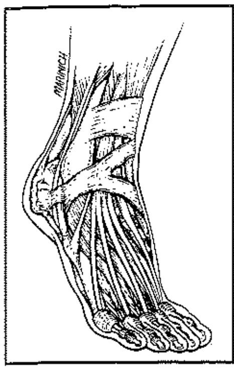

CHAPTER 22

Complications of Hallux Abducto Valgus Surgery

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Surgical correction of hallux abducto valgus and related deformities is commonly performed. Unfortunately, complications of hallux abducto valgus surgery may develop, many of which are unpredictable. Common complications of hallux valgus surgery include recurrence of the deformity, hallux varus, and complications of bone healing, such as delayed union, nonunion, or malunion. The purpose of this chapter is to provide an overview of and insight into the diagnosis and treatment of some of the more common complications of hallux abducto valgus surgery.

RECURRENCE OF DEFORMITY

Definition, Incidence, and Etiology

Experience has shown that even when strict criteria are followed for the repair of hallux abducto valgus deformity, the condition can recur. Generally, patients with *recurrent hallux abducto valgus* may be divided into two groups: those patients who manifest with hallux abducto valgus early in the postoperative period, perhaps in the first few months to 1 year, and those patients who present some time later with recurrent deformity. Although one or two factors may play a dominant role in the development of recurrent deformity, others may also be involved to a lesser degree.

Early Recurrent Deformity

In general, early recurrence of the deformity may be attributed to one of several different factors: (a) an error in judgment in the selection of procedures; (b) inadequate execution of the procedure; (c) events during the postoperative care, including patient noncompliance; and (d) failure to recognize or to address concomitant deformities such as metatarsus adductus.

Most cases of hallux abducto valgus deformity are caused by a combination of dynamic soft tissue factors as well as structural factors. Although some bunion deformities have a more dynamic cause, others have a structural component as the primary etiologic factor.

The degree and extent of displacement of the sesamoidal apparatus may be strong indicators of the dynamic component of the bunion deformity. Failure to release the plantar lateral soft tissues of the first metatarsophalangeal joint can increase the incidence of recurrence after hallux valgus correction. With contracture of adductor hallucis muscle and other periarticular structures, the sesamoid apparatus displaces in a lateral direction relative to the first metatarsal head and contributes to further progression of the deformity. The failure of the surgeon to release these lateral soft tissue structures properly, a failure that inhibits relocation of the sesamoidal apparatus beneath the first metatarsal head, significantly increases the risk of recurrence. Even in cases with an adequate release of the plantar lateral structures, the surgeon may find that the sesamoid apparatus is not adequately mobilized, and consequently fibular sesamoidectomy may be necessary.

Kitaoka et al. studied 49 feet that underwent simple bunionectomy for hallux valgus deformity. The primary reason for treatment failure was recurrence, and 14% of these patients underwent revisional surgery as a result. Patients who had a lateral capsulotomy had less likelihood of experiencing recurrence of the deformity (1).

Restoring integrity to the medial joint capsule is helpful in maintaining rectus hallux alignment. As such, a deliberate reinforcement or medial joint capsulorrhaphy is sometimes performed to restrain the tendency for recurrent valgus drift of the hallux. In a cadaveric study, Kura et al. investigated the functional significance of the medial capsule and the transverse metatarsal ligament in hallux valgus deformity. A three-dimensional imaging technique was used to track the effect of sectioning these structures to assess their influence in deformity about the first metatarsophalangeal joint. No significant deformity was noted when the transverse metatarsal ligament was sectioned. Valgus deformity of the hallux increased an average of 22 degrees when the medial capsule was sectioned, a finding that underlines the contribution of this structure to joint stabilization. However, this does not imply that medial capsulorrhaphy is the critical aspect of the soft tissue procedure responsible for maintenance of correction (2), although it is an adjunctive measure that may assist in restoring overall balance to the joint. The study does indicate the concern for addressing lateral joint contractures, because compromise of the medial joint structures is required to alleviate the bunion prominence.

Perhaps the most common cause of recurrence is an error in judgment in the selection of the surgical procedure for the correction of a hallux valgus deformity (Fig. 1) (3,4). Typically, a capital osteotomy was employed, yet it proved inadequate to provide full correction of the intermetatarsal

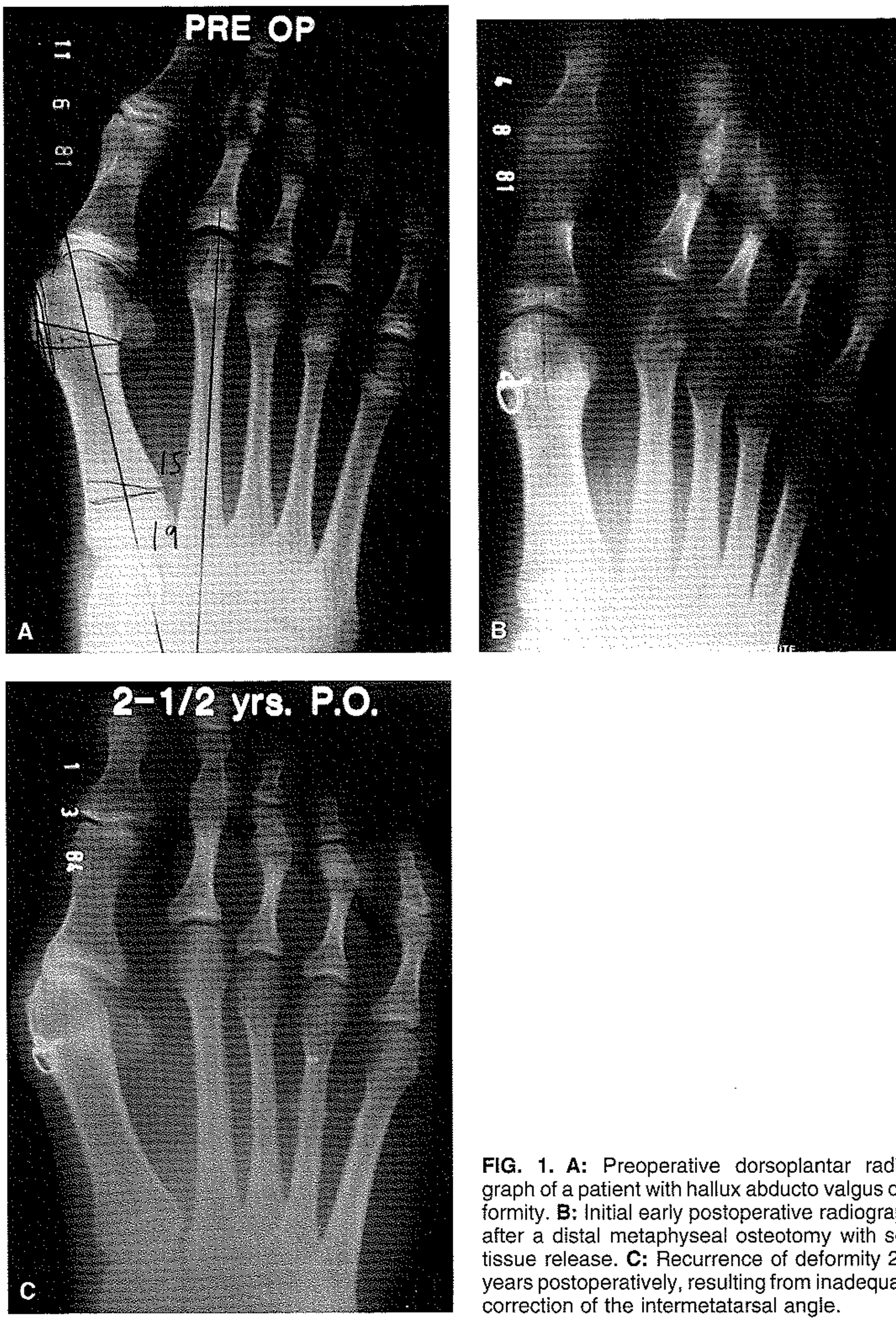
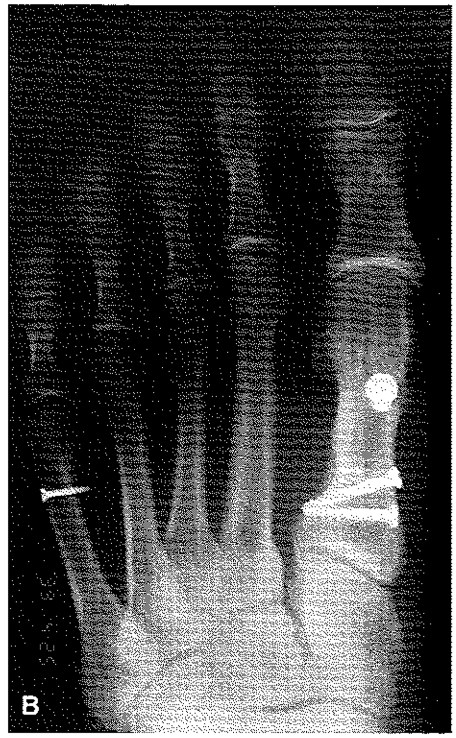


FIG. 1. A: Preoperative dorsoplantar radiograph of a patient with hallux abducto valgus deformity. **B:** Initial early postoperative radiograph after a distal metaphyseal osteotomy with soft tissue release. **C:** Recurrence of deformity 2½ years postoperatively, resulting from inadequate correction of the intermetatarsal angle.



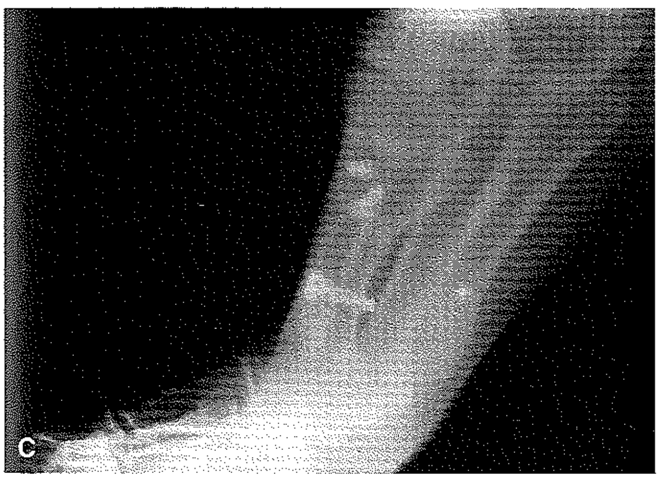


FIG. 2. A: Preoperative dorsoplantar radiograph of previously failed hallux abducto valgus surgery, which consisted of an offset-V osteotomy. The patient complained of an excessively wide forefoot incompatible with conventional shoes. **B:** Follow-up radiograph 4 months postoperatively. Procedures consisted of muscle-tendon balancing as well as an oblique closing base wedge osteotomy of the first metatarsal and a distal oblique closing wedge osteotomy of the fifth metatarsal. Excellent correction of the deformity was achieved. **C:** Stressed dorsiflexion lateral showing excellent range of motion in spite of apparent joint space narrowing.

angle (Fig. 2). Often, this is not so much a recurrent deformity as a residual hallux abducto valgus that was not fully corrected with the original procedure.

The recurrence rate after distal metaphyseal osteotomies has been proposed to involve approximately 10% of patients undergoing these surgical procedures (3). Historically, distal metaphyseal osteotomies have been indicated for the correction of mild to moderate bunion deformities with an intermetatarsal angle of 12 to 15 degrees (4–7), although surgeons commonly employ these types of procedures in patients with larger intermetatarsal angles if the deformity is flexible. Meier and Kenzora found that 94% of the patients undergoing distal metaphyseal osteotomies with a preoperative intermetatarsal angle of less than 12 degrees had a satisfactory result, compared with 74% of the patients with an intermetatarsal angle greater than 12 degrees (8).

Clearly, in some cases, a proximal osteotomy is far more effective in reducing the intermetatarsal angle than a distal metaphyseal osteotomy. Historically, procedures may have been selected based on radiographic findings alone, such as the intermetatarsal or hallux abductus angle. However, strict radiographic criteria should not serve as the sole basis for the selection of a procedure. Appreciation of the intermetatarsal angle can be better assessed intraoperatively after a complete release of the periarticular structures.

Inadequate postoperative care may also encourage the development of a recurrent bunion. Immediate postoperative bandaging should be employed to help maintain the great toe in a rectus position. When the toe is not splinted properly during first several weeks after surgery, the likelihood of recurrence of the deformity is increased. Inadequate splinting and poor maintenance of alignment allow the medial capsular structures to undergo stretching, whereas the lateral structures attempt to recontract and shorten, with a resulting recurrence of the deformity in the earlier stages after bunion surgery (3). Obviously, the cooperation of the patient is essential during this period, to ensure the best possible result.

Delayed Recurrence of Deformity

Failure to address concomitant deformities associated with hallux valgus deformity has also been associated with recurrence of the deformity over time (3,4,9,10). Hypermobility of the first ray may contribute to recurrence of the deformity if it is not addressed either surgically or postoperatively with orthotic control or other measures. Other deformities and conditions associated with recurrent hallux valgus may include ankle equinus, collapsing pes valgo planus deformity, metatarsus adductus, spasticity, or hyperelasticity or ligamentous laxity, such as in Ehlers-Danlos syndrome (3,4,9,10).

In particular, patients with concomitant hallux abducto valgus and metatarsus adductus present a challenging problem. Failure to recognize the existence of metatarsus adductus before surgical intervention is apt to result in a less than a satisfactory outcome. Recurrence and undercorrection are common and vary depending on the severity of the underlying metatarsus adductus and digital abduction (Fig. 3).

In radiographic evaluation of such feet, the intermetatarsal angle must be considered to be significantly greater than that determined by actual measurement (11–14). It is not uncommon to strive to obtain a reduction of the intermetatarsal angle intraoperatively, to 0 to −2 or −3 degrees. In some cases, an opening wedge osteotomy of the first metatarsal or medial cuneiform may be an appropriate procedure, although we have not found this approach necessary (15).

Clinical experience shows that even when the intermetatarsal angle has been reduced to a slightly negative value, an increased separation between the first and second metatarsals may be seen later when full weight-bearing function has been restored to the foot. This ultimately results in a final intermetatarsal angle of approximately 0 to 5 degrees.

Patients who undergo surgical correction of a hallux abducto valgus deformity in the presence of a structural metatarsus deformity frequently have a residual bunion deformity, or clinical hallux abducto valgus deformity, without any radiographic evidence of such. In many cases, the surgeon may identify full correction and normal values of most radiographic parameters. The degree to which the clinical appearance of a residual bunion and hallux abducto valgus deformity occurs is proportional to the degree of metatarsus adductus deformity and the degree of compensation present (10,16–21). The greater the metatarsus adductus deformity,

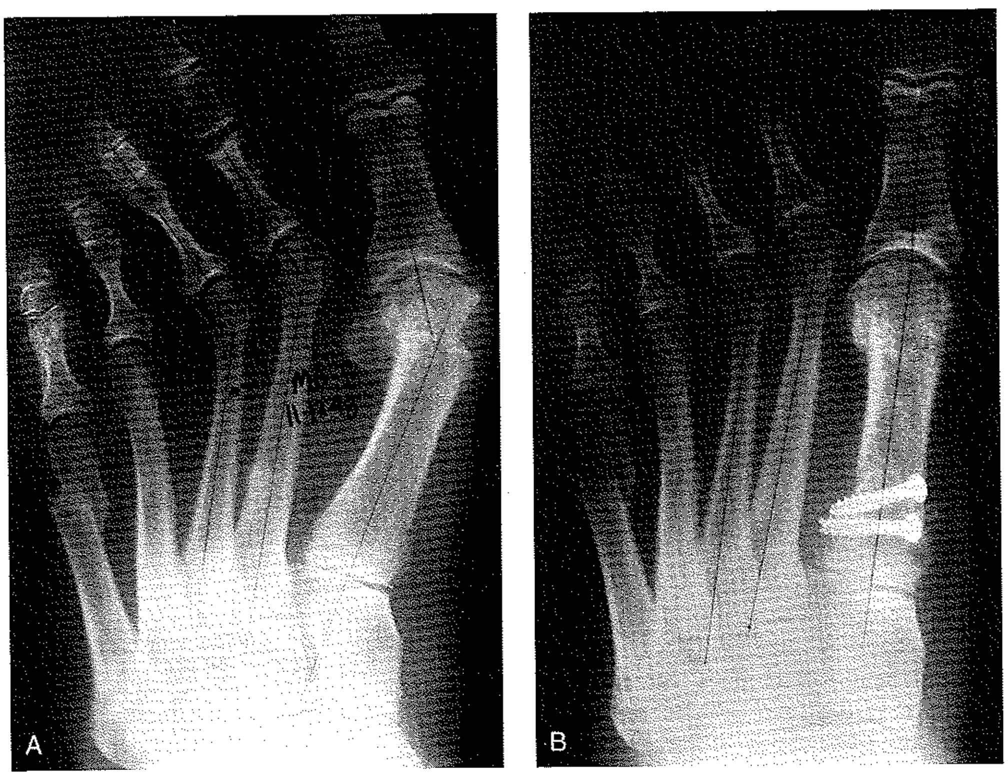


FIG. 3. A: Preoperative dorsoplantar radiograph of an adult patient who had undergone two previous bunionectomy procedures without success. Note the structural residual metatarsus adductus deformity, as well as the lesser digital abduction. **B:** Correction of the deformity postoperatively by aggressive reduction of the intermetatarsal angle by an oblique closing base wedge osteotomy and internal screw fixation. Note the reduction of the intermetatarsal angle to 0 degrees with restoration of a congruous first metatarsophalangeal joint. Revision arthrodesis of the lesser toes was also performed.

the greater is the abduction of the hallux and lesser digits on their adjacent metatarsal (10,16,22–23).

Clinical and Radiographic Evaluation

The clinical and radiographic findings associated with a recurrent hallux abducto valgus deformity are usually not different from those seen before the first surgical procedure, with one exception: they are usually worse. Both the type and the intensity of the pain as well as the clinical deformity are more extreme than the original presentation. Patients may also complain of a "tingling, numbness, or pins and needles" sensation suggestive of an entrapment neuropathy of the medial proper digital branch of the medial dorsal cutaneous nerve or the terminal branches of the saphenous nerve. A sharp focal area of pain may be caused by a residual osseous prominence. Pain along the plantar aspect of the joint, especially at the medial portion, may indicate an abnormal articulation between the sesamoid and the first metatarsal head.

The hallux may underride or overlap the second digit, a feature that may not have been present with the original deformity. The bunion prominence is typically larger even though aggressive resection of bone may have already been performed. Lateral bowstringing of the extensor hallucis longus tendon may be seen. Although the original deformity may be purely transverse, increased valgus rotation of the hallux is often seen in patients with a recurrent deformity.

Of significance is the degree to which the deformity is reducible and the joint range of motion is maintained while in the corrected position. A patient with a limited range of motion associated with pain and crepitation may require a joint-destructive procedure regardless of the radiographic findings. An assessment of the reducibility and flexibility of the deformity not only is helpful in identifying the most appropriate procedure, but also it may signify the propensity or likelihood that a transverse plane hallux varus deformity will develop. An inability to reduce the deformity strongly suggests tight plantar lateral structures, most notably the adductor hallucis and secondarily the lateral head of the flexor hallucis brevis muscles.

Patients should also be observed while they are in a relaxed stance position. It is not uncommon to see an exacerbation of the deformity when the foot is fully loaded. In addition, one gains a much greater appreciation of the plane of the deformity (i.e., purely transverse versus a combination of transverse and frontal). Clinical observations are then correlated with the radiographic findings.

Finally, the presence of concomitant deformities is assessed. Emphasis is placed on the presence of metatarsus adductus, as well as any pronatory changes in the foot consistent with severe collapsing pes valgo planus deformity that could require treatment to ensure correction of the recurrent hallux abducto valgus deformity, especially in the juvenile or adolescent patient.

Treatment Considerations

Most patients with symptomatic recurrent hallux abducto valgus deformity do not respond well to conservative treatment modalities. The surgical correction of a recurrent deformity is more challenging than that of the original condition. Although the goals of the revisional operation should be to establish a congruous, pain-free, functional first metatarsophalangeal joint, this cannot always be achieved. Joint-salvage procedures can only be employed when the patient has sufficient bone and stable architecture at the first metatarsophalangeal joint. Patients who have had excessive resection of the medial eminence may not have adequate bone stock to support a traditional distal metaphyseal procedure. In such cases, proximal osteotomies may be necessary despite a relatively low intermetatarsal angle. In cases of significant arthrosis, joint compromise, or instability, a resection arthroplasty, implant arthroplasty, or arthrodesis may be required. Joint-preservation procedures are preferred whenever possible.

Meticulous surgical technique is critical to achieving the desired outcome. In most cases, a dorsomedial skin incision is employed. Every attempt is made to separate the skin and subcutaneous tissues from the deep fascial layer, to prepare for anatomic closure. One must be cautious to avoid the dorsal cutaneous nerves and pertinent vascular structures. In patients with clinical evidence of nerve entrapment, the nerve is carefully explored, and any surrounding scar tissue is released; when necessary, nerve resection may be performed.

Unless the fibular sesamoid has been previously excised, attention is directed to the first interspace. Complete release of the plantar lateral structures is performed. In most cases, this operation involves release of the adductor hallucis tendon and fibular sesamoidal ligament. In more severe cases, release of the lateral head of the flexor hallucis brevis muscle may also be necessary. If adequate immobilization of the sesamoid apparatus cannot be achieved, then considerations should be given to removal of the fibular sesamoid.

After release of the intermetatarsal space, the deformity must be reassessed. When a recurrent contracture of the plantar lateral structures has occurred, or an inadequate release was performed initially, a significant improvement in the alignment of the hallux on the first metatarsal is generally seen. After plantar lateral release, one can more readily appreciate the true structural components of the deformity and decide on the need for additional procedures to achieve adequate joint congruity and position.

Various medial capsular approaches can be employed for exposure of the joint. The choice depends on the experience and preference of the surgeon. The first metatarsal head and phalangeal base are inspected. The orientation of the articular cartilage on the first metatarsal head is inspected and should be compared in position with the long axis of the metatarsal shaft.

Although some contouring of the dorsal and medial as-

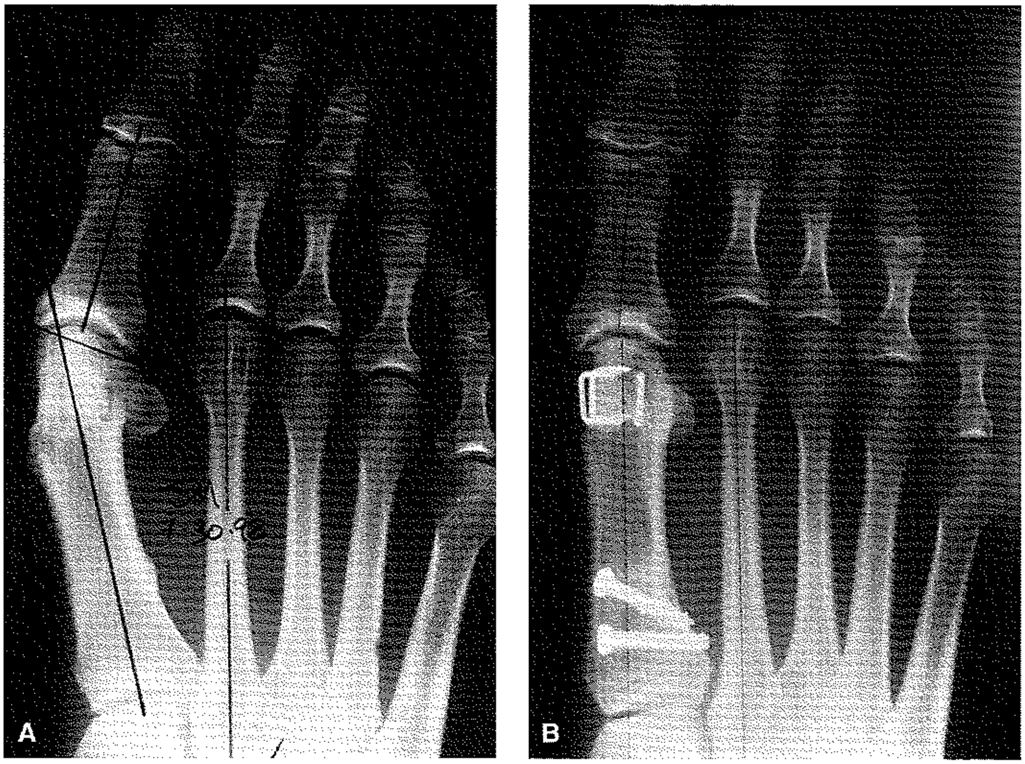


FIG. 4. A: Recurrent hallux abducto valgus deformity in a patient who had undergone a prior modified bunionectomy with osteotomy at the proximal diaphyseal area. A resection of the metatarsal head has left the remaining articular cartilage in a laterally deviated position. **B:** Postoperative correction, 1½ years postoperatively, after a base wedge osteotomy with a Reverdin osteotomy for realignment of the articular cartilage. Excellent correction was achieved.

pects of the first metatarsal head may be necessary, aggressive resection of the metatarsal head should not be performed. Further "staking" of the metatarsal head only compromises function.

If excessive resection of bone was not performed in the initial surgical procedure, then a distal metaphyseal osteotomy may be appropriate for correction of any residual splaying between the first and second metatarsal. The type of osteotomy performed depends on several factors. In patients with significant deviation of the articular cartilage on the first metatarsal head, a Reverdin-type osteotomy may be used to reposition the articular surface properly. This form of osteotomy may also be considered to rotate the remaining cartilage into a more effective position when the first metatarsal head has been staked. Any remaining intermetatarsal splay is corrected by a more proximally oriented procedure (Fig. 4).

Structural splaying between the first and second metatarsal is usually addressed by a proximal procedure. The most common procedure is a closing base wedge osteotomy, not only to reduce the intermetatarsal angle, but also to minimize the amount of shortening. When postoperative elevatus has occurred in conjunction with recurrence of the deformity, the osteotomy may be modified to achieve both reduction of the intermetatarsal angle and simultaneous plantarflexion of the distal fragment. In some cases, a first metatarsocuneiform arthrodesis or opening wedge osteotomy of the metatarsal base or cuneiform may be appropriate, especially when restoration of length is an important consideration. Lengthening of the first ray segment may create tension at the first metatarsophalangeal joint and may possibly lead to limitation of motion, with or without symptoms.

In cases of recurrent juvenile or adolescent hallux abducto valgus deformity, careful consideration must be given to the surgical correction of concomitant deformities. In patients with a significant ankle equinus, a tendo Achillis lengthening or gastrocnemius recession may be performed. Patients with severe collapsing pes valgo planus deformity may also need surgical correction if they cannot be treated effectively with an appropriate orthotic device or shoe modifications. Finally, the influence of metatarsus adductus deformity cannot be overemphasized. Residual metatarsus adductus can have a profound influence on first ray disorders. Although it is rare to attempt full correction of the deformity in an adult, it may be important in obtaining the best correction of a juvenile or adolescent suffering with a painful hallux valgus deformity.

HALLUX VARUS

Definition, Incidence, and Etiology

Hallux varus is classified as either a congenital or an acquired deformity and has been a subject of study for many years (1,3,4). Although acquired hallux varus may have several causes (i.e., postsurgical, trauma, rheumatoid arthritis), this discussion focuses on those cases noted after surgical correction of hallux abducto valgus or related deformities. Regardless of whether a hallux varus deformity is congenital or acquired, common denominators exist. In virtually all cases, one appreciates a muscle imbalance in which the abductor hallucis muscle gains a significant mechanical advantage over its antagonistic muscle, the adductor hallucis. In a postsurgical hallux varus, the abductor hallucis muscle usually is responsible for deformity, although in some cases the deformity may occur primarily as a result of structural alterations of the first metatarsal, proximal phalanx, or both.

We use the term *hallux varus (or hallux adductus)* to describe purely transverse plane, medial deviation of the great toe with the apex of deformity at the metatarsophalangeal joint. This condition is readily identified both radiographically and clinically. The term *hallux malleus* is used to describe a great toe with an extension contracture at the metatarsophalangeal joint and concomitant flexion contracture at the interphalangeal joint. When the conditions occur simultaneously, we refer to the condition as *hallux varus with a concomitant hallux malleus deformity* (Fig. 5). Regardless of the terminology, one must be aware of the apex of deformity and the presence of combination deformities to ensure adequate surgical selection and treatment.

The combination of the transverse and sagittal plane deformities usually represents the end point of the deformity. The rate of progression and the ultimate severity of the condition depend on several factors, including inherent flexibility, the time elapsed since the surgical procedure, the degree of musculotendinous imbalance, the amount of structural malalignment, and other underlying concomitant disorders such as neuromuscular or connective tissue diseases.

Iatrogenic hallux varus alone or in combination with a hallux malleus deformity can be more painful, disfiguring,

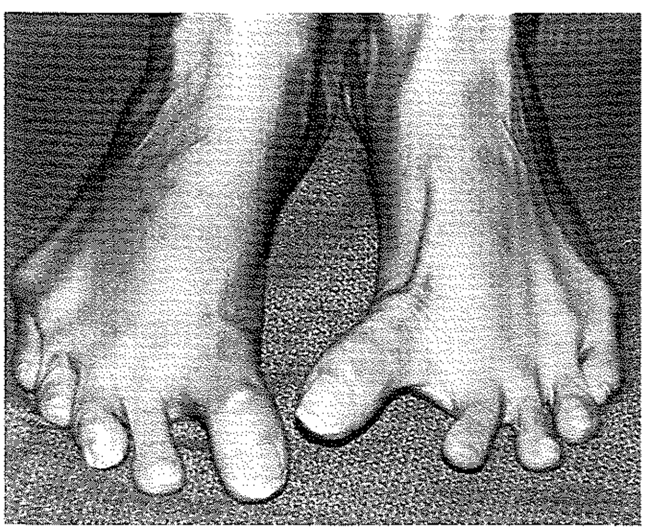


FIG. 5. Hallux varus deformity with concomitant hallux malleus.

and disabling than the original hallux valgus condition. Cosmetic complaints are rare when the varus deformity is less than 10 degrees (24). Pain associated with the deformity is often coincident with significant joint incongruity or degenerative joint disease.

McBride first described the complication of hallux varus in the follow-up study of his procedure and reported an incidence of 5.1% (25). The incidence of postoperative hallux varus reported by other authors approximates 1% (26–28). In a review of 878 first metatarsophalangeal joint procedures, Feinstein and Brown reported 10 cases of hallux varus, with an overall incidence of 1.13%. This study involved procedures for the correction of hallux abducto valgus and hallux limitus. Other studies, which reviewed procedures performed only for the correction of hallux abducto valgus, cited a similar incidence of postoperative hallux varus. Combining two separate reviews, 21 cases of hallux varus were discovered in 1,400 postoperative cases for an overall incidence of 1.5% (26,27).

In more recent literature, the reported range is from 2% to 17% (29–31). The length of the first metatarsal has been purported to predispose to the development of hallux varus (28). Janis and Donick found 18 cases of hallux varus in a review of 1,110 bunion operations. These investigators concluded that all but 2 cases were in patients with a long first metatarsal and deduced that this feature was influential in the development of a hallux varus deformity. However, considering that the normal metatarsal protrusion with respect to the first and second metatarsals is plus or minus 2 mm, with scrutiny of the results, one finds that the first metatarsal was abnormally long in only 50% (9 of 18) of these cases. In another study of 10 cases of hallux varus, the first metatarsal measured more than 2 mm longer than the second in only 2 cases. In the remaining 8 cases, the length pattern of the first metatarsal was not considered a significant cause (26). Therefore, it appears that the length of the metatarsal may not predispose a patient to hallux varus, as was once suspected.

The shape of the first metatarsal head, specifically a round first metatarsal head, has also been implicated as a factor leading to the formation of hallux varus after bunion operations (28,31). A round metatarsal head seemingly implies an absence of the sagittal groove or plantar, medial condyle. Although the morphology of the sagittal groove and plantar medial condyle may vary from patient to patient, we have yet to perform an initial bunion operation and find these structures to be absent. Furthermore, no reports exist in the literature that correlate the architecture and shape of the first metatarsal noted intraoperatively with the preoperative radiographs. The concept of a round first metatarsal head as a contributory factor to hallux varus is strictly a supposition based on retrospective radiographic analysis and clinical experience. The apparent shape of the first metatarsal head is easily altered by positional changes of the foot or by changing the tube head angle in x-ray acquisitions. Therefore, the validity of a round metatarsal head as a contributory factor to the development of iatrogenic hallux varus deformity should be questioned.

The flexibility of the first ray may certainly be a contributory factor in the development of postoperative hallux varus deformities (32). A foot that is extremely mobile and has an excessive sagittal plane range of motion may be more susceptible to postoperative deformity. It seems logical that patients with an excessive range of motion of the first metatarsophalangeal joint (90 to 100 degrees or greater) and first ray will tend to be flexible in the transverse plane as well.

Certain connective tissue disorders (i.e., Marfan's syndrome and Ehlers-Danlos syndrome) are associated with an inherent joint laxity that predisposes the patient to recurrent deformity or hallux varus. In addition, patients with disorders such as Down's syndrome or other neuromuscular diseases such as cerebral palsy may also be predisposed to developing a postoperative hallux varus condition.

Historically, the development of an hallux varus deformity has been largely attributed to a McBride-type procedure. Hawkins stressed the importance of maintaining either the adductor tendon or the lateral head of the flexor hallucis brevis tendon. In Hawkins' study of 300 cases of McBride bunionectomies, all 3 cases of hallux varus were attributed to the removal of the fibular sesamoid or sectioning of the lateral head of the flexor hallucis brevis tendon (27). However, at that time, correction of hallux abducto valgus deformity was largely performed without the benefit of an osteotomy. Therefore, much of the risk involved with the McBride procedure may have resulted from attempts to reduce significant deformity with soft tissue procedures alone, as opposed to the sesamoidectomy.

Although the lateral head of the short flexor tendon does not actively abduct the great toe, it does provide some passive restraint against adductory forces because it is lateral to the midline of the first metatarsal. Many true McBride procedures have been performed without the development of subsequent hallux varus deformity. This finding highlights the importance of a stepwise approach to the lateral release performed for hallux abducto valgus deformities. A properly performed interspace release establishes a rectus or congruous joint; however, significant compromise to the integrity of the plantar lateral soft tissues may be necessary to achieve the desired result. Most cases of hallux abducto valgus require at least the release of the adductor tendon and the fibular sesamoidal ligament (33). Although empiric removal of the fibular sesamoid may unnecessarily disrupt the plantar lateral support of the first metatarsophalangeal joint (27,34), this may still be required to provide full correction of the hallux abducto valgus deformity in some patients.

Obviously, other factors contribute to the articular and periarticular instability at the first metatarsophalangeal joint and lead to the development of an iatrogenic hallux varus. In most cases of hallux varus, one of the following must be present in conjunction with a plantar lateral release: (a) staking of the first metatarsal head, (b) overcorrection of structural deformities, and (c) excessive tightening of the medial capsular structures (22,32,35,36).

Many surgeons have recognized the concept of *staking* the first metatarsal head. The sagittal groove represents the articular confine for the medial aspect of the base of the proximal phalanx. The bone medial to the sagittal groove acts as a buttress and provides support to help prevent the phalanx from drifting medially. The plantar medial aspect of the first metatarsal head also provides medial stability and is essential to the normal function of the tibial sesamoid. Loss of the medial condyle allows the tibial sesamoid to sublux medially. This significantly alters the function of both the abductor hallucis muscle and the medial head of the flexor hallucis brevis. Both muscles then become primary transverse plane deforming forces.

Unfortunately, some surgeons still improperly use the sagittal groove as a landmark for resection of the medial exostosis during the "bunionectomy" or exostectomy portion of hallux abducto valgus correction procedures. This results in removal of all the bone medial to the sagittal groove. Perhaps this aspect of the surgical correction has resulted in the claim of a "round metatarsal" as a significant factor in the development of a hallux varus deformity. Clearly, the loss of articular stability and alteration of the muscle-tendon function favors the development of a hallux varus or hallux malleus deformity.

The creation of a negative intermetatarsal angle may also be a significant contributing factor to the cause of a hallux varus deformity. Youngswick reviewed 40 cases of hallux varus deformity and concluded that a negative intermetatarsal angle was a significant factor in most cases (37). Although this may be true, slight overcorrection of this radiographic-anatomic parameter may not be a significant factor in hallux varus if the integrity of the joint surface has been preserved and other factors known to be contributory are absent. In patients with a considerable degree of metatarsus adductus, we routinely reduce the intermetatarsal angle to a slightly negative value without a subsequent increase in the risk of developing a hallux varus deformity.

The physician should understand that what appears to be the intermetatarsal angle on conventional radiographs is actually a combination of a structural relationship between the first and second metatarsals and the positional effect of the hallux on the first metatarsal as a result of retrograde forces. Just as a lateral deviation of the great toe results in an increase in the intermetatarsal angle, so a negative intermetatarsal angle in a hallux varus deformity may simply be the result of retrograde forces as the hallux deviates medially on the metatarsal head. In some cases, the identification of a negative intermetatarsal angle on conventional radiographs is the result of an osteotomy either at the head or at the base of the first metatarsal. Excessive displacement of a capital osteotomy, or resection of too large a wedge from the base of the first metatarsal, may result in a true negative angular relationship between the first and second metatarsals. In such cases, muscle-tendon balancing about the joint is unlikely to resist hallux varus deformity.

Significant alteration of first metatarsophalangeal joint congruity may be associated with the development of hallux varus, but it is unlikely to be the direct cause of the deformity. The creation of a negative proximal articular set angle is not likely to result in a hallux varus deformity unless other contributing factors are realized.

Overtightening of the medial capsule in conjunction with either a plantar lateral release or an aggressive osteotomy is likely to contribute to the propagation and development of a hallux varus deformity. In some cases, the surgeons may have chosen to use a medial soft tissue plication in lieu of correcting an underlying osseous deformity. In some cases, an osseous deformity may be underappreciated, and an aggressive capsulorrhaphy may be used in isolation to correct the deformity.

An underlying deformity of the hallux (increased distal articular set angle or hallux interphalangeus) that increases the degree of hallux abduction may provide the appearance of joint abduction even though the joint is congruous. In this situation, the surgeon may continue to tighten the medial capsule to provide a rectus hallux. However, because the residual deformity resides in the toe as opposed to the joint, the base of the hallux may displace medially and may result in hallux varus (35). In this situation, an osteotomy of the proximal phalanx is indicated.

Clinical and Radiographic Evaluation

It is important to understand the chief complaint of the patient, to identify appropriate care and treatment. Although the patient may present with a severe, rigid hallux varus and hallux malleus deformity, the only complaint may be irritation with formation of a dorsal callus on the dorsal medial aspect of the hallux interphalangeal joint, which is painful with shoe gear. In such cases, complete correction of the deformity may not be necessary. This is particularly true in any patient who has already lived with the condition for many years. Understanding the patient's complaint and expectations is helpful in determining the most appropriate procedure to correct the deformity. This information should be correlated with the clinical observations and radiographic findings (Fig. 6).

An exaggeration of the deformity with weight bearing suggests an increased role of muscle-tendon imbalance. This applies not only to the transverse plane adduction deformity, but also to the sagittal plane contracture and loss of appropriate toe purchase with the ground-supporting surface.

Integrity and preservation of function of the intrinsic musculature are evidenced by a hallux that purchases the ground-supporting surface with weight bearing; a floating toe or hallux malleus deformity suggests partial or complete loss of intrinsic function responsible for stabilization of the proximal phalanx. An ability to flex the interphalangeal joint of the great toe actively against resistance suggests integrity

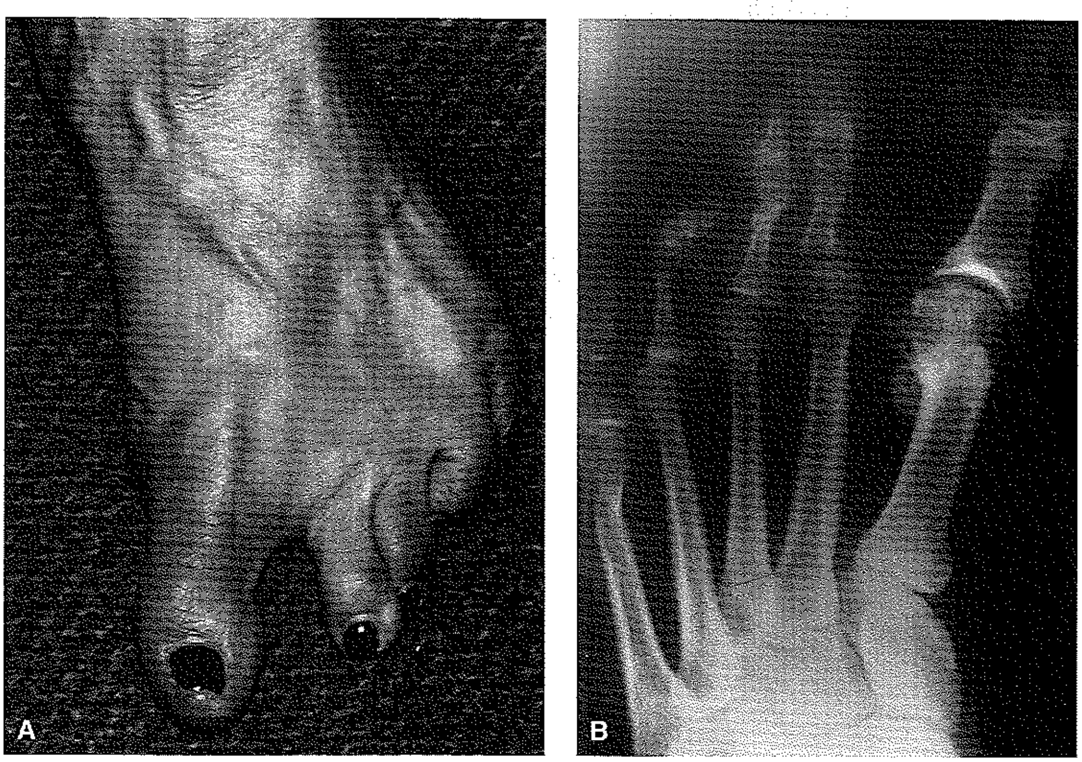


FIG. 6. A: Clinical photograph of a patient with postoperative hallux adductus deformity. Because of the flexibility of the deformity, revisional surgery was not required. **B:** Dorsoplantar radiograph of the same patient.

and function of the flexor hallucis longus tendon; the inability to plantarflex the proximal phalanx at the metatarsophalangeal joint against resistance suggests dysfunction of the flexor hallucis brevis muscle. It is easier to assess the function of the extensor hallucis longus tendon. Although active contracture of this tendon may not result in extension of the interphalangeal joint in cases of severe hallux malleus, visual confirmation of tendon function aids in the assessment. Manipulation of the great toe in the transverse plane provides the surgeon with an appreciation of the amount of contracture and contribution of the abductor hallucis muscle to the hallux varus deformity. Tautness of the tendon is readily appreciated on digital palpation of the medial border of the foot.

Other clinical factors to assess are the reducibility of the deformity and the presence or absence of degenerative joint disease at both the metatarsophalangeal and interphalangeal joints. The quality and quantity of motion, as well as the ability to reduce the deformity, are important factors in determining whether muscle-tendon balancing procedures or more aggressive osseous procedures may be needed to achieve correction. A deformity that is flexible, and therefore reducible, without evidence of crepitation or restriction of joint range of motion, suggests that the deformity will be amenable to tendinous rebalancing and joint preservation procedures. In contrast, a nonreducible deformity causing pain and crepitation on range of motion may indicate the need for some type of joint-destructive procedure.

The dorsoplantar radiograph provides information regarding the severity of the transverse plane hallux deviation, the condition of the joint surfaces, the alignment of the first metatarsal segment, and the presence or absence of each sesamoid bone. The alignment of the tibial sesamoid may also provide some measure of the severity of the condition. The intermetatarsal angle may be assessed by determining the true bisector of the first metatarsal (12), measured from the shaft of the metatarsal to a point just proximal to the previous osteotomy, as well as the bisector through the cartilage of the metatarsal head and the base of the metatarsal. These two lines are distinctly different. An evaluation of the two may provide insight into the extent of osseous malalignment of the first metatarsal from previous osteotomy.

Additional views may be useful for further assessing the metatarsal and interphalangeal joints. Findings on these views should confirm clinical observations. The forefoot axial view may provide information on the congruence of the crista and sesamoids as well as further evaluation of the condition of the metatarsal head. The extent of preservation or destruction of the sagittal groove and plantar medial articulation for the tibial sesamoid can also be appreciated.

Finally, if clinical findings are equivocal, obtaining a dorsoplantar radiograph while the patient's great toe is manipulated into a corrected position will provide a more definitive image showing the flexibility and reducibility of the deformity. When the deformity can be reduced, the intermetatarsal angle can be further assessed to determine whether the deformity is more likely secondary to medial retrograde pressure from the phalangeal base or whether it is perhaps more structural, as a result of the previous procedure.

Treatment Considerations

Multiple procedures have been described for the surgical management of a hallux varus deformity (3,4,22,32,35, 38–44). The basic principles used in the correction of an hallux varus deformity are often similar to those applied in hallux abducto valgus surgery.

A standard dorsomedial approach is usually employed. This approach provides adequate exposure of all aspects of the joint. The operation is often performed using a tourniquet to enhance visualization. Sharp and blunt dissection techniques are used to separate the skin and subcutaneous tissues from the overlying deep fascia and capsular tissues on both the medial and lateral sides.

Various deep fascial, periosteal, and capsular incisional approaches can be employed. Most commonly, a modified capsular approach is necessary to facilitate effective lengthening of the abductor hallucis and medial capsular tissues. Our most common approach is an inverted-L capsulotomy similar to that used in conventional hallux valgus surgery, except the vertical portion of the incision is placed proximal to the joint at the level of the metaphyseal-diaphyseal junction. Subcapsular dissection is performed to expose the first metatarsal head. The abductor hallucis is readily identified at the plantar medial aspect of the joint and can be transected, or a section of the tendon can be excised if desired. Further dissection and release provide identification of the tibial sesamoid. If the tibial sesamoid is significantly displaced from beneath the medial aspect of the joint, every attempt is made to relocate the tibial sesamoid beneath the metatarsal head. If this cannot be achieved, consideration is given to excision of the tibial sesamoid. However, this procedure should be performed with great caution, especially when the fibular sesamoid has already been excised. Additional excision of the tibial sesamoid may induce or further accelerate a hallux malleus deformity. The inability to relocate the tibial sesamoid beneath the first metatarsal head may result from a structural deformity, such as overcorrection of the intermetatarsal angle by either a proximal or a distal osteotomy or excessive staking of the sagittal groove.

Scarring and fibrosis of the deep transverse intermetatarsal ligament or structures within the first intermetatarsal space may prevent the first metatarsal from returning to its more normal position even after the retrograde forces of the hallux have been released. Therefore, dissection and release of scar tissue in this region should be considered before the execution of an osteotomy or removal of the tibial sesamoid. This approach helps to identify the true structural position of the first metatarsal. Increased medial displacement (adduction) of the metatarsal head may occur in a flexible first ray after release of the deep transverse intermetatarsal ligament and appropriate soft tissue release medially (35).

If the deformity is not completely reduced after proper soft tissue balancing techniques and the joint does not have any significant degenerative changes, the intermetatarsal angle may have to be corrected. The deformity can be addressed by reverse Austin, Reverdin, or modified Reverdin procedures or by a reverse closing base wedge osteotomy (Fig. 7).

When the joint cannot be salvaged, three options have been advocated: (a) resection arthroplasty, (b) resection arthroplasty with implant, and (c) arthrodesis. A joint-

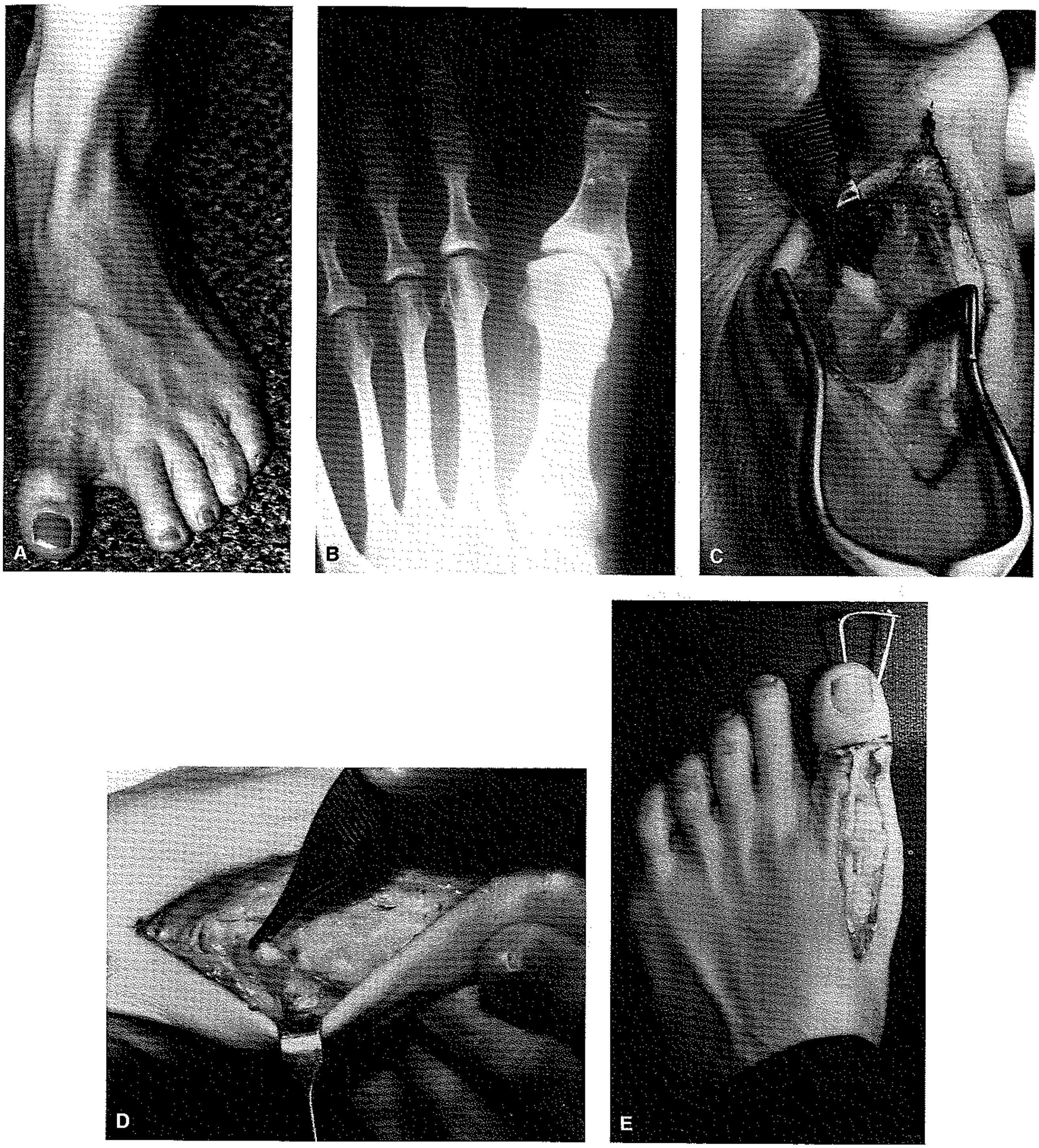


FIG. 7. A: Preoperative appearance of a patient with hallux varus deformity with concomitant hallux malleus. **B:** Radiographic appearance. **C:** Incision of the lateral capsule in an inverted-L fashion to facilitate later tightening. **D:** Release of the medial capsular tissues including the abductor hallucis tendon. **E:** Intraoperative appearance before closure. Procedures consisted of a reverse Reverdin-Green osteotomy and arthrodesis of the hallux interphalangeal joint. *(continued)*

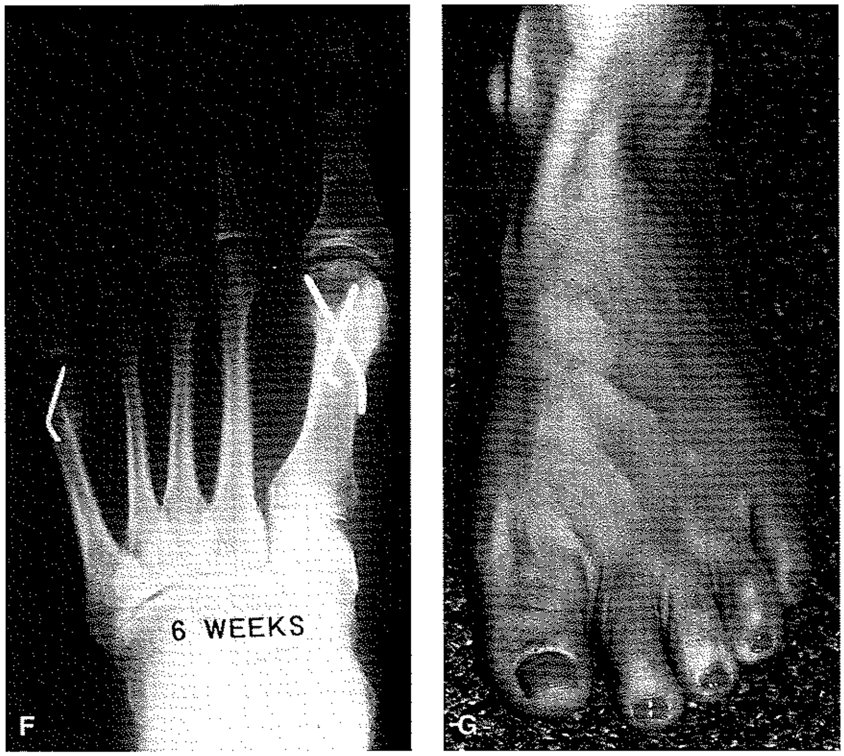


FIG. 7. *Continued.* **F:** Radiograph 6 weeks postoperatively. **G:** Clinical appearance 4 months postoperatively.

destructive procedure should be considered under the following conditions: (a) a rigid, nonreducible deformity; (b) clinical and radiographic evidence of degenerative joint disease; (c) an excessively staked first metatarsal head; (d) the presence of disorders that produce joint laxity; and (e) the presence of an underlying neuromuscular disorder involving spasticity.

Occasionally, significant compromise of the quality and architecture of the bone may have left the metatarsal unfit to accommodate an implant. In addition, the use of a hemiimplant may not be a good choice because the remaining metatarsal head may not be an acceptable ''receptor site'' for an implant (35). Implants are also likely to fail when arthritic changes are present at the tibial sesamoid–first metatarsal articulation. Finally, restoration of a normal intermetatarsal angle is also a prerequisite for the successful use of a resection arthroplasty or implant arthroplasty procedure. If arthrodesis is selected in lieu of implant arthroplasty, correction of the deformity can usually be achieved without the need for correction of the intermetatarsal angle. This is in accordance with the premise that relief from retrograde force on the metatarsal head allows for adequate reduction of deformity.

Additional adjunctive soft tissue measures have also been described. In some cases, the abductor hallucis tendon is freed from its insertion into the base of the proximal phalanx and is dissected proximally. This is done in a manner similar to release of the adductor tendon in correction of a bunion deformity. The abductor tendon can then be passed subperiostally over the metatarsal and sutured onto the lateral capsular tissues to assist in derotation and relocation of the sesamoid apparatus. Alternatively, one may pass the abductor tendon beneath the metatarsal head.

The lateral component of muscle-tendon rebalancing consists of a lateral capsulorrhaphy. This is usually performed by the use of over-and-over sutures using 2-0 absorbable or a braided polyester suture. An overly aggressive lateral capsulorrhaphy may result in a recurrent hallux valgus deformity.

Complete reapproximation of the medial capsular tissues is not necessary. The small amount of bone that is exposed on the medial side is not of concern. If the surgeon is compelled to have complete coverage of the first metatarsal, then a V-to-Y capsulotomy may be performed. The surgeon must not retighten the medial capsular tissues because this is likely to encourage a recurrence of the hallux varus deformity. It is better simply to lay the capsule in place than to suture the capsule in a manner that tends to adduct or rotate the hallux into a varus position.

In patients with a concomitant hallux malleus deformity, strong consideration should be given to arthrodesis of the hallux interphalangeal joint of the great toe. Lengthening of the extensor hallucis longus tendon and an extensor hood recession may be necessary to realign the great toe in the sagittal plane.

BONE HEALING COMPLICATIONS OF THE FIRST METATARSAL

Malunion of the First Metatarsal

Definition, Incidence, and Causes

A *malunion* is referred to as a consolidated fracture (osteotomy) site that has healed with an angular or rotatory deviation, in one or more cardinal planes, in reference to the long axis of the bone (45). Other investigators have defined malunion of distal metaphyseal osteotomies of the first metatarsal as any movement of the capital fragment or consolidation of the osteotomy in a position other than that placed intraoperatively (46).

We propose a modified definition as follows: a malunion should be considered an angular or rotatory deviation, or excessive shortening of the bone that is other than that achieved in surgery and has resulted in clinical symptoms. This includes deviations in the sagittal, transverse, or frontal planes of the bone different from that position established at the time of osteotomy or fusion. Patients who demonstrate angular, rotational, or shortening deformities, but who have no clinical sequelae, are classified as having *asymptomatic malalignment.*

Malunion or malalignment after a distal metaphyseal osteotomy of the first metatarsal for the correction of hallux valgus surgery can occur in any direction, but most commonly it manifests itself as a "dorsal tilting" of the capital fragment. In one study, up to 14% of cases demonstrated tilting of the distal fragment (47). Conversely, Mancuso et al. reviewed 500 distal metaphyseal osteotomies and reported an incidence of only 1.6% malunion in these patients. He indicated that "mild displacement" was of no clinical significance, a philosophy similar to ours (46).

Elevatus after a basilar-type osteotomy of the first metatarsal is a well-known complication. This complication can be all but eliminated by maintaining patients non–weight bearing after proximal osteotomies.

Clinical and Radiographic Evaluation

As previously stated, malalignment after hallux valgus surgery may not have any clinical significance. Some patients have only minimal symptoms, and no significant conservative or surgical treatment is warranted or necessary. For example, Mann et al. reported a 28% rate of radiographic elevatus and no new painful transfer lesions in 109 feet (48). These surgeons concluded that because the first metatarsophalangeal joint was realigned adequately after hallux valgus surgery, the hallux continued to bear weight in a normal manner, thereby compensating for any dorsiflexion that may have occurred. Broughton and Winson reported that dorsal malunions of up to 10 degrees after Mitchell bunionectomy did not appear to influence the result or to cause metatarsalgia (49).

In other cases, clinical symptoms may be significant. The most common sequela of sagittal plane malunion is the development of lesser metatarsalgia. In some cases, this is associated with the development of plantar hyperkeratosis beneath one or more of the metatarsal segments; in rare cases, a porokeratoma or nucleated hyperkeratotic lesion may develop. Patients may complain of a feeling of imbalance because of the off-loading of the first ray segment. As weight is transferred to the lesser metatarsal segments, other clinical symptoms may develop, such as a neuroma or hammer toe contractures. Some patients may complain that the medial column of the foot has minimal contact with the ground-supporting surface.

If the metatarsus primus elevatus is significant, a hallux limitus deformity may develop. In such cases, patients may report pain and limitation of motion. In severe cases, patients may complain of a dorsal "bump" that is aggravated by conventional shoe gear.

Although sagittal plane malalignment or malunion of the osteotomy is perhaps the most common complication (Figs. 8 and 9), other planal deformities may also develop. Significant transverse plane deviation of an osteotomy may result in clinical overcorrection or undercorrection of the original hallux valgus deformity. Transverse or frontal plane malalignments may affect the overall quality and quantity of motion present at the first metatarsophalangeal joint.

The dorsoplantar view demonstrates any evidence of medial or lateral translocation of the metatarsal. Metatarsus primus elevatus is appreciated best on a lateral film. A forefoot axial view may also aid the surgeon in assessing elevation of the first metatarsal. Camasta studied metatarsus primus elevatus radiographically and classified it as either extrinsic (positional) or intrinsic (structural). Extrinsic metatarsus elevatus is noted when the architecture of the first metatarsal is normal and there is divergence between the first and second metatarsals. Intrinsic metatarsus elevatus occurs with divergence between the first and second metatarsals and evidence of a structural abnormality within the first metatarsal. This is most commonly seen postoperatively after a proximal

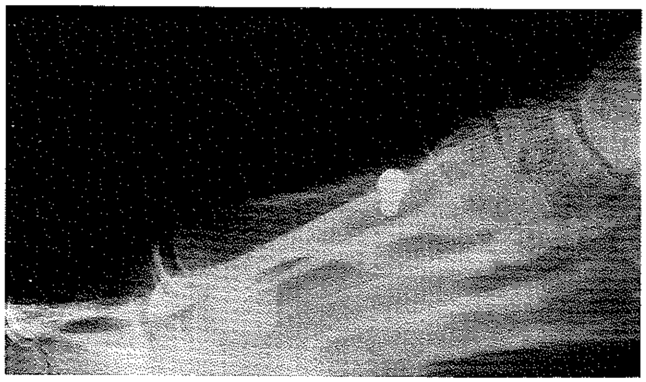


FIG. 8. Malunion after a previous closing base wedge osteotomy with sagittal plane elevation. In most instances, this complication results from premature weight bearing.

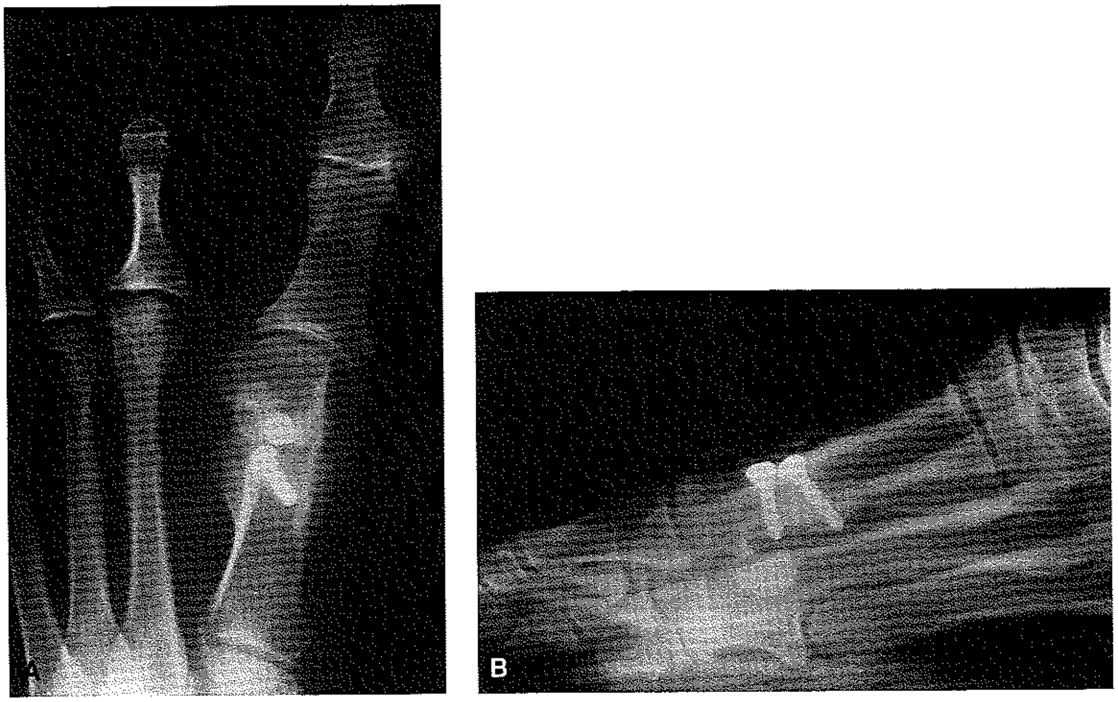


FIG. 9. A,B: Dorsoplantar and lateral radiographs of a patient with a postoperative hallux varus deformity compounded by a bone healing complication. Note the excessive callus formation and the shortening and elevation of the first metatarsal head, in spite of the screw fixation.

or distal procedure for the correction of a hallux valgus deformity (50).

Frontal plane malalignment may be difficult to evaluate. The forefoot axial view may reveal rotation of the metatarsal head. Clinical correlation is essential to understanding this complex problem fully.

Treatment Considerations

Conservative treatment modalities consist of shoe modifications, orthotic devices, and possibly alterations in activity. A balance mold orthotic device may prove to be the most beneficial. A Morton extension on any type of orthotic device helps to increase weight bearing to the first ray segment.

The surgical management of malunion deformities has two basic approaches. The first is geared toward recognition of the cause of the problem with a goal of restoring normal architectural alignment, and thus function, of the first ray. In other cases, this approach may not be realistic, and consequently a symptomatic approach may be appropriate. This section focuses primarily on sagittal plane malunion. The reader is referred to the remainder of the chapter for transverse plane malunion deformities that contribute to the recurrence of a hallux valgus or hallux varus deformity.

Any significant aberration in the length of the first metatarsal is appreciated, along with sagittal plane malunion. The excessive shortening in combination with a metatarsus primus elevatus is more commonly seen after procedures performed in the proximal portion of the first ray (base wedge osteotomy, first metatarsocuneiform arthrodesis, or first metatarsocuneiform osteotomy). When excessive shortening is seen after a procedure that was not intended to accomplish this goal, it usually results from a disturbance of the bone healing process. When reviewing postoperative radiographs to assess alignment and position, one should also evaluate whether the osteotomy has progressed to a successful union. The presence of a radiolucent line, excessive osteoporosis, or bone callus proliferation may suggest the need for further evaluation of the bone healing process.

Dorsal angulation may be seen after distal metaphyseal osteotomies; subtle transverse or frontal plane malalignment may also be seen with the dorsal angulation. This problem may be treated by performing a plantarflexory osteotomy in the distal metaphyseal area of the first metatarsal by using an opening wedge osteotomy with the apex plantar and the base dorsal, with the insertion of a corticocancellous bone graft. An alternative is a closing plantarflexory osteotomy (base plantar, apex dorsal); this effectively accomplishes plantargrade realignment of the capital fragment. The surgeon may also perform a V osteotomy in a dorsal to plantar direction that also allows plantar displacement of the metatarsal head. The decision regarding which osteotomy is more appropriate should be based on the surgeon's preference, on the amount of shortening of the first metatarsal, and on the ability to restore normal range of motion and to avoid ''jamming'' of the joint with the procedure. In some cases, it is simply not realistic to attempt correction if the deformation is severe. Alternative approaches including panmetatarsal head resection may unfortunately be necessary, depending on the individual patient.

Historically, postoperative metatarsus primus elevatus has been seen after a proximal osteotomy. Many of these cases are seen in combination with a disturbed union process that eventually goes on to heal with a significantly shortened first metatarsal segment. As previously mentioned, the primary goal of surgical treatment is the restoration of weight bearing to the first metatarsal with preservation of the range of motion at the first metatarsophalangeal joint. Length may also need to be restored, but one must be more careful in correcting this component of the deformity because lengthening beyond a certain point creates jamming at the first metatarsophalangeal joint.

Once the base osteotomy has undergone complete healing from the first operation, revisional surgical treatment can be attempted. Plantarflexion of the first metatarsal can be accomplished by several different means. One technique is a closing, oblique plantarflexory osteotomy of the first metatarsal. A proximal dorsal cortical hinge is preserved. The base of the osteotomy is plantar distal. One or two small cortical or, more commonly, cancellous bone screws may be effective for fixation of the osteotomy.

A plantarflexory osteotomy oriented in a perpendicular relationship with the first metatarsal can also be performed at the base. The apex is be dorsal and the base is plantar. Because of the architectural configuration of the first metatarsal base area, adequate exposure can be difficult. Complete subperiosteal stripping around the entire proximal metaphyseal area of the bone is necessary to execute this osteotomy in the proper location. The more proximal the location of the cortical hinge (for either this osteotomy or the oblique osteotomy), the more effective is the radius-arm concept. Fixation of this type of osteotomy is also more difficult. Crossing 0.062-inch Kirschner wires, small Steinmann pins, horizontal stainless steel cerclage wire, or staples can be used for fixation.

In patients with excessive shortening of the first metatarsal segment and preservation of the range of motion at the first metatarsophalangeal joint, an opening wedge osteotomy can be performed. This osteotomy requires a corticocancellous bone graft. We recommend the use of autogenous bone. This may be procured from the body of the calcaneus for this procedure. This approach provides cortical bone to prevent the osteotomy from collapsing and excellent cancellous bone to facilitate bone healing. Autogenous calcaneal bone graft for reconstructive foot surgery has proved efficacious in a variety of settings (51).

An alternative to a plantarflexory osteotomy, which requires the preservation of a cortical hinge, is to reosteotomize the bone through the original oblique osteotomy. The metatarsal is then rotated within the plane of the osteotomy itself and then undergoes fixation. This technique is less technically demanding and can employ the principles of the hinge-axis concept to resolve metatarsus primus elevatus successfully. In addition, the procedure can be modified to accomplish some restoration of length as weight bearing is restored. If one needs to reduce the intermetatarsal angle, a wedge of bone can be removed in the more traditional manner, the hinge can be sacrificed, and then the osteotomy can be rotated to correct for the elevatus deformity.

A versatile means of addressing both sagittal plane and length problems of the first ray is with the sagittal Z osteotomy (52). Because this is a through-and-through osteotomy, no hinge needs to be protected or preserved. This feature allows the surgeon the opportunity to stabilize the osteotomy temporarily and to assess the overall position and alignment, then to readjust as deemed necessary before the fixation process without compromising the osteotomy. The distal segment may be distracted to restore length.

In some cases, a symptomatic approach may be appropriate. This is particularly true when one or more lesser metatarsal osteotomies may have already been performed. For example, if the patient has had a previous second or third metatarsal osteotomy, then it may be appropriate to treat the isolated transfer lesion by way of a lesser metatarsal osteotomy directed toward relieving pressure under the prominent area. Other patients may have marked distortion of the entire transverse weight-bearing arch of the forefoot, so panmetatarsal head resection may be the treatment of choice. Although this approach seems aggressive, in some cases it is the most appropriate and efficient way to achieve resolution of symptoms and to salvage foot function.

Delayed Unions and Nonunions

Definition, Incidence, and Causes

The definition of a *delayed union,* as opposed to a nonunion, is not without controversy. Taylor stated that the difference is mostly in degree, and the time to unite a fracture site cannot be set arbitrarily. He further stated that union is delayed when healing has not advanced at the average rate for the location and type of fracture (53,54). Mayer and Evarts referred to a delayed union as one in which repair is not complete, spaces between the fracture are filled with granulation tissue (not scar tissue), and clinical evidence indicates that healing is taking place. Rosen defined a nonunion as a failure to heal in 6 to 8 months and a delayed union as an absence of complete healing in 2 to 6 months (55). The Arbeitsgemeinschaft for Osteosynthesefragen/Association for the Study of Internal Fixation (AO/ASIF) group classified a delayed union as a fracture that is not united by 4 to 5 months from the time of injury (53).

Nonunion, conversely, was once defined by the United States Food and Drug Administration for the purposes of testing bone healing devices. This diagnosis was established when a minimum of 9 months had elapsed from the time of injury and the fracture had shown no visible progressive signs of healing for 3 months (53). The definition has changed significantly over time. At one time, these definitions were used to justify the expense of using electrical bone stimulator devices for the treatment of nonunions. Today, the definition by the Food and Drug Administration has become more generalized; a nonunion is considered to be established when no signs of progressive healing are visible on plain radiographs; most physicians would agree that this definition is more suitable.

Nonunions have been classified based on their ability to heal conservatively with local vascularity at the site. A hypertrophic nonunion occurs when a proliferative, well-vascularized bone reaction occurs at the fracture site. Usually, the interposed fibrous tissue calcifies, ossifies, and eventually maturates. Hypertrophic nonunions are considered viable and are reportedly more common after closed reduction of fractures. In hypertrophic nonunions, electrical stimulation is beneficial in the conservative plan (56).

This finding is in contrast to atrophic nonunion, in which no local bone reaction occurs and the site is not well vascularized. This situation occurs primarily after open reduction and internal fixation of fracture or osteotomy (53).

The temporal sequence that distinguishes a delayed union of the first metatarsal is not universally accepted. Naimark et al. defined an osteotomy that was not healed by 4 months as delayed union, whereas other surgeons use 6 months as the differentiating time. Mancuso et al. defined delayed union as a prolongation of secondary bone healing. However, this definition excludes osteotomies that are healing by primary intention but fail to unite completely in the time anticipated. The review by Mancuso et al. of 500 distal metaphyseal osteotomies with Kirschner wire fixation revealed only a single delayed union and no nonunions when delayed union was defined as a lack of clinical or radiographic consolidation by 8 weeks, but occurring by 8 months postoperatively (46).

We recommend the following definitions. A union should be considered delayed when clinical symptoms and radiographic findings suggest a healing process slower than expected for the type and location of osteotomy performed. The presence of inappropriate pain and swelling is usually the first sign of a delayed union. At this time, further radiographic investigation is needed to substantiate the diagnosis. However, radiographic studies may be equivocal with respect to the clinical findings, and clinical symptoms are more important than radiographic manifestations. With appropriate treatment, a delayed union may go on to a successful osseous union. A nonunion with clinical symptoms and persistent radiographic evidence is consistent with an improbability to heal. To distinguish a nonunion, at least 6 months should elapse from the initial surgical procedure, and in general, the diagnosis is made between 8 and 12 months. However, the time to initiate therapy can be more expeditious, given newer philosophies and definitions of nonunion in bone.

A delayed union or nonunion is considered asymptomatic when the clinical findings do not suggest a disturbance of the bone healing process, but conventional radiographs show marked disturbance of the union process and findings consistent with a nonhealing osteotomy. An asymptomatic nonunion may or may not require intervention.

Nonunions of the first metatarsal fortunately are not common. Jones et al. retrospectively reviewed more than 300 hallux abducto valgus procedures and reported only 2 nonunions (41). Austin, in his original article, reported no nonunions of the chevron osteotomy in which no fixation was employed. The review by Mancuso et al. revealed no nonunions in more than 500 procedures (46).

Basilar osteotomies are more commonly associated with malunion, but, once again, nonunion is rare overall. In Mann and Coughlin's series of more than 250 crescentic osteotomies fixed by the use of Kirschner wires or screws, only a single nonunion was reported (3). Other authors have indicated that the frequency of nonunions after a first metatarsal osteotomy is low, even when there is no fixation and early weight bearing is permitted (57,58).

Certain factors contribute to the development of a delayed union or nonunion. Systemic factors including pregnancy, iron deficiency anemia, diabetes mellitus, corticosteroids, and irradiation have been implicated. However, the primary cause appears to arise from local factors (53). These factors include infection, interruption of blood supply, lack of contact between bone ends, inadequate immobilization, and actual loss of bone substance. In addition, early aggressive ambulation, thermal osteonecrosis, inadequate or improper fixation, disruption of the fixation, and soft tissue stripping at the osteotomy site may also contribute to the development of a delayed union or nonunion process.

Although delayed union or nonunion can occur in any patient at any time without identification of any specific inciting event or reason for the disturbed healing process, the overall incidence is still extremely low. Particular care should be placed on the risks versus gains of weight bearing; it is common practice to maintain patients with a basilar osteotomy in a non–weight-bearing attitude for approximately 6 to 7 weeks, whereas distal metaphyseal osteotomies can usually be weight bearing. Even then, some distal metaphyseal osteotomies (Mitchell or Roux) are inherently more unstable by the nature of the osteotomy alone, and consequently patients should be non–weight bearing unless the type of fixation is capable of supporting and withstanding the stresses generated by weight bearing. Finally, monitoring of patients after surgery by clinical and radiographic assessment further reduces the incidence of a bone healing complication.

Clinical and Radiographic Evaluation

Most surgeons would agree that a delayed union is associated with clinical symptoms. Nonunions, conversely, have varying degrees of symptoms. Although some patients have profound clinical symptoms throughout the entire period of the disturbed bone healing process, others are asymptomatic.

Investigators have estimated that up to 50% of nonunions involving the first metatarsal are asymptomatic (4). The clinical signs and symptoms may include pain and edema, induration, clinical motion, and instability at the osteotomy site. Increased warmth may also be present. Patients may report difficulty with weight bearing, especially on the affected area, and they consequently develop metatarsalgia resulting from a compensatory gait pattern. Difficulty with wearing conventional shoe gear is not uncommon. In some cases, these clinical signs and symptoms may suggets an infectious process. If the physician is highly suspicious of an infectious process associated with the bone healing complication, then further investigation by specialized studies or, more appropriately, a bone biopsy may be necessary.

Serial radiographs usually identify a disturbed bone healing process. Evaluation is focused on subtle alterations and disturbances of alignment and healing. Increased radiolucency or resorption at the osteotomy site, loosening and migration of internal fixation devices, secondary bone callus formation, and increased soft tissue volume and density may be seen in early cases of a delayed union or nonunion process. Subtle or overt changes in the alignment and position of the osteotomy indicate that undesirable motion is taking place and contribute to a delayed union or a nonunion. In some cases, obvious failure of the internal fixation device is seen; fracture of a screw or pin may only be seen on one of three views, a finding emphasizing the need for careful evaluation of each view.

When an osteotomy has failed to go on to a successful union within a reasonable time after surgical treatment, then further radiographic investigation may be considered. Radionuclide imaging studies are often used to help classify the type of disturbed healing process (59). A conventional technetium bone scan helps in classifying the nonunion as hypertrophic or viable or as atrophic and nonviable. In some cases, bone scan results are indeterminate. Radionuclide imaging studies or other ancillary imaging should not be used as a substitute for clinical acumen or, when necessary, the current standard of bone biopsy.

Finally, a magnetic resonance imaging study or computed tomography scan may further help to delineate a nonunion process. The presence of internal fixation devices may significantly alter the quality and reliability of such imaging studies. One should also be aware of the lack of experience in the interpretation of lower extremity imaging by many radiologists.

Treatment Considerations

Delayed union and nonunion of bone can be treated conservatively or surgically. The decision regarding the approach to undertake depends on several factors. Although the viability of the bone, and thus the ability to treat a bone healing complication by noninvasive means, may be readily ascertained from radiographs, this is only one factor in the clinical decision-making process. More important than radiographic findings are the clinical implications of the bone healing process. If one notes significant alteration in the alignment and position of the bone, then consideration should be given to a more aggressive treatment approach. This may mean manipulation with administration of local or general anesthesia to restore the alignment and position or surgical intervention to accomplish the same. It is an exercise in futility to spend up to 6 months with conservative treatment modalities only to end up with a severe malunion. When the alignment and position are satisfactory, then conservative treatment modalities are appropriate and should result in nearly full functional recovery.

Conservative treatment modalities consist primarily of immobilization and non–weight bearing, with or without the use of noninvasive electrical bone stimulation. A severe delayed union may require as long as 4 to 6 months to respond to this treatment approach.

When significant malunion is present, it is likely to result in a significant negative impact on foot function. Therefore, surgical intervention should be considered. In cases of delayed union, the osteotomy should be repositioned and restabilized. When possible, rigid internal compression fixation modalities should be employed. If the bone substance is tenuous, then stable internal fixation may be achieved by conventional fixation techniques such as stainless steel wire, staples, or large Kirschner wires or Steinmann pins. In some instances, external fixation may prove more efficacious if the bone segments are compromised and cannot support internal fixation devices. If a small bone deficit exists, this may require grafting. Autogenous bone procured from the calcaneus would be an excellent source, although the ileum and distal tibia are also good sources for autogenous corticocancellous bone grafts. Demineralized bone matrix may also prove valuable.

The treatment of frank nonunion depends on the type and location, as well as the size of the involved nonunion fragments. In some cases, excision of nonunion fragment may be the best and most realistic alternative treatment. An example is a distal osteotomy (i.e., Reverdin-type procedure) that has developed a complete nonunion. These patients have insufficient viable cartilage on the distal fragment to warrant repair of the defect. Excision of the fracture fragment alone or in combination with arthrodesis or implant arthroplasty may be the best approach.

Most nonunions of the first metatarsal warrant preservation of the bone and repair of the nonunion site. Depending on the amount of nonviable bone and the extent of shortening that has already occurred, bone grafting may or may not be necessary. In all cases, the nonunion site should be resected. In some cases, this can be accomplished by simply passing the saw blade through the original osteotomy site several times and planing the original osteotomy or nonunion site until viable bleeding bone is visualized. If sufficient length of the metatarsal has been preserved, then the fragments can be placed in their desired anatomic position, and appropriate fixation can be achieved.

Although resection of the nonunion itself with or without bone grafting is likely to result in healing at the nonunion site, this in and of itself does not ensure resolution of pain and restoration of function. A more normal alignment and position may need to be restored as well. In some cases, malalignment is present in only one plane (sagittal plane or transverse plane), whereas in other cases, an equal amount of deformity is present in two planes. Multiple planar deformities can be extremely difficult to correct. In addition to resection of the nonunion of the nonunion site itself, the surgeon must devise a mechanism for restoration of alignment. When a bone graft will be used, the surgeon often must spend considerable time fashioning the graft to achieve multiplanar correction (Fig. 10). Intraoperative radiographs are helpful in such cases.

In some cases, aggressive major resection of bone is nec-

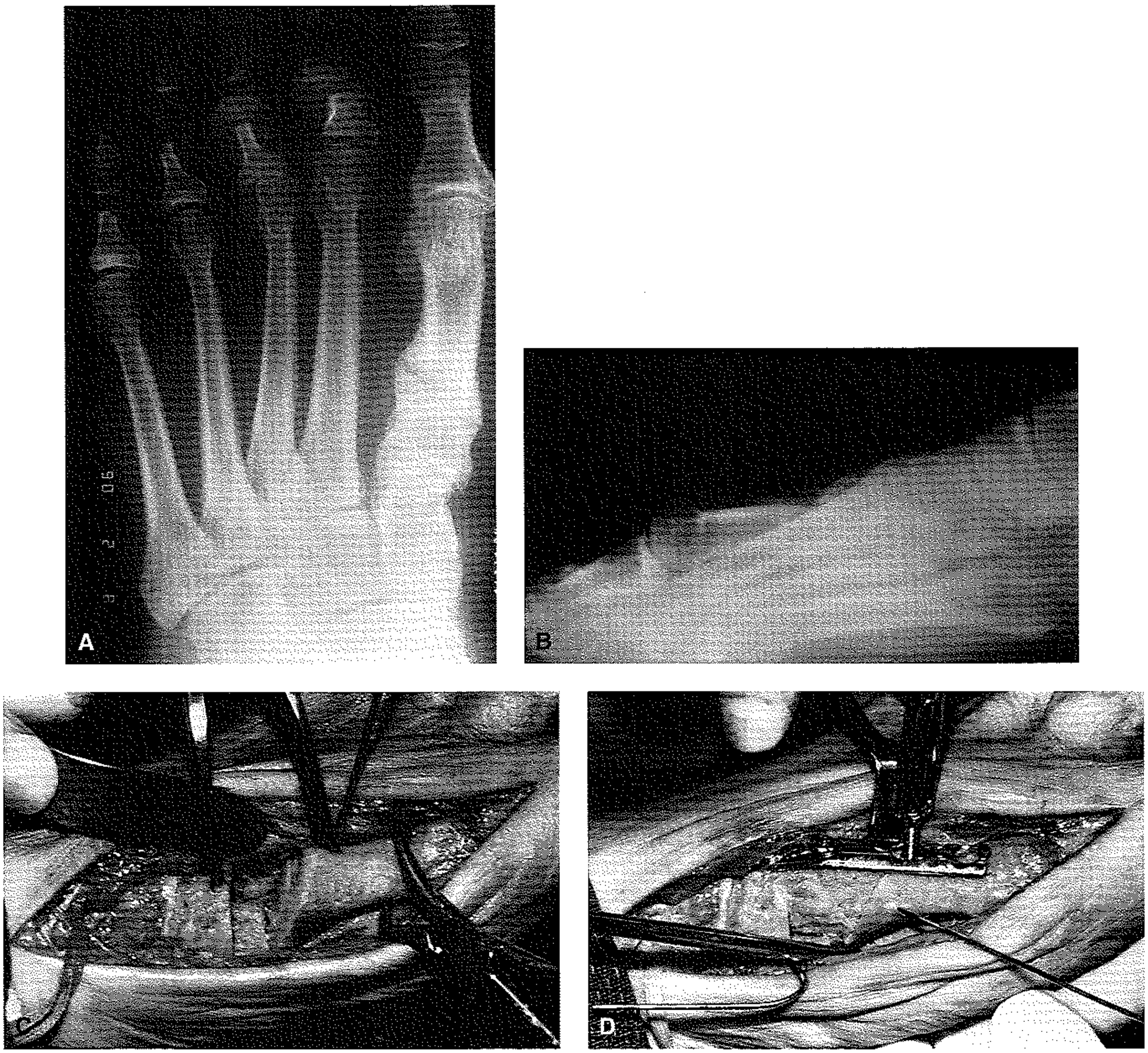


FIG. 10. A: Dorsoplantar radiograph of a patient with nonunion of the first metatarsal osteotomy. Note the callus formation and radiolucency. Significant clinical symptoms were also present. **B:** Lateral radiograph of the same patient. Note the severe metatarsus primus elevatus, as well as the malalignment of the first metatarsophalangeal joint. The distal osteotomy of the first metatarsal healed. **C:** Intraoperative appearance after resection of the nonunion site. Note the presence of sclerotic bone. Aggressive drilling was performed. The plantar cortex was preserved to provide some inherent stability and to serve as a hinge for correction of the sagittal plane malalignment. The laminar spreader is maintaining in plantarflexed position of the first metatarsal before insertion of the bone graft. **D:** Insertion of autogenous tricortical iliac crest graft with fixation by Kirschner wire and one-third tubular plate with multiple screws. *(continued)*

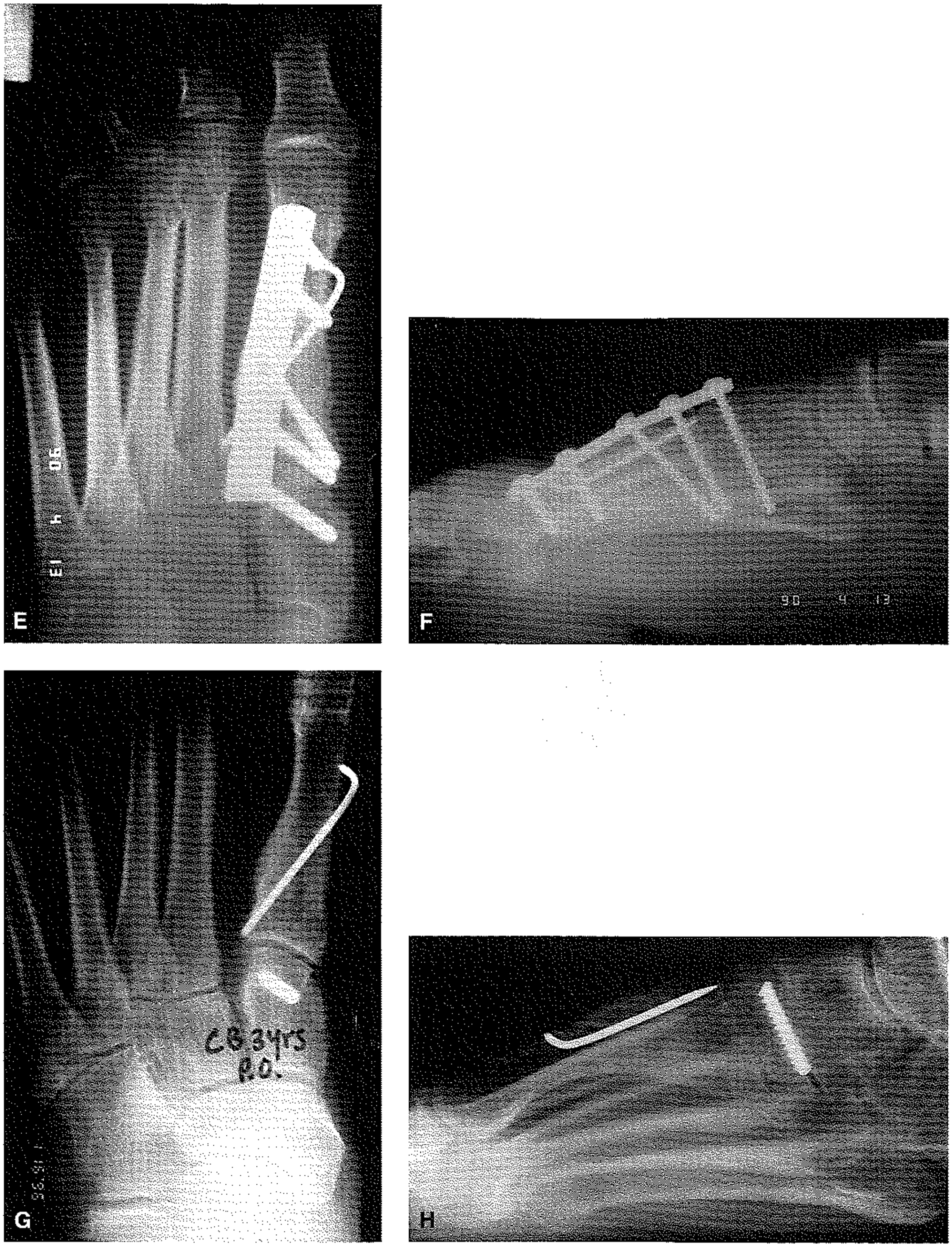


FIG. 10. *Continued.* Postoperative dorsoplantar **(E)** and lateral **(F)** radiographs after excellent healing and incorporation of bone graft. Correction of the metatarsus primus elevatus was achieved as well as restoration of length. Dorsoplantar **(G)** and lateral **(H)** radiographs 3 years postoperatively. Because of stress across the metatarsocuneiform joint, the plate failed and was subsequently removed. The retained portion of the screw within the medial cuneiform remained asymptomatic.

essary. These patients require autogenous bone grafting. The iliac crest provides excellent tricorticocancellous grafts with a combination of stability and osteoinductive bone. More recently, autogenous calcaneal bone has proven to be an excellent source of bone graft for repair of nonunions of the first metatarsal (51,60). In some instances, callus distraction techniques may also be employed to restore length to the first metatarsal when shortening is significant (Fig. 11).

In some cases, the surgical procedure can be augmented by the use of noninvasive or implantable electrical bone

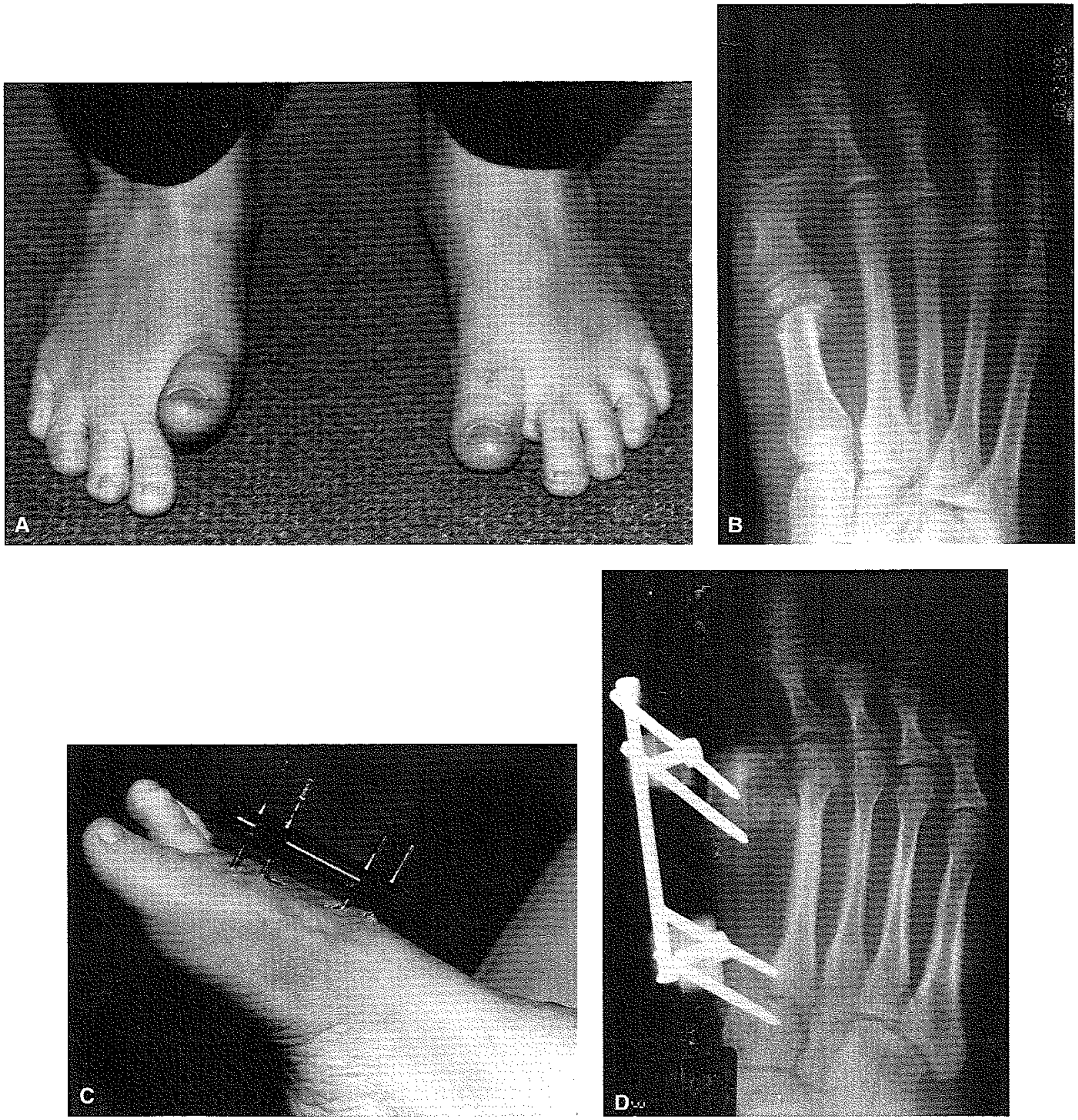
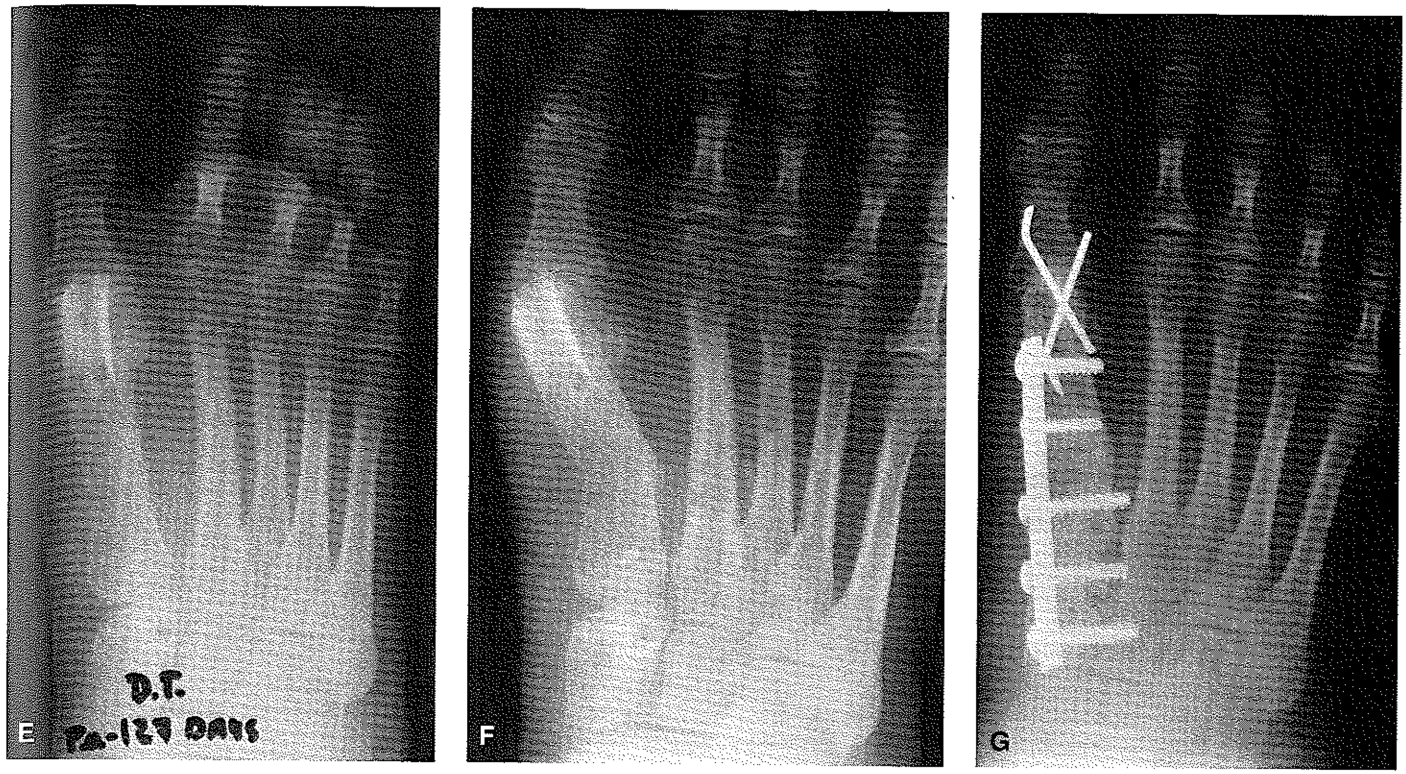


FIG. 11. A: Clinical appearance after surgical procedures of the first ray and both feet. The patient's right foot developed a severe nonunion with a severely dorsiflexed hallux resulting from proximal retraction. **B:** Dorsoplantar radiograph of the same patient. Note the obvious frank nonunion of a previous distal metaphyseal osteotomy 1½ years later. **C:** Clinical photograph showing the miniature external fixator that was used for distraction osteogenesis for the first stage of surgery. **D:** Oblique radiograph of same after successful lengthening. Note the early callus formation. *(continued)*



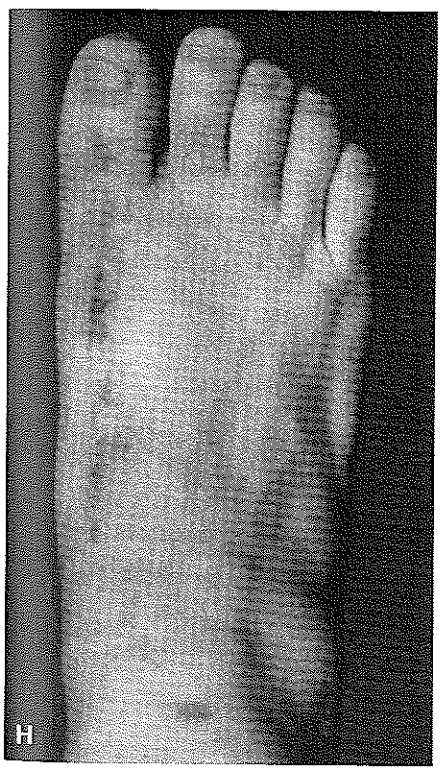


FIG. 11. *Continued.* **E:** Dorsoplantar radiograph of the same patient after removal of the internal fixator. **F:** Dorsoplantar radiograph showing angular deformity of the first metatarsal resulting from weakness of the medial cortex after successful distraction osteogenesis. **G:** Stage II surgery consisting of first metatarsophalangeal joint arthrodesis and stabilization of the first metatarsal using a one-third tubular plate. The deformity of the first metatarsal is readily corrected by simply passing a surgical blade through the soft bone area and applying a plate. Note restoration of length compared with the preoperative radiograph. **H:** Final clinical appearance of the same patient 1½ years postoperatively.

stimulation (61). The effects of electrical stimulation on bone healing are well known and proven, although their specific use and success with respect to nonunion or delayed unions of osteotomy sites within the foot have not been reported.

Although some differences in the management of patients may depend on the type of surgical procedure performed, most patients require a non–weight-bearing period of 8 to 12 weeks. The extent of non–weight bearing depends primarily on the radiographic evidence of bone healing. This is particularly important when bone grafting procedures have been performed. When adequate radiographic consolidation is seen, patients are permitted partial weight bearing for a 1- to 2-week period. Patients then progress to full weight bearing. Serial radiographs are taken throughout the postoperative course.

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