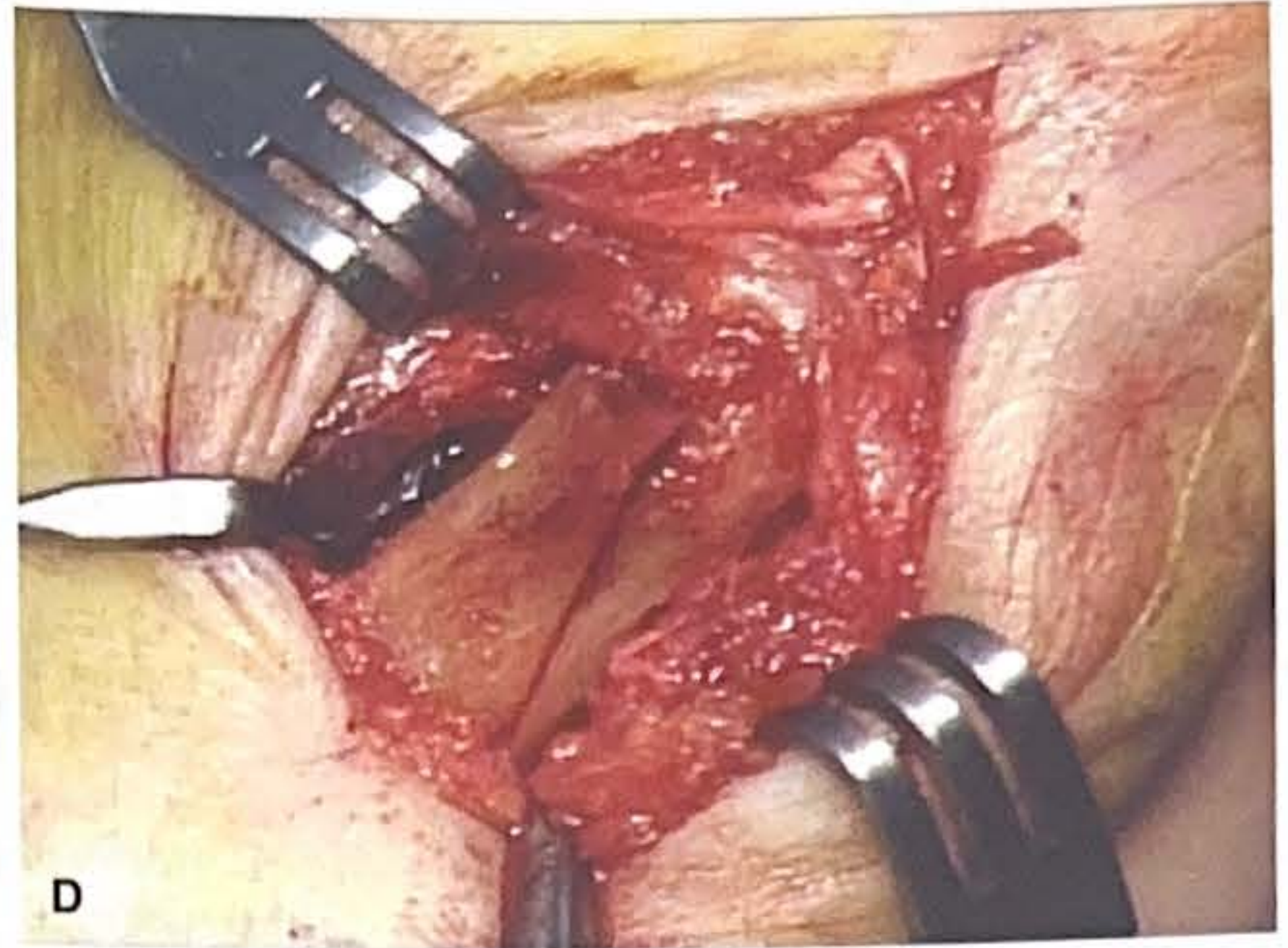


FIGURE 9.17 (Continued) **C.** The periosteum is incised from the metatarsal shaft and then the capsule is incised to visualize the joint. When the 5th toe is pulled/distracted, the lateral capsule will pucker and a scalpel can be inserted in the pocket to detach the lateral capsule (arrow). **D.** A long plantar arm osteotomy. **E.** Healed osteotomy with cortical screws.

REFERENCES

- Schuh R, Trnka HJ. Metatarsalgia: distal metatarsal osteotomies. *Foot Ankle Clin.* 2011;16(4):583-595.
- Searle A, Spink MJ, Ho A, et al. Association between ankle equinus and plantar pressures in people with diabetes. A systematic review and meta-analysis. *Clin Biomech (Bristol, Avon).* 2017;43:8-14.
- Greisberg J, Prince D, Sperber L. First ray mobility increase in patients with metatarsalgia. *Foot Ankle Int.* 2010;31(11):954-958.
- Walker AK, Harris TG. The role of first ray insufficiency in the development of metatarsalgia. *Foot Ankle Clin.* 2019;24(4):641-648.
- Lopez V, Slullitel G. Metatarsalgia: assessment algorithm and decision making. *Foot Ankle Clin.* 2019;24(4):561-569.
- Yu GV, Judge MS, Hudson JR, et al. Predislocation syndrome. Progressive subluxation/dislocation of the lesser metatarsophalangeal joint. *J Am Podiatr Med Assoc.* 2002;92(4):182-199.
- Barrôco R, Nery C, Favero G, et al. Evaluation of metatarsal relationships in the biomechanics of 332 normal feet using the method of measuring relative lengths. *Rev Bras Ortop.* 2011;46(4):431-438.
- Stoupine A, Singh BN. A cadaveric study of metatarsal length and its function in the metatarsal formula and forefoot pathology. *J Am Podiatr Med Assoc.* 2018;108(3):194-199.
- Fleischer AE, Hsieh S, Crews RT, et al. Association between second metatarsal length and forefoot loading under the second metatarsophalangeal joint. *Foot Ankle Int.* 2018;39(5):560-567.
- Herzog JL, Goforth WD, Paden MH. A modified fixation technique for a decompressional shortening osteotomy: a retrospective analysis. *J Foot Ankle Surg.* 2014;53(2):131-136.
- Coughlin MJ. Treatment of bunionette deformity with longitudinal diaphyseal osteotomy with distal soft tissue repair. *Foot Ankle.* 1991;11(4):195-203.
- Fishco WD. Surgically induced Charcot's foot. *J Am Podiatr Med Assoc.* 2001;91(8):388-393.

Lapidus Bunionectomy

Paul Dayton and Daniel J. Hatch

DEFINITION

HISTORY

The Lapidus bunionectomy has evolved over the years and has become increasingly popular with foot and ankle surgeons. Our re-discovery that the first tarsometatarsal joint (1st TMT) is the anatomic apex of the deformity, a concept originally associated with the procedure indications, is driving new discussions on the utility of this procedure. Albrecht first described 1st TMT arthrodesis in 1911.¹ Truslow coined the term metatarsus primus varus in 1925.² This was in reference to the adduction deformity in the transverse plane and not varus as we understand it now in the frontal plane. In 1934, Lapidus stated “the only mechanically sound osteotomy for metatarsus primus varus should be at the metatarsocuneiform joint which is at the apex of the angulation between the first metatarsal and cuneiform joint.”³ A true Lapidus procedure involves arthrodesis of the first tarsometatarsal joint and the bases of the first and second metatarsals. Modifications are commonly performed by either only fusing the first tarsometatarsal joint or employing screw stabilization or arthrodesis between the first and second rays if instability is observed in either the sagittal or transverse plane.

Although Dr. Lapidus’ name is still ascribed to 1st TMT arthrodesis for correction of hallux valgus, the procedure as well as the indications have evolved. For the past two decades, we have seen dramatic improvement in fixation and bone healing and a new understanding of surgical anatomy. These factors have put aside some of the traditional fears of the 1st TMT arthrodesis such as healing problems and prolonged convalescence with earlier iterations of the procedure. We now know that the 1st TMT is a powerful site to correct not only the intermetatarsal (IM) angle but also the other triplane components of the deformity.⁴ We no longer see this as a procedure reserved for the most severe deformities or only for those needing first ray stabilization. In fact, there are many surgeons that use the 1st TMT corrective arthrodesis as their priority procedure for correction of hallux abducto valgus (HAV).

HISTORICAL INDICATIONS

Traditional indications for the Lapidus bunionectomy have been based upon severity-based algorithms. In the past, and to a large extent today, the procedure fits in the spectrum of severity only for the most severe deformities of the IM angle.

Other indications are the presence of osteoarthritis of the first tarsometatarsal joint, which is not a common component of hallux valgus deformity, and significant elevation of the first ray. Condon et al. in 2002 described a severity-based algorithm for hallux valgus repair in which a severe deformity was classified as an IM angle of 16 degrees or greater.⁵ This also was supported by Coughlin and Jones in 2007.⁶ Traditionally, it has been in this severe class that the Lapidus procedure would be performed. Additionally, hypermobility of the first ray has also been a criterion for the Lapidus procedure. While still a clinical enigma, many descriptions of hypermobility have been attempted. Due to the difficulty of definition, many now prefer to call this first ray insufficiency or functional instability. Many authors believe that hypermobility of the first ray unlocks the forefoot predisposing it to HAV deformity.^{3,7,8} D’Amico wrote a review of first ray mechanics in 2016.⁹ In that article he stated “hypermobility of the first ray ... occurs primarily at the medial cuneiform-navicular articulation caused by subtalar and mid-tarsal joint pronation as a result of inherently induced phylogenetic and ontogenic induced imperfections.” Kimura et al. in 2017 stated that hypermobility occurs along the entire first ray and is not limited to or predominated by range of motion at the 1st TMT.¹⁰

Most commonly those that have studied and discussed first ray range of motion discuss hypermobility in the sagittal plane. Root et al. in 1977 defined hypermobility as motion in excess of equal amounts of dorsal and plantar displacement of the first ray compared to the second ray.¹¹ Roukis and Landsman described a dynamic Hick test in their review of the literature in 2003.¹² In this case, the windlass mechanism would be engaged while evaluating the disbursement of the first ray. The power of the windlass mechanism was detailed in Rush et al. article in 2000.¹³ They found that there was significant loss of the windlass with hallux valgus deformity. Additionally, realignment of the first ray and sesamoids provides successful engagement of the windlass. Shibuya et al. found in their systematic review that there was 3.62-mm displacement in the sagittal plane in the hallux valgus group.¹⁴ Radiographic signs of sagittal plane instability include second ray overload with stress fractures and plantar gapping of the 1st TMT (Fig. 13.1).

Descriptions of transverse instability or splay are less common in the literature. Weber et al. described a “splay test” that represented transverse plane instability especially in a Romash 1 foot type.¹⁵ This was later reinforced by a study from Fleming et al. finding that in patients with hallux valgus, 73.8% had transverse plane instability.¹⁶



FIGURE 13.1 Sagittal plane instability with plantar gap at the first TMTJ. (From Hatch DJ, Santrock RD, Smith B, Dayton P, Weil L. Triplane Hallux Abducto Valgus Classification. *J Foot Ankle Surg.* 2018;57(5):972-981.)

Hypermobility not only influences the HAV deformity but it increases the chance of recurrence and overload to the second rays as pointed out by Feilmeier et al.¹⁷ As with sagittal plane instability, transverse plane movement and potential functional instability occurs at multiple first ray joints including the 1st TMT. Traditional thought is that fusing the 1st TMT as part of the Lapidus procedure will eliminate recurrence of the deformity. Because the motion comes from multiple joints, recurrence of HAV is certainly possible even when the 1st TMT is solidly fused. This especially may occur if the IM angle is not reduced enough. Lapidus in his original description included fusion of the first and second metatarsal bases, possibly because he recognized this. Fusion of metatarsals 1-2 at the bases certainly reduces the chances of recurrence but may limit the desirable windlass function of the first ray. As we will discuss later in this chapter, a more modern approach to 1st TMT fusion for HAV is a triplanar correction philosophy.

MODERN INDICATIONS

Current indications for Lapidus originate from improved understanding of three-dimensional (3-D) anatomy of the first ray. This triplanar anatomic-based approach has been discussed by Hatch et al.¹⁸ (Table 13.1). Understanding of the frontal plane component of the first ray as a component of the HAV and adherence to the principle that the 1st TMT is the anatomic apex of the deformity changes our thought process from the 1st TMT fusion being an occasionally performed procedure, to one that is indicated for most HAV deformities. Comprehension of the 3-D aspects of the first ray has evolved since Mizuno first described this in 1956.¹⁹ Scranton and Rutkowski in their 1980 study found that patients with HAV had 14.5 degrees of valgus rotation of the first ray vs 3.1 degrees in the normal population.²⁰ Eustace in 1994 described a valgus rotation of the first metatarsal with bunion deformity.²¹ Talbot and Saltzman found that pronation of the first metatarsal changed the apparent position of the sesamoids on the AP radiographic view.²² Okuda et al. described a lateral rounding of the first metatarsal in his HAV group indicating a rotation in the frontal plane.²³ This was also substantiated by Yamaguchi et al. in 2015.²⁴ Mortier in 2012 found that the first ray was pronated in the HAV group by an average of 12.7 degrees.²⁵ Dayton et al. pointed out that our traditional evaluations of the bunion deformity may be flawed if the frontal plane is not considered and also found significant valgus rotation of the first ray in HAV patients.²⁶ With improved imaging provided by three-dimensional computerized tomography (CT), it has become clear that a majority of patients with hallux valgus possess a valgus rotation of the first ray. This may be intrinsic as described by Ota et al.²⁷ or extrinsically rotated in valgus as elucidated by many recent authors. Unless the valgus rotation is addressed surgically, recurrences can be expected due to malalignment of the sesamoid complex.²⁸

TABLE 13.1 Triplane Classification of HAV			
Triplane Hallux Valgus Classification and Treatment Algorithm			
Class	Anatomic Findings	MTP Joint Status	Treatment Recommendation
1	Increased HVA and IMA No first metatarsal pronation evident on AP and sesamoid axial radiograph Sesamoids may be subluxed	No clinical or radiographic evidence of DJD	Metatarsal osteotomy or TMT correction. Sesamoid release to help realign complex
2A	Increased HVA and IMA First metatarsal pronation evident on AP and sesamoid axial radiograph No sesamoid subluxation on axial	No clinical or radiographic evidence of DJD	Triplane correction including first metatarsal inversion
2B	Increased HVA and IMA First metatarsal pronation evident on AP and sesamoid axial radiograph With sesamoid subluxation on axial	No clinical or radiographic evidence of DJD	Triplane correction including first metatarsal inversion Lateral capsular/sesamoidal release prior to correction
3	Increased HVA and IMA >20 degrees MTA	No clinical or radiographic evidence of DJD	Metatarsal 2 and 3 transverse plane correction Metatarsal osteotomy or TMT correction per class 1 and 2 recommendations
4	Increased HVA and IMA ± first metatarsal pronation	Clinical and/or radiographic evidence of DJD	First MTP arthrodesis preferred Resectional/implant arthroplasty may also be utilized

The center of rotation and angulation (CORA) is defined by Paley as either mechanical or anatomic and is a vital concept for deformity mapping and choosing the most appropriate site for correction.²⁹ The 1st TMT is the most advantageous site to address the triplane components of HAV because it represents the anatomic apex of the deformity between the medial cuneiform and the first metatarsal.^{26,30,31} The mechanical axis of the first ray has been discussed by LaPorta et al. in 2016 as more proximal in the midfoot.³² Indeed the majority of motion within the first ray is at the navicular-medial cuneiform joint.⁹ With traditional severity-based algorithms, we measure and address the transverse plane variables (two-dimensional approach) and chose from a variety of metatarsal osteotomies. Because metatarsal osteotomy does not move the segment at the anatomic apex and can provide only limited 3-D correction, we are left with less than desirable alignment in many instances. This is highlighted by the fact that the overall foot width following osteotomy is not reduced after osteotomy as described by Tenenbaum.³³ When correcting the deformity at the anatomic apex, a true correction can be obtained with consistent reduction in the width of the forefoot. We measured a consistent width reduction in 109 1st TMT arthrodesis procedures along with true IM angle correction and consistent decrease in forefoot width (Dayton, unpublished results, 2019). Central concepts that have changed our thinking regarding the indications for 1st TMT arthrodesis are the concept of anatomic apex, the need for multiplane correction, which is most surgically amenable at the 1st TMT, and ease of addressing first and second ray instability at that site when it exists.

INDICATIONS

- No longer severity based. It is anatomic based with anatomic CORA at the 1st TMT.
- Based upon HAV and any increased IM angle.
- Presence of frontal plane rotation.

RADIOGRAPHIC EVALUATION

Both clinical and radiographic preoperative planning is essential to set the stage for adequate deformity correction. The weight-bearing AP projection is used to evaluate the IM angle and the hallux valgus angles (HVA). Good intra- and inter-rater reproducibility of these angles has been studied and published. The distal metatarsal articular angle (DMAA), also known as the proximal articular set angle (PASA), has proven to be less reliable.^{6,34,35} The possibility that DMAA is a radiographic artifact has been raised by several researchers who have noted the articular surface alignment to change substantially with repositioning of the first metatarsal without osteotomy.^{4,36} Tibial sesamoid position (TSP) is also assessed on the AP radiographic projection and is thought to be an important indicator of both severity of deformity and a marker of adequate correction. Recent findings have confirmed that dramatic changes in the apparent AP TSP can be affected by frontal plane rotation of the first ray.^{37,38} The sesamoids may appear subluxed on the AP projection when in fact they are in their normal location medial and lateral to the median crista. Axial sesamoid views or weight-bearing CT scans are needed to assess the true positions of the sesamoids, and the AP radiograph should not be relied



FIGURE 13.2 Axial sesamoid view demonstrating eversion of the first ray.

upon exclusively preoperative, intraoperative, or postoperative. There is a renewed importance of the weight-bearing axial sesamoid view since Kim et al. demonstrated frontal plane rotation via 3-D CT analysis.³⁹ The axial view will evaluate the amount of eversion of the metatarsal when it exists and the degree if any of sesamoid subluxation (Fig. 13.2). When sesamoid subluxation occurs, a first MTPJ lateral release should be performed to properly align the sesamoid complex upon realignment of the metatarsal. The weight-bearing lateral projection is utilized to mainly assess the Meary angle and Seiberg index. If elevation of the first ray is observed, then it should also be addressed at the time of surgery.

As discussed previously using a more modern approach, the angular severity measurements are not as important as the 3-D relationship of the first ray to the remainder of the foot. We do not ascribe to an absolute minimum or maximum value for IMA, HAV, or TSP in the selection of 1st TMT arthrodesis correction. Instead we observe the entire three-dimensional relationship and design the correction based on these findings.

ANATOMY AND SURGICAL BIOMECHANICS

It has long been thought that the obliquity of the medial cuneiform was a primary etiological factor in hallux valgus. Tuslow in 1925 coined the term "metatarsus primus varus" with his understanding of the deviation of the first metatarsal cuneiform joint in the transverse plane even though we understand varus to be a component of the frontal plane.² D.J. Morton described metatarsus atavicus in 1927.⁷ Lapidus described the "atavistic" foot in 1934 as an etiological factor in hallux valgus.³ However, more recent studies show that the obliquity of this joint does not correlate with HAV deformity.⁴⁰⁻⁴³ Vyas specifically found that the morphology of the medial cuneiform was not involved in HAV deformity.⁴⁰ Others have observed change in the perceived

obliquity after rotation without manipulations at the 1st TMT, indication that the AP representation of the cuneiform angle may not be an accurate representation.⁴ Doty et al. gave a comprehensive description of the first metatarsal cuneiform joint.⁴¹ Their cadaveric study revealed an average depth of 28.3 mm and width of 13.1 mm. The joint is typically continuous (59%) vs bi-lobed (38%). The lateral inclination angle averages 26.5 degrees. The first ray is inherently unstable and as such there are stabilizers of the first ray that should be appreciated. There are static and dynamic stabilizers of the first ray. Static stabilizers are the articulations of the 1st TMT: intercuneiform joint and the medial cuneiform and second metatarsal base.^{11,44,45} Additionally, the plantar first metatarsal medial cuneiform ligament is a static force.⁴⁶ Dynamic stabilizers include the plantar aponeurosis and the peroneus longus. The effects of the plantar aponeurosis on stabilization of the first ray have been described by Rush et al.¹³ Later Coughlin et al. also noted this effect.⁴⁷ The peroneus longus will lock the first ray in eversion.⁴⁸⁻⁵⁰ This action is inhibited by significant equinus and pronation of the subtalar and midtarsal joints.^{9,51} Bierman et al. discussed the effects of the Lapidus on peroneal longus function.⁵² They found increased efficiency of the longus in stabilizing the first ray after the Lapidus procedure. It also everts the medial cuneiform and elevates the talus. Lastly, as previously stated, the windlass mechanism is now more functionally employed.^{13,51}

SURGICAL CONSIDERATIONS

There are many variations of this surgical technique with the common denominator being fusion of the 1st TMT. Incisional exposure is based upon surgeon preference and may be a long dorsal incision or a smaller dorsal at the base of the 1st TMT and an additional medial incision if needed over the first MTPJ. Medial-based incisions over the TMT have also been described and have the cosmetic benefit that the scar is more hidden from the patient's sight. Because the 3-D alignment is complicated to observe intraoperatively, we find the dorsal incision to be more advantageous to visualize the angular and rotational positions of each segment simultaneously.

Research has supported the importance of proper sesamoid alignment postoperatively to prevent recurrence of the HAV deformity.^{28,53} Understanding of the sesamoid-metatarsal complex has evolved through current 3-D CT that the deformity is indeed a triplanar condition. Hatch et al. have developed a new classification scheme that is based upon this 3-D anatomy (Table 13.1).¹⁸ In that system, the sesamoids may be rotated with the metatarsal and or displaced. When displaced, especially in long-standing conditions, the sesamoid complex must be released in order to be properly realigned (Fig. 13.3). When the sesamoids are deviated in the AP projection but aligned in the axial, that is a sign of net first ray rotation that must be addressed at the time of surgery (Fig. 13.4). Adjacent ray fusion is employed when transverse or sagittal plane instability is observed or noted.^{15,16} This later technique may fuse the medial cuneiform to second metatarsal base or intercuneiform joints (Fig. 13.5).

Unlike the traditional Lapidus procedure that prioritized transverse plane correction, we approach the procedure with a multiplanar mindset. Regardless of the degree of IMA, sagittal deviation, and frontal plane rotation, the procedure is approached in the same manner. All three components are



FIGURE 13.3 Displaced sesamoid complex that should be surgically released.

corrected to the amount necessary concurrently, not individually. Correction is assessed clinically and fluoroscopically in real time using anatomic landmarks rather than arbitrary and inaccurate measurements. That is, the first metatarsal is angulated in the transverse and sagittal planes and rotated in the frontal plane until the IMA, HVA, TSP, and lateral round sign are normal (Fig. 13.6). Using this multiplanar approach, the degree of each planar deformity does not matter preoperatively, as all patients receive the same three plane realignment. Three-dimensional correction can be made easier with a joystick pin in the first metatarsal and with specialized guides and jigs. It must be emphasized that the 1st TMT must be fully mobilized and any lateral ankylosis at the metatarsophalangeal joint released to allow for three plane correction. We have found that attempts to correct one planar component at a time are frustrating and do not result in satisfying alignment.

SURGICAL PEARLS

- Correct the deformity, then make precise cuts utilizing a cutting jig (preferred by authors).
- Release sesamoids if subluxed on axial views.
- Pay attention to all three planes when correcting deformity.
- Employ fixation that is amenable to early weight bearing.

As with any fusion procedure, healing is dependent on many factors. Patient health concerns such as smoking, diabetes, metabolic bone disease, and other factors must be identified and controlled. Surgical dissection should be minimally invasive and avoidance of excessive tissue plane separation is priority. We prefer intracapsular and subperiosteal dissection at both the 1st TMT and the first MTP to maintain all blood supply in full-thickness flaps (Fig. 13.7). Bone preparation

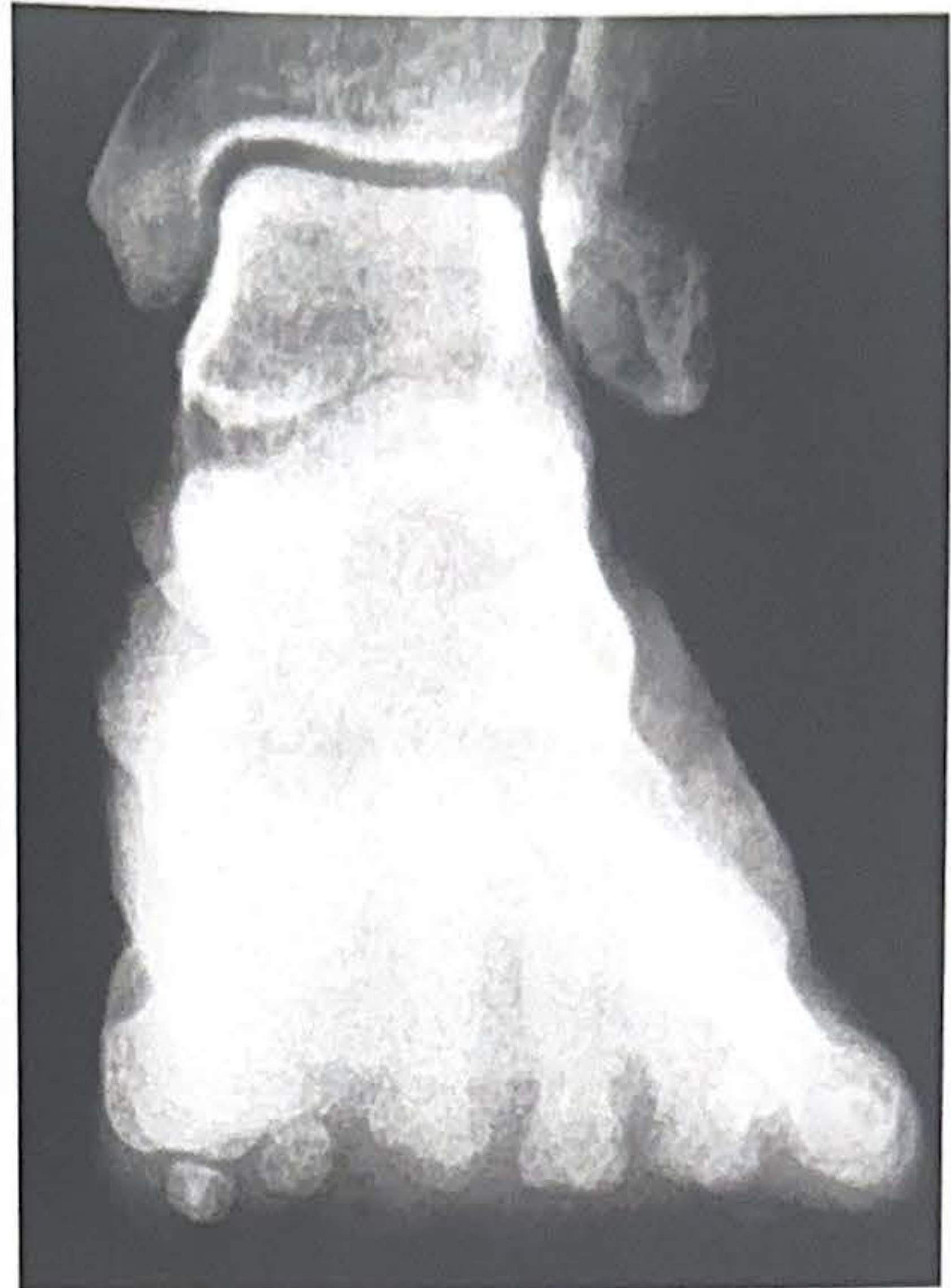


FIGURE 13.4 AP—apparent subluxation of sesamoids; and axial—normal alignment—illustrative of rotation.

must also be carried out appropriately to foster rapid healing. Curettage of the cartilage is a common method of fusion site preparation. Although curettage may have some advantage of reducing bone removal and limiting first ray shortening, studies have suggested that up to 50% of the surfaces prepared

with curettage maintain calcified cartilage, which theoretically reduces the surface area for healing.⁵⁴ We prefer complete removal of all cartilage and subchondral plate using low heat generating saws. Additionally, we find benefit in fenestration of the fusion surfaces with a fluted drill bit. Unlike a wire, when a drill is used for fenestration less heat is generated and bone fragments are pulled into the fusion site acting as autogenous graft. The fragments are left in the site and not irrigated (Fig. 13.8). Shortening is limited by careful execution of bone cuts and alignment of the surfaces before the cuts are made. We generally find 3 mm or less shortening is possible with careful execution. Allograft products and other proprietary products are sometimes recommended as potential adjuvants to fusion healing. We find no need for addition of graft products and feel these products can interfere with the natural healing characteristics of a properly prepared and fixated fusion site. Most products require a separate biologic process and may compete with the body's healing resources, despite our hopes for augmentation. Another factor that is not often discussed is maximizing fusion surface area by reducing the amount of hardware crossing the surfaces. The 1st TMT has a relatively small surface area for healing, and any reduction of bone surface by intraosseous hardware represents a relative reduction in bone contact. We prefer multiplane locking plates because there is not intraarthrodesis reduction in bone surface area taken up by screws or other devices.

Fixation constructs have evolved over time with the quest for earlier weight bearing postoperatively. The priorities are to both set the stage for consistent healing of the arthrodesis and allow the patient to maintain active range of motion and protected weight bearing throughout the entire recovery. This prevents or reduces the incidence of stiffness, weakness, and



FIGURE 13.5 Arthrodesis between first and second rays to prevent transverse plane instability. **A.** Between medial cuneiform and second metatarsal base. **B.** Between cuneiform 1 and 2.

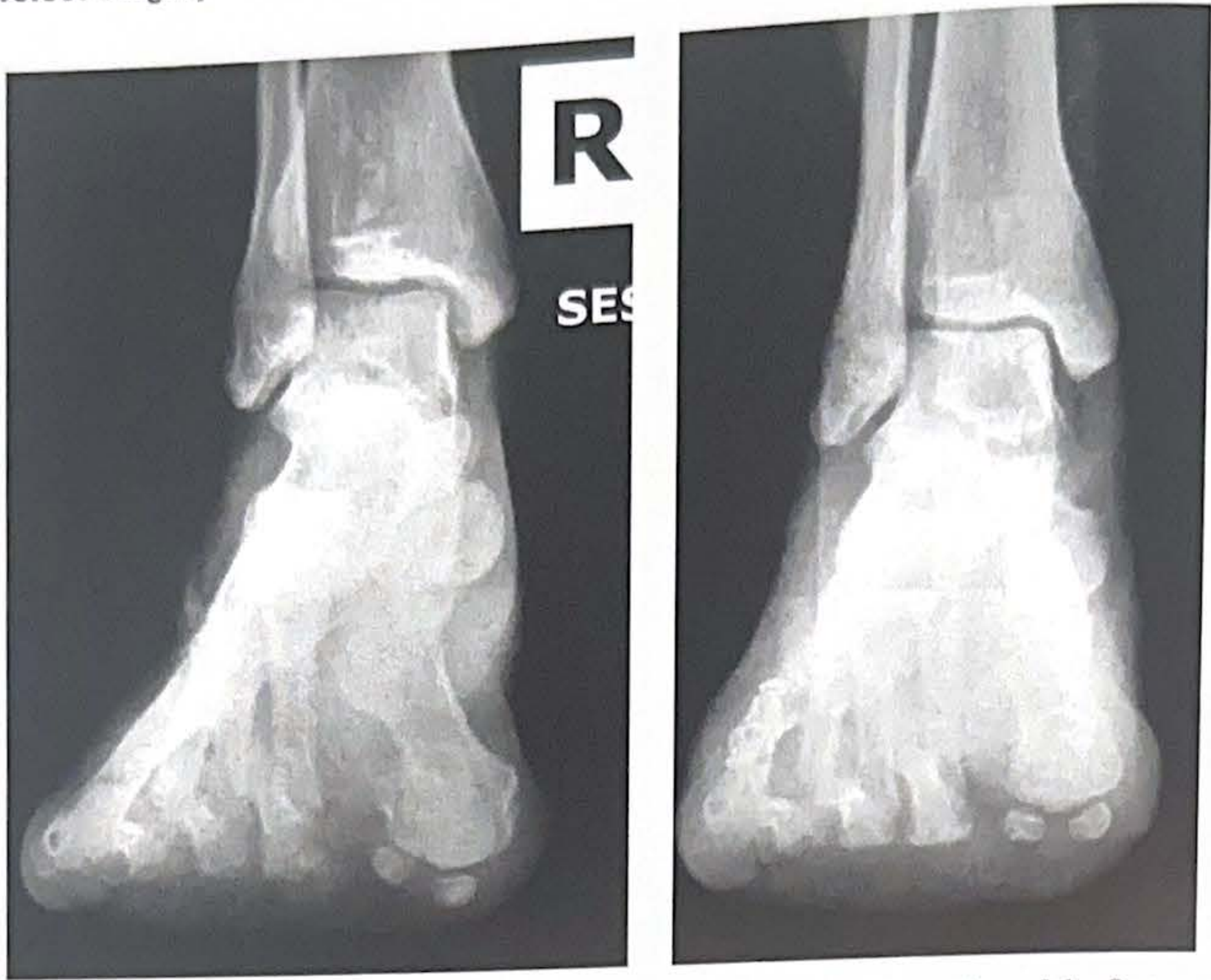


FIGURE 13.6 Pre- and postop axial view demonstrating rotational correction of the first metatarsal and sesamoid complex.

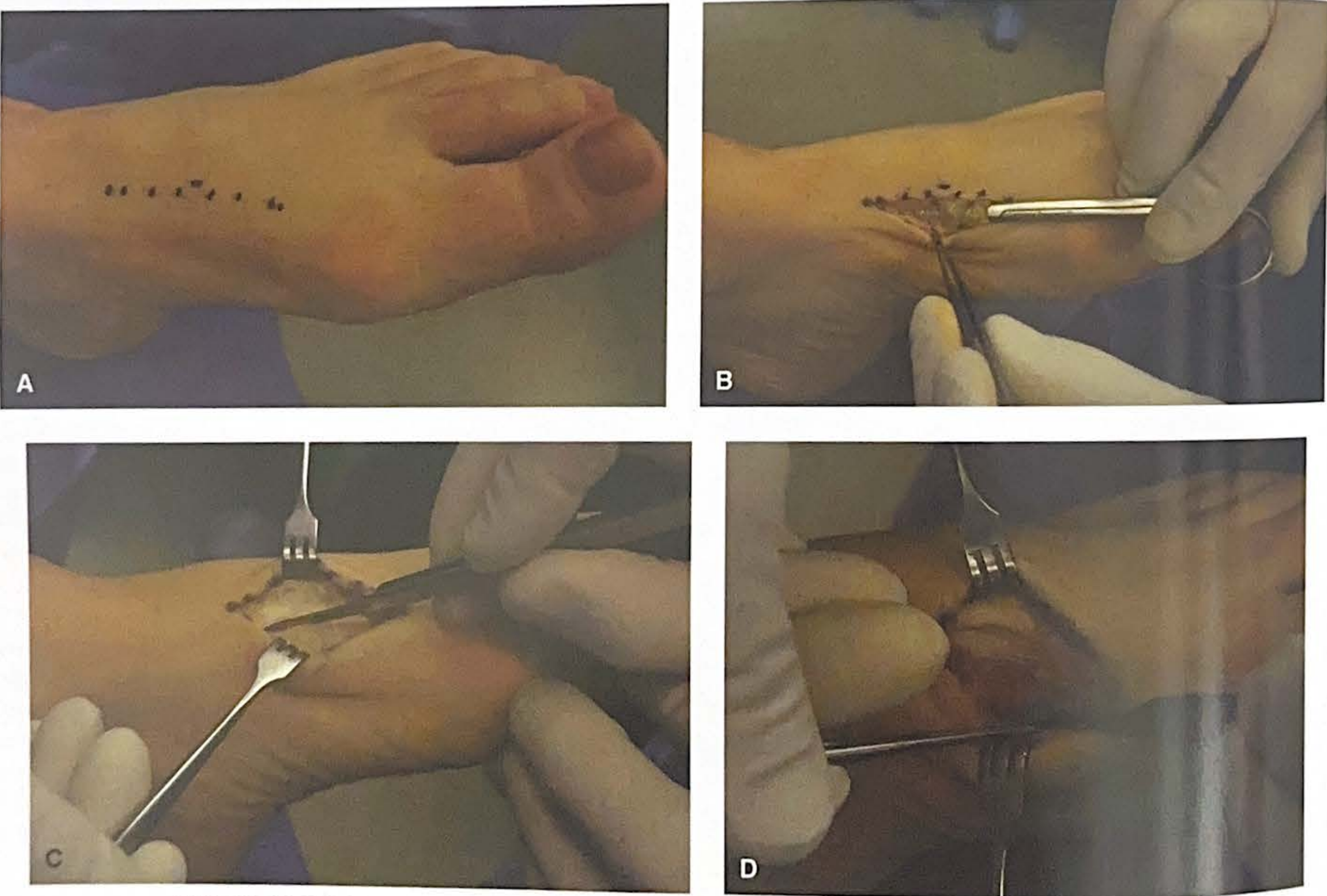


FIGURE 13.7 Photographs illustrating minimal dissection technique: **A.** Incision is medial to EHL from midshaft first metatarsal to proximal of medial cuneiform. **B.** No subcutaneous undermining. **C.** Capsule and periosteal incision is medial to EHL. **D.** Expose medial ridge of first metatarsal then dissect proximally.

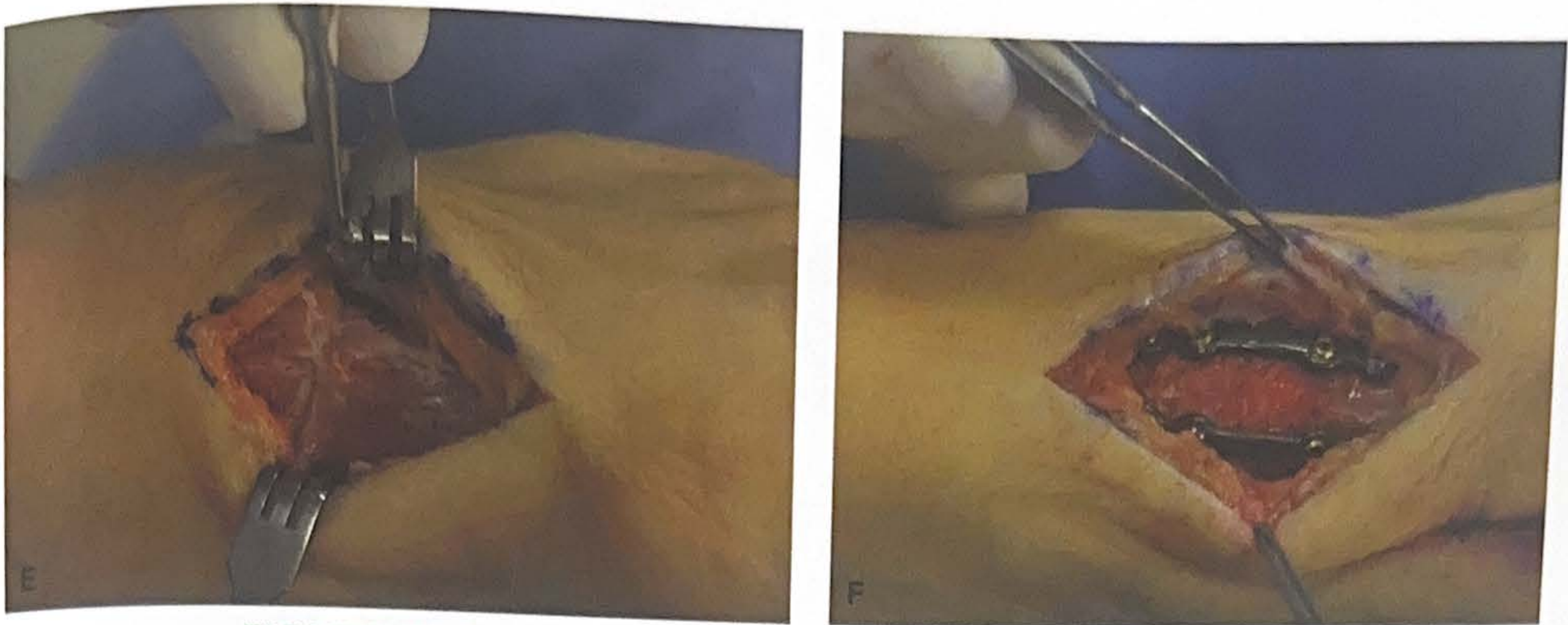


FIGURE 13.7 (Continued) **E.** Create a pocket for the fulcrum. **F.** Final construct after cuts are made using a jig. Flap remains full thickness.

DVT seen with casting and non-weight bearing. Commonly, a 2-3 screw construct is employed using the principles of friction-based rigidity produced with compression screws. Hansen realized that precompressing a joint and allowing the patient to weight bear created shear at the fusion site due to the angular loading of the compressed surfaces can impair healing.⁵⁵ Hence, he developed a shear strain relieved bone graft to mitigate this effect. This has been supported by a level four study by Mani et al. study in 2015.⁵⁶ Commonly, screw constructs include 6 weeks of NWB with or without casting, followed by 6 weeks of protected weight bearing in a CAM boot. King reported results with a screw construct and early partial WB at 12 days and full at 4 weeks.⁵⁷ Patient acceptance of these parameters was low and hence a strive for earlier weight bearing and newer surgical constructs. Several recent studies have advocated early weight

bearing with conventional screw constructs.^{57,58} Plate and screw combinations have evolved earlier weight bearing.⁵⁹ Newer biplanar construct takes into account the concept of “biologic healing” and advocated by Perren in 2002.⁶⁰ Micromotion at the arthrodesis site allows for callus formation yielding a faster and stronger arthrodesis. Consistent healing in a series of 195 first ray fusions using a biplane locked plate construct and protected weight bearing in a cam boot within the first postoperative week was published in 2018.⁶¹ Using stable multiplanar fixation fosters callus healing, which is known to achieve intrinsic stability quicker than primary healing seen in compression screw fixation. While at the same time we can encourage protected weight bearing when multiplane stability is provided. A large level III study was done by Prissel et al. 2016 comparing early vs delayed weight bearing and found no differences in

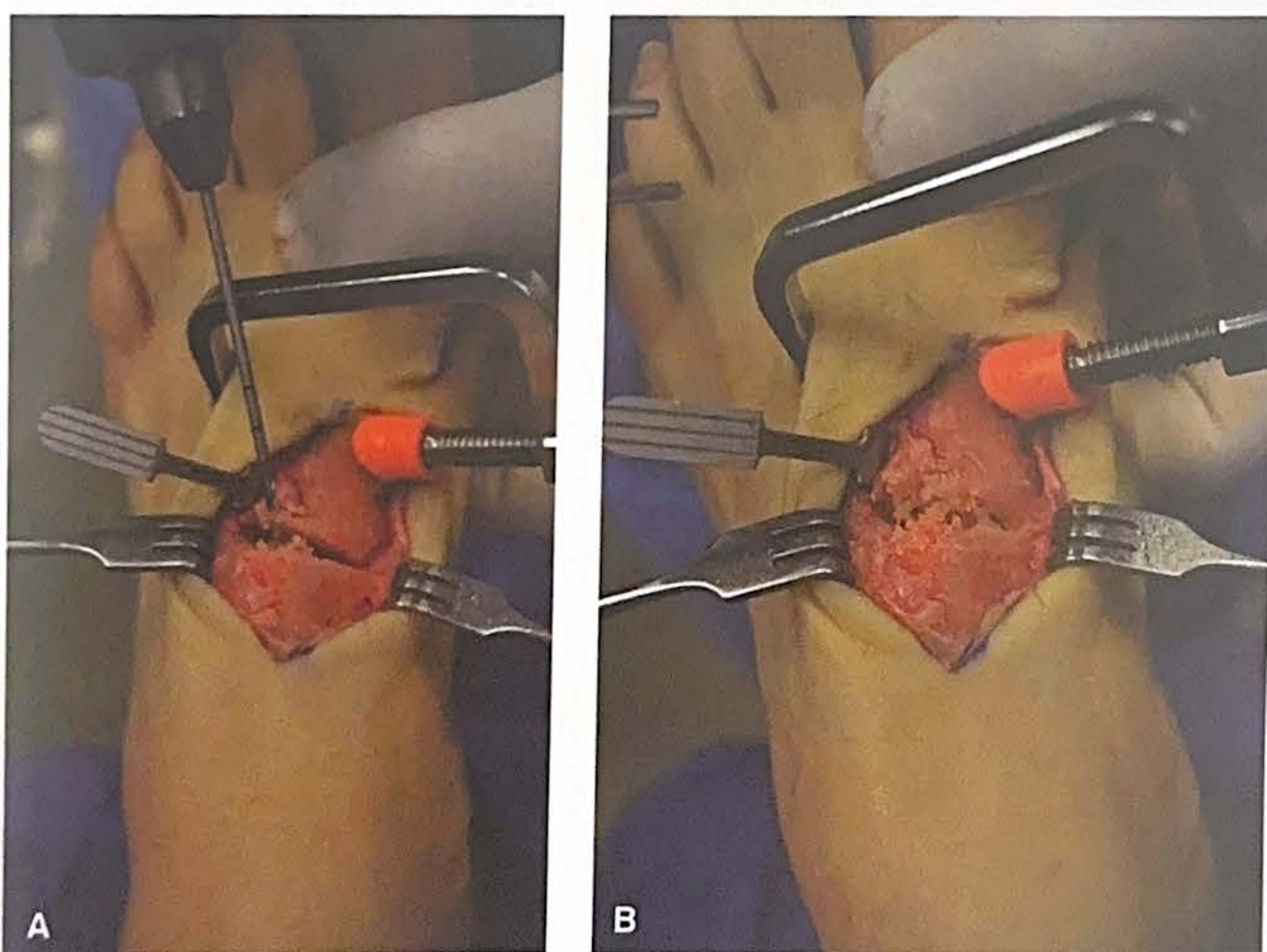


FIGURE 13.8 **A.** Joint preparation technique with drill bit. **B.** Note fenestrations and bone debris in arthrodesis site.



FIGURE 13.9 Biplanar construct **(A)** clinically and **(B)** radiographically.

union rates when appropriate stability was provided.⁶² Newer constructs may allow for weight bearing from immediate to early (2 weeks) (Fig. 13.9).

COMPLICATIONS

The complications of the Lapidus bunionectomy are not different from other types of bunion procedures. These would include shortening, elevation, nonunion, and recurrence of deformity. Shortening is minimized by paying attention to minimal joint resection. Elevation of the first metatarsal is avoided by proper technique and checking during the surgical procedure with intraoperative fluoroscopy. Reports of nonunion have ranged from 5% to 10%.⁵⁷ Barp et al. reported nonunion rates of 6.7% in 147 procedures.⁶³ Even more encouraging was Mani et al. study in 2015 reporting a 2.7% nonunion rate if meticulous joint preparation, internal fixation, and a shear-strain bone graft is utilized.⁵⁶ The shear strain relieved bone graft was advocated by Hansen in 2000.⁵⁵ Since the foot is loaded tangentially to the long axis of the bone, shear forces are created with weight bearing and joint compression with standard rigid internal fixation. The bone graft allows micromotion and secondary bone healing, which has shown to be quicker and stronger by Perren's studies.⁶⁰ Recurrences are due to lack of sesamoid alignment^{28,64} and undercorrection of the first metatarsal second metatarsal angle.⁶⁵ Achieving a collinear alignment of the first ray will optimize the direct pull of the tendons inserting into the hallux. With a dorsal incision, there may be compromise or irritation to the cutaneous nerve branch of the medial dorsal cutaneous nerve.

SUMMARY

The Lapidus bunionectomy is a dependable procedure that helps minimize chances of recurrences while providing a surgically amenable site to address the triplane deformity of the first ray. The 1st TMT site is considered the anatomic apex of the deformity. That is not discounting that more proximal motions are pathologic for this condition. This especially involves motion at the intercuneiform joint and navicular cuneiform joint. When excessive motion occurs at those joints stabilization may be achieved by intercuneiform or medial cuneiform-second metatarsal base arthrodesis. The triplane deformity of the first ray may be easily addressed at the 1st TMT, and by arthrodesis at that site, the effects of the peroneus longus and windlass mechanisms are enhanced to stabilize the first ray.

REFERENCES

1. Albrecht GH. The pathology and treatment of hallux valgus. *Russ Vrach*. 1911;10(14):14-19.
2. Truslow W. Metatarsus primus varus or hallux valgus. *J Bone Joint Surg Br*. 1925;7:98.
3. Lapidus P. Operative correction of the metatarsal varus primus in hallux valgus. *Surg Gynecol Obstet*. 1934;58:183-191.
4. 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):348-354.
5. Condon F, Kaliszer M, Conhyea D, O'Donnell T, Shaju A, Masterson E. The first intermetatarsal angle in hallux valgus: an analysis of measurement reliability and the error involved. *Foot Ankle Int*. 2002;23(8):717-721.
6. Coughlin MJ, Jones CP. Hallux valgus: demographics, etiology, and radiographic assessment. *Foot Ankle Int*. 2007;28(7):759-777.
7. Morton DJ. Metatarsus atavicus. *J Bone Joint Surg Br*. 1927;9:531-534.
8. Hansen ST Jr. Introduction: the first metatarsal: its importance in the human foot. *Clin Podiatr Med Surg*. 2009;26(3):351-354, Table of Contents.
9. D'Amico JC. Understanding the first ray. *Podiatr Manag*. 2016;109-120.
10. Kimura T, Kubota M, Taguchi T, Suzuki N, Hattori A, Marumo K. Evaluation of first-ray mobility in patients with hallux valgus using weight-bearing CT and a 3-D analysis system: a comparison with normal feet. *J Bone Joint Surg Am*. 2017;99(3):247-255.
11. Root ML, Orien WP, Weed JH. Normal and abnormal function of the foot. *Clin Biomech*. 1977;2. <https://ci.nii.ac.jp/naid/10031091761/>. Accessed July 25, 2018.
12. Roukis TS, Landsman AS. Hypermobility of the first ray: a critical review of the literature. *J Foot Ankle Surg*. 2003;42(6):377-390.

PERILS and PITFALLS

- Imperative to analyze correction in all three planes
- Ensure first metatarsal is neutrally aligned in the sagittal plane
- Must strive to reduce IM deformity to 4 degrees or less
- Must check instability of the first and second rays