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Surgical Correction of Moderate and Severe Hallux Valgus

Proximal Metatarsal Osteotomy with Distal Soft-Tissue Correction and Arthrodesis of the Metatarsophalangeal Joint

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The painful bunion deformity is a common and relatively disabling condition that affects individuals of all ages. More than 150 procedures have been described for the treatment of hallux valgus, and the orthopaedic literature has focused predominantly on surgical management of this condition; however, successful treatment is often achieved with use of simple off-the-shelf orthotic devices and appropriate shoe-wear modifications. Given the potential for surgical complications, the substantial recovery period associated with bunion surgery, and patients’ occasional dissatisfaction with the results of otherwise technically successful procedures, it is recommended that nonoperative treatment be initiated prior to proceeding with surgery. It is not uncommon for a patient with an asymptomatic bunion to actively seek surgical correction because of cosmetic concerns or because of an inability to wear fashionable shoes comfortably. While pain alone is not the only indication for surgery, it is not recommended that surgery be performed for cosmetic reasons alone. The American Orthopaedic Foot and Ankle Society has issued a position statement reflecting this.

Pain resulting from hallux valgus deformity is mechanical in nature and can have extrinsic and intrinsic causes. Most commonly, extrinsic pain is related to mechanical irritation of the prominent medial eminence by shoe-wear or is due to impingement of the hallux on the second digit. A painful callus may develop on the medial border of the hallux as a result of pronation of the digit, and pain beneath the second metatarsal head is also common as a result of the transfer of forces as the weight-bearing function of the hallux is compromised by increasing deformity. Most extrinsic pain can be alleviated with nonoperative treatment, including extra-depth shoes with a wide toe box and soft leather uppers. A silicone toe spacer between the hallux and the second toe decreases pain from impingement, and an accommodative shoe insert with a metatarsal bar can be used to diminish pain beneath the lesser metatarsal heads. Intrinsic pain is caused by abnormal joint mechanics that cause increased joint contact stresses and synovitis and can lead to cartilage degeneration. Pain intrinsic to the joint is typically reproduced with axial loading and motion of the joint and can also manifest as plantar pain with palpation of the sesamoids. Intrinsic pain is caused by abnormal joint mechanics that cause increased joint contact stresses and synovitis and can lead to cartilage degeneration. Pain intrinsic to the joint is typically reproduced with axial loading and motion of the joint and can also manifest as plantar pain with palpation of the sesamoids. Intrinsic pain is caused by abnormal joint mechanics that cause increased joint contact stresses and synovitis and can lead to cartilage degeneration. Pain intrinsic to the joint is typically reproduced with axial loading and motion of the joint and can also manifest as plantar pain with palpation of the sesamoids. Intrinsic pain is caused by abnormal joint mechanics that cause increased joint contact stresses and synovitis and can lead to cartilage degeneration. Pain intrinsic to the joint is typically reproduced with axial loading and motion of the joint and can also manifest as plantar pain with palpation of the sesamoids. Intrinsic pain is caused by abnormal joint mechanics that cause increased joint contact stresses and synovitis and can lead to cartilage degeneration. Pain intrinsic to the joint is typically reproduced with axial loading and motion of the joint and can also manifest as plantar pain with palpation of the sesamoids. Intrinsic pain is caused by abnormal joint mechanics that cause increased joint contact stresses and synovitis and can lead to cartilage degeneration. Pain intrinsic to the joint is typically reproduced with axial loading and motion of the joint and can also manifest as plantar pain with palpation of the sesamoids. Intrinsic pain is caused by abnormal joint mechanics that cause increased joint contact stresses and synovitis and can lead to cartilage degeneration. Pain intrinsic to the joint is typically reproduced with axial loading and motion of the joint and can also manifest as plantar pain with palpation of the sesamoids. Intrinsic pain is caused by abnormal joint mechanics that cause increased joint contact stresses and synovitis and can lead to cartilage degeneration. Pain intrinsic to the joint is typically reproduced with axial loading and motion of the joint and can also manifest as plantar pain with palpation of the sesamoids.

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sic pain is less amenable to conservative treatment but can be managed with an orthotic device that incorporates a stiff Morton extension. Corrective devices may prevent progression of a deformity, but they will not permanently correct it. An in-depth review of conservative treatment of painful bunion deformities is beyond the scope of this paper, and the reader is referred to a recent article in which current concepts of nonoperative management are reviewed in greater detail.1

The primary indication for operative treatment of hallux valgus is pain that fails to respond to conservative treatment, usually within six to twelve months. Some conditions may not cause substantial pain but may require surgical correction because of functional problems or rapid progression. Substantial progression of a deformity by one grade or more over a six to twelve-month period may be an indication for surgical correction even if pain is not a major symptom. These conditions are uncommon in patients with idiopathic hallux valgus and typically are related to neuromuscular disease or trauma.

Selection of the proper procedure for hallux valgus surgery is critical to achieving an adequate result and durable correction of the deformity. Bunion deformity has been classified, and the algorithm developed by Mann and Coughlin defines modern decision-making in hallux valgus surgery.3 The metatarsophalangeal joint should be examined radiographically for congruency (Figs. 1-A and 1-B). If the joint is congruent, surgery must be planned so that it does not alter the congruency. When the metatarsophalangeal joint is incongruent, surgery is planned to restore joint congruency. Bunion deformity is classified as mild, moderate, or severe on the basis of the radiographic findings. Other considerations are the presence of metatarsophalangeal arthritis, hypermobility of the tarsometatarsal joint complex, and the presence of hallux valgus interphalangeus. This article is limited to a review of two procedures: bunion correction by proximal metatarsal osteotomy with distal soft-tissue rebalancing and bunion correction by arthrodesis of the metatarsophalangeal joint. Bunion correction by proximal metatarsal osteotomy with distal soft-tissue rebalancing is indicated primarily for moderate and severe bunions when the intermetatarsal angle must be corrected by >5° to achieve the desired postoperative position of <10°. The hallux valgus angle in these cases is typically >30°. Mild bunion deformities with an intermetatarsal angle of ≤14° can typically be corrected with a distal osteotomy; however, in elderly individuals or those with osteoporosis, a more proximal osteotomy may be considered to improve the available bone stock for fixation of the osteotomy site and to lessen the chances of osteonecrosis of the first metatarsal head. Fusion is most commonly done for the treatment of hallux valgus associated with arthritis or as a salvage procedure following failed previous bunion surgery and attempted arthroplasty. Other indications include neuromuscular conditions that cause spasticity, such as cerebral palsy and stroke, because of the high recurrence rate associated with standard procedures and the tendency for progression of the deformity with time.4 Primary arthrodesis may also be considered for patients with severe deformity who are at high risk for failure of an osteotomy because of osteoporosis or an inability to comply with weight-bearing and

Fig. 1-A Preoperative weight-bearing radiograph showing hallux valgus with an incongruent joint. Note the lateral subluxation of the proximal phalanx and the sesamoid complex. Fig. 1-B Weight-bearing radiograph made one year postoperatively. The intermetatarsal angle was corrected with a proximal osteotomy of the first metatarsal, and the hallux valgus angle was corrected distally with lateral soft-tissue release and medial capsular plication.
other activity restrictions during the postoperative period. The indications for these procedures are outlined in Tables I and II.

**Proximal Osteotomy with Distal Soft-Tissue Rebalancing**

Traditionally, the complication rates associated with proximal osteotomies have been higher than those associated with distal osteotomies. Many authors have noted a high prevalence of dorsal malunion following proximal metatarsal osteotomies, and this is primarily due to either loss of fixation or fracture of the metatarsal once weight-bearing is initiated. Factors that may contribute to complications include patient age, bone density, and the degree of stability of the osteotomy site. The development of newer (and more expensive) fixation devices has not necessarily improved the situation. A thorough understanding of the anatomy and biomechanics of the first ray is key to avoiding complications.

**Anatomical and Biomechanical Factors Associated with Bunion Correction Surgery**

The biomechanics of the metatarsals in the human are unique in that they are the only long bones that support load perpendicular to their axis during most phases of gait and standing. The forces acting on the first metatarsal during gait were defined in the classic article by Stokes et al., who described the factors responsible for the forces in the metatarsal during gait; these include the inclination of the first metatarsal to the ground, the lengths of the first metatarsal and phalanges, the forces generated by the plantar muscles and soft tissues through the windlass mechanism, and the weight of the individual. These factors directly affect the forces that act on the first metatarsal; namely, bending moment, shear, and axial load. For a given load, bending moment and shear forces increase with increasing metatarsal length and decreasing metatarsal inclination. Conversely, axial load increases and bending moment decreases as the metatarsal inclination increases.

Stokes et al. also calculated the effects of the tension generated by the plantar soft tissues on these forces. Force at the metatarsal head is a combination of direct force through the plantar aspect of the foot and sesamoids and joint reaction forces across the metatarsophalangeal joint. This is an intrinsic mechanism whereby part of the force of weight-bearing is transferred to axial load rather than shear and bending. Functionally, this is known as the “windlass mechanism” whereby dorsiflexion of the metatarsophalangeal joints causes increased tension in the longitudinal arch and raises the longitudinal arch of the foot. Increasing pull from the short and long toe flexors and increasing tension within the plantar fascia as the metatarsophalangeal joint rolls into dorsiflexion diminish bending moment and shear forces across the metatarsal while increasing axial load and the joint reaction force at the metatarsophalangeal joint. It should be noted that the calculations by Stokes et al. were based on an ideal model with a normal first metatarsophalangeal joint. Diminished motion at the metatarsophalangeal joint from arthritis or other pathological conditions can decrease the function of the windlass mechanism and increase shear and bending forces through the metatarsal.

The osseous anatomy must also be considered in the planning of a first metatarsal osteotomy. Metaphyseal osteotomies have the advantage of a larger surface area for osseous healing and screw fixation. Diaphyseal osteotomies involve less surface area and may be subject to higher strains due to disruption of the cortical architecture of the bone. A computerized finite-element analysis was performed by Kristen et al. using a three-dimensional model derived from digitized cadaveric data to calculate stress and strain patterns in the first metatarsal. Simulated weight-bearing loads were applied across this model from 30° to 70° of dorsal extension, and stress and strain were visualized with use of von Mises stress analyses. Stresses were concentrated along the plantar aspect of the diaphysis and at the dorsolateral diaphyseal-metaphyseal junction, and slight dorsomedial deformation occurred. The authors suggested that, when
performing an osteotomy, the surgeon should avoid violating these areas to minimize the chance for displacement.

In hallux valgus deformity, the anatomy of the first metatarsophalangeal joint becomes distorted and the subluxated joint capsule causes deforming forces that pull the hallux into further valgus and displace the first metatarsal head medially. This problem is primarily related to lateralization of the flexor hallucis longus, flexor hallucis brevis, and adductor hallucis tendons, which occurs as the joint subluxates laterally and the hallux pronates. Lateral and plantar migration of the abductor hallucis tendon and attenuation of the dorsomedial aspect of the joint capsule diminish the normal resistant forces to valgus deviation. These changes, while flexible early in the disease process, tend to become rigid and fixed as time progresses. Contractures of the lateral aspect of the joint are accompanied by permanent shortening and fibrosis of those tissues and require meticulous surgical release for adequate correction. The combination of the lateralized moment across the metatarsophalangeal joint and loss of the normal balancing structures medially create a medial deforming vector on the first metatarsal head. Saltzman et al. performed a force vector analysis of these moments in a cadaveric model and noted an increase in medializing forces on the first metatarsophalangeal joint with increasing hallux valgus and supination. Translational and derotation osteotomies had minimal effect on these vectors. These authors concluded that normalization of these vectors through soft-tissue reconstruction was as important as realignment of the osseous structures in the prevention of recurrence of the deformity in the frontal plane. In a cadaver study, Coughlin et al. demonstrated the importance of restoring the axial alignment of the osseous structures and that correction of the intermetatarsal angle with an osteotomy increased the stability of the first ray.

**Principles Governing First Metatarsal Osteotomies**

Osteotomy of the first metatarsal has been studied extensively. The geometric principles used in determining correction were explored by Kummer and Jahss. Correction of the intermetatarsal angle is increased per degree of rotation or lateral translation as the osteotomy is moved more proximally. One degree of correction is achieved on average for each millimeter of lateral translation in distal osteotomies of the metatarsal head, and only about 5° of correction can be achieved with a distal chevron-type osteotomy because further translation will result in instability of the final construct. Moving the osteotomy more proximally moves the center of rotation, and more correction is achieved per degree of rotation. Kummer and Jahss also noted that a degree of shortening and elevation of the first metatarsal head is inherent in these osteotomies. Nyska et al. performed a geometric analysis of the Ludloff, Mau, Scarf, proximal chevron, proximal crescentic, and wedge osteotomies. They noted the best correction was achieved by the Ludloff osteotomy angled 16° to the shaft; however, this caused elevation and shortening. The 8° Ludloff osteotomy provided angular corrections similar to those provided by the basilar wedge and crescentic osteotomies, but with less elevation and shortening.

The stability of first metatarsal osteotomies has been studied extensively, and these osteotomies have been classified according to their geometry (Fig. 2). Complete osteotomies are those that divide the metatarsals into two separate fragments. These osteotomies can achieve correction through multiplanar manipulation of the distal...
fragment. Incomplete opening and closing wedge osteotomies leave one cortex intact to act as a hinge, which adds stability but decreases the freedom of correction. Complete osteotomies may be classified as intrinsically stable or as intrinsically unstable (Fig. 3). Intrinsic stability is present when an osteotomy incorporates the direct transfer of deforming forces from the distal fragment into the proximal fragment by nature of its geometry. For displacement into dorsiflexion, which is the primary force that causes early failure, stability is related to the sagittal orientation of the osteotomy. A limb of the osteotomy that is oriented from proximal-plantar to dorsal-distal will impart intrinsic stability to the distal fragment. Osteotomies that are intrinsically unstable are those that have no osseous resistance to deforming forces and that are entirely dependent on internal fixation for maintenance of position during osseous healing. These include any osteotomy that has a single plane oriented from dorsal-proximal to plantar-distal or is perpendicular to the shaft of the metatarsal.

Consideration should be given to the method of fixation of the metatarsal osteotomy site. Fixation of all metatarsal osteotomy sites is recommended regardless of inherent stability or instability. Distal osteotomies have intrinsic stability of great enough magnitude that Kirschner wire fixation is often adequate. Because of the increased moment arm present with proximal osteotomies, simple Kirschner wire fixation is usually inadequate for definitive fixation. Screw fixation of osteotomy sites has been proven to be biomechanically superior to pin fixation in several studies and can provide rigid fixation of some otherwise unstable constructs. The bending strength of the screw is much greater than that of a Kirschner wire because of the screw’s increased diameter, and stability to rotation can be achieved through compression of the osteotomy site itself. The predominant mechanical disadvantage of screw fixation is the stress risers created by their application. Fracture can occur through these stress risers once weight-bearing is initiated. Use of a plate for primary fixation in bunion surgery is relatively uncommon despite mechanical and clinical data that show that they provide more stability than simple screw fixation. Technically, application of small plates designed for fracture fixation can be quite time-consuming because of the need for finely adjusted contouring of the devices. Rigid fixation can be achieved, but this technique is usually reserved for cases in which standard fixation is deemed inadequate intraoperatively because of osteoporosis or fracture. New, procedure-specific devices, including wedge plates and locking plates, have recently been marketed, but there is no published clinical data supporting their use and justifying their expense.

Proximal Crescentic Osteotomy
To perform a proximal crescentic osteotomy, as popularized by Mann et al., the surgeon utilizes a curved oscillating saw to create an osteotomy from the proximal-dorsal aspect of the metaphysis to the plantar aspect of the proximal part of the diaphysis. The intermetatarsal angle is corrected by rotating the distal fragment in the trough created in the base of the first metatarsal. Rather than simply rotating in a single plane, the distal fragment rolls in the inclined trough created by the saw blade, and medial or lateral angulation of the osteotomy will cause elevation or depression of the metatarsal head, respectively, as the distal fragment is rotated laterally.

Some of the proximally based osteotomies currently in use for correction of varus angulation of the first metatarsal associated with hallux valgus.
of the fixation screw allowing loss of correction and elevation of the distal fragment. Regardless of the fixation technique, the proximal crescentic osteotomy remains one of the most unstable first metatarsal osteotomies. Biomechanical studies have shown the loads to failure following a crescentic osteotomy to be lower than those following Ludloff, proximal closing wedge, Scarf, and Mau osteotomies. Fatigue studies have shown stability to cyclic loading after crescentic osteotomies to be relatively inferior as well. Modifying this osteotomy with a proximal crescentic shelf (a dorsal dome cut and an inferior oblique cut) does not appear to improve the relative loads to failure. Stability can be improved by fixing the osteotomy site with a new procedure-specific plate.

Clinical data have varied widely among studies of the proximal crescentic osteotomy. Brodsky et al. prospectively evaluated plantar pressure measurements at a mean of twenty-nine months after proximal crescentic osteotomy in thirty-two patients. Twelve patients had first metatarsal elevation of >2 mm, and a transfer lesion developed under the second metatarsal head in five of those patients. These authors found control of the crescentic osteotomy to be unpredictable in the sagittal plane. In a prospective, randomized study, Easley et al. compared proximal chevron osteotomy with proximal crescentic osteotomy for hallux valgus correction in eighty-four feet followed for a minimum of one year. While the clinical results were good in both groups, the sites of the proximal chevron osteotomies healed faster and a higher prevalence of dorsal malunion was seen in the group treated with the proximal crescentic osteotomy. Thordarson and Leventen reported the results of thirty-three proximal crescentic osteotomies done to treat hallux valgus deformity. After a minimum of two years of follow-up, these authors reported good clinical results but noted an average dorsiflexion malunion of 6.2° through the osteotomy site. Staple fixation was noted to be more unstable and to result in more dorsiflexion. In a retrospective study of fifty patients who had undergone hallux valgus correction with either a proximal chevron or a proximal crescentic osteotomy, Markbreiter and Thompson noted equivalent good results in the two groups. Okuda et al. reported excellent correction of radiographic parameters and good clinical results in a study of forty-seven feet followed for an average of forty-eight months after proximal crescentic osteotomy done to treat hallux valgus. Okuda et al. also reported that the one-year results of this procedure were predictive of the three-year results.

**Proximal Chevron Osteotomy**

The distal chevron osteotomy was first described by Austin and Leventen and refers to a horizontally directed “v” pattern that imparts inherent stability to the distal fragment. The chevron osteotomy pattern has also been used in the proximal part of the metatarsal for correction of moderate and severe metatarsus primus varus. Biomechanically, the osteotomy site derives stability as forces are directly transferred from the distal fragment to the proximal fragment through the dorsal shelf. The osteotomy should be directed with the apex distal, as directing the apex proximally creates a stress riser in the proximal fragment adjacent to the articular surface and may result in a fracture into the first tarsometatarsal articulation. Directing the apex distally moves the stress riser distally, and into the distal fragment, thus diminishing the moment arm and eliminating the risk of intra-articular fracture should failure occur. The osteotomy site is fixed from plantar to proximal-dorsal, which provides compression on the tension side of the osteotomy. The screw should not be applied from dorsal to plantar as that concentrates stresses at the apex of the osteotomy and predisposes the bone to fracture under low loads.

The chevron osteotomy has been studied biomechanically to determine its corrective potential and stability. Nyska et al. found that less correction was achieved with the proximal chevron osteotomy than with the Ludloff, crescentic, and closing wedge osteotomies; however, correction was achieved by lateral translation only, without rotation. According to Kummer’s analysis, the proximal chevron osteotomy can achieve high levels of correction if the distal fragment is rotated with translation, as is commonly done in clinical practice. McCluskey et al. compared stiffness and load to failure between cadaveric models of proximal crescentic and proximal chevron osteotomies and noted greater stability with the proximal chevron osteotomy. In a study of the Ludloff, Scarf, and proximal chevron osteotomies in cadaveric preparations, Trnka et al. noted less stability with the proximal chevron osteotomy than with the others tested except for the proximal crescentic osteotomy; however, the fixation screw was placed dorsally rather than plantarly, which allows distraction of the plantar cortex during loading. We think that this study demonstrated the importance of using a plantar-based screw rather than identifying an inherent problem with the osteotomy. Acevedo et al. studied five osteotomies in a cyclic loading model and found the site of the proximal chevron osteotomy to be stronger than all others tested in both Sawbones and cadaveric models with a screw placed from plantar to dorsal.

Correction of hallux valgus with the proximal chevron osteotomy has reportedly yielded good clinical results with few complications. My colleagues and I previously reported on forty-three patients who had undergone surgical correction of hallux valgus with a proximal chevron osteotomy for correction of the intermetatarsal angle. We found no malunions, and the American Orthopaedic Foot and Ankle Society (AOFAS) score improved significantly. Sammarco and Russo-Alesi reported the results of seventy-two consecutive procedures after an average duration of follow-up of forty-one months. Again, dorsal malunion was not observed, and they noted improvement in the AOFAS scores. Easley et al. reported good clinical results after both the proximal chevron and the proximal crescentic osteotomy but noted a lower
complication rate and faster healing of the osteotomy site after the proximal chevron osteotomy\(^\text{7}\). Those authors thought that improved stability of the osteotomy site was responsible for these outcomes. Markbreiter and Thompson reported the results in fifty feet in which either a proximal crescentic or a chevron osteotomy had been done for the correction of hallux valgus\(^\text{37}\). Excellent results were reported in both groups, but the proximal chevron osteotomy was thought to be technically easier to perform because of its inherent stability.

**Scarf Osteotomy**

The Scarf osteotomy was introduced to the surgical community by Zygmunt et al.\(^\text{38}\), and its use for the correction of moderate and severe metatarsus varus has steadily increased in Europe and elsewhere. As originally described, the osteotomy is horizontal in the distal part of the diaphysis, with a limb exiting superiority at the distal end of the metatarsal and a limb exiting proximally at the midpart of the diaphysis. The osteotomy provides tremendous inherent stability to displacement as a result of the long dorsal shelf afforded with the horizontal saw cut. The originally described osteotomy achieved correction by lateral translation of the distal fragment. Barouk\(^\text{40}\) and Weil\(^\text{41}\) proposed numerous modifications, including shortening or shortening of the metatarsal, rotation of the distal fragment, raising or lowering of the metatarsal head, and correction of the distal metatarsal aricular angle by rotation of the distal fragment. Nyska et al. noted less correction of the intermetatarsal angle with the Scarf osteotomy than with the Ludloff, closing wedge, and crescentic osteotomies\(^\text{39}\).

Barouk’s modifications extend the osteotomy proximally, which allows greater correction of the intermetatarsal angle but also increases the moment arm on the dorsal shelf, and fracture of the metatarsal has been reported as a complication\(^\text{41}\). Trnka et al. performed static load-to-failure testing in cadavers in which the Scarf osteotomy had been performed and compared the results with those after five other osteotomies of the first metatarsal\(^\text{43}\). They found that the osteotomy site was stable and concluded that it should be acceptable for patients with normal bone density to immediately bear weight in a postoperative shoe. In their study, however, the osteotomy did not include the proximal extension that is currently used to achieve greater corrections of the intermetatarsal angle. Acevedo et al. performed cyclic loading of the sites of Scarf osteotomies in Sawbones models and found substantial problems with fracture of the metatarsal at the proximal part of the dorsal limb\(^\text{51}\). There may also be problems with positioning of the final construct as a result of the diaphyseal nature of the osteotomy. Since the osteotomy divides the metatarsal horizontally along its length, the distal fragment may rotate axially as the medial cortex of the distal fragment slides into the medullary canal of the proximal fragment, causing undesired elevation and supination of the distal articular surface (so-called troughing)\(^\text{47}\).

Clinical studies of the Scarf osteotomy have demonstrated mixed results. Aminian et al. evaluated the results of twenty-seven consecutive Scarf osteotomies at an average of sixteen months\(^\text{49}\). The complication rate was low, and the AOFAS scores improved. Fracture of the metatarsal was not noted. Jones et al. reviewed the results at a mean of twenty months after thirty-five Scarf osteotomies done for hallux valgus correction\(^\text{31}\). Excellent correction was achieved, as demonstrated radiographically and clinically, and pedobarographic measurements made after more than one year were noted to be normalized. One intraoperative fracture was noted, but no postoperative stress fractures occurred. The authors concluded that the procedure is effective, with reproducible results, for correction of moderate and severe deformity. Coetzee reported less promising clinical results after twenty Scarf osteotomies\(^\text{52}\). Malunion from troughing, malrotation, and fracture were responsible for major complications despite postoperative immobilization in a short leg cast for six weeks. Forty-five percent of the patients were dissatisfied with the result of the surgery at one year. At an average of twenty-two months following eighty-four Scarf osteotomies, Crevoisier et al. noted improvement in radiographic parameters and AOFAS scores, although 11% of the patients were not satisfied and required additional procedures\(^\text{15}\). Problems with the fixation of the osteotomy site and stiffness of the first metatarsophalangeal joint occurred. Fracture was not reported.

**Ludloff Osteotomy**

The metatarsal osteotomy described by Ludloff extends from the dorsal aspect of the metaphysis proximally to the plantar aspect of the diaphysis distally. Despite the inherent instability of its geometry, the Ludloff osteotomy affords a broad surface for screw fixation, which substantially increases the relative strength of the construct. Some biomechanical studies have shown the load-to-failure values after the Ludloff osteotomy to be superior to those after the proximal chevron or crescentic osteotomies. Lian et al. noted that a Ludloff osteotomy site fixed with two screws was 82% stronger than the site of a crescentic osteotomy fixed with a single screw\(^\text{2}\). Using a cadaver model, Trnka et al. noted that, compared with five other constructs, the Ludloff osteotomy provided excellent stability and stiffness\(^\text{47}\). Acevedo et al. noted that the Ludloff osteotomy resulted in excellent fatigue endurance under cyclic loading in both a cadaver and a Sawbones model\(^\text{15}\). The osteotomy site is fixed with two screws, which compress the proximal and distal fragments in diaphyseal bone. When loaded to failure, the osteotomy site fails either by fracture of the metatarsal at the proximal screw head or from pullout of the screw threads. In a Sawbones model, Nyska et al. noted that the sagittal inclination of the Ludloff osteotomy plays a large role in the amount that the intermetatarsal angle can be corrected\(^\text{42}\). A 16° angulation allowed the most correction but also caused shortening and elevation of the first metatarsal head, whereas an 8°
Modification of the Mau osteotomy moves the osteotomy proximally into the metaphysis and the proximal part of the diaphysis of the bone. This allows greater correction of the intermetatarsal angle and provides more predictable healing. (Reprinted, with permission, from: Sammarco VJ. Surgical strategies: Mau osteotomy for correction of moderate and severe hallux valgus deformity. Foot Ankle Int. 2007;28:857-64.)

Original Mau

Modified Mau

Fig. 4

Modification of the Mau osteotomy moves the osteotomy proximally into the metaphysis and the proximal part of the diaphysis of the bone. This allows greater correction of the intermetatarsal angle and provides more predictable healing. (Reprinted, with permission, from: Sammarco VJ. Surgical strategies: Mau osteotomy for correction of moderate and severe hallux valgus deformity. Foot Ankle Int. 2007;28:857-64.)

angulation afforded correction comparable with that provided by other proximal osteotomies without substantial shortening or elevation. Beischer et al. noted that 10° is the ideal orientation for correction without shortening or elevation56.

The Ludloff osteotomy with screw fixation for correction of hallux valgus has had excellent clinical results to date. Chiodo et al. reviewed the results of seventy procedures for correction of moderate and severe hallux valgus55. After an average duration of follow-up of thirty months, the satisfaction rate was 94% and few complications had developed. The authors noted that fixation was adequate in two patients who had required a steeper osteotomy in the sagittal plane. These two osteotomy sites healed with callus formation and slight shortening, and elevation of the first metatarsal was noted on the final follow-up radiographs. Improved fixation methods may negate these issues55-57. Petroutas and Trika reported the results in seventy patients at a minimum of two years after they had undergone a Ludloff osteotomy for hallux valgus repair58. Radiographic measurements had improved. Evaluation with a 4-point clinical scale showed that 81% of the patients were satisfied or very satisfied, but 5% had continued pain.

Mau Osteotomy

The osteotomy described by Mau and Lauber is an oblique diaphyseal osteotomy that is directed from proximal-plantar to distal-dorsal59. With this procedure, as originally described, the angular correction that can be achieved by rotation of the distal fragment is less than that possible with the more proximal osteotomies. Nyska et al. showed that both the 8° and the 16° Mau osteotomies provide angular correction without substantial elevation but the correction is greater with the Ludloff osteotomy, probably because of the more proximal center of rotation56.

Although clinical comparison studies of the Mau osteotomy are lacking, mechanical testing has shown that it provides superior stability. Both static and dynamic fatigue studies have shown Mau osteotomy sites to be more stable than the sites of other proximal and shaft osteotomies, including the Scarf and the Ludloff procedures53-55. In one clinical study with a short follow-up (eighteen weeks), Neese et al. noted a low prevalence of shortening and mal-union60. More long-term prospective trials are needed in order to determine the clinical efficacy of the procedure. We modified this osteotomy with a second cut through the plantar metaphyseal cortex, which allows it to be extended more proximally in order to gain more substantial correction while taking advantage of its superior biomechanical properties (Fig. 4). A detailed description of our preferred surgical technique for the modified Mau osteotomy was recently published61.

Arthrodesis of the Hallux Metatarsophalangeal Joint for Treatment of Hallux Valgus

Arthrodesis of the first metatarsophalangeal joint for the treatment of hallux valgus is a salvage procedure that is primarily used when more standard bunion correction procedures will not provide durable results or pain relief or have a high risk of early failure. Coughlin et al. reported the results of arthrodesis for the treatment of twenty-one moderate or severe cases of idiopathic hallux valgus62. Arthrodesis was considered for moderate bunions if degenerative changes of the first metatarsophalangeal joint were seen radiographically or if there was advanced deformity of the lesser metatarsophalangeal joints. Primary arthrodesis was considered for severe deformity in which the hallux valgus angle was >40°, regardless of the presence of degenerative changes or involvement of the lesser metatarsophalangeal joints. Three nonunions occurred; two were asymptomatic and one was revised to a fusion, which was successful. All patients were considered to have a good or excellent result at the time of final follow-up, at an average of
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8.2 years (range, twenty-four to 272 months). Similarly, Riggs and Johnson noted that in most cases arthrodesis for the treatment of hallux valgus was successful at the time of short or long-term follow-up (range, one to fifteen years), with resolution of pain in 92% of patients. Overall satisfaction was rated as 86%, although hardware frequently had to be removed (in 30% of the cases) and the rate of complications, including infection and failure, was 8%. Tourné et al. suggested that arthrodesis of the metatarsophalangeal joint was a predictable method for managing hallux valgus deformity in elderly individuals. Arthrodesis should also be considered the primary treatment for hallux valgus in patients with clinically relevant osteoarthritis or inflammatory arthritis of the metatarsophalangeal joint, as reconstructive procedures designed to restore axial alignment do not address the underlying loss of cartilage or destruction of the normal supporting structures. Hallux valgus associated with spasticity, as is commonly seen in patients with cerebral palsy, has a high recurrence rate when treated with standard techniques. Davids et al. reviewed twenty-six cases of hallux valgus managed with arthrodesis of the first metatarsophalangeal joint in children with cerebral palsy. They noted high satisfaction among both patients and caregivers, with excellent radiographic and clinical correction. They recommended fusion for primary treatment in children with a spastic foot deformity.

Salvage following failed bunion surgery is technically demanding, and attempts at revision are associated with increased failure rates. If a specific cause for the failure can be identified, it may be possible to revise the previous bunion surgery successfully, but arthrodesis can usually be used for salvage in difficult cases in which nonunion, osteonecrosis, or extensive arthritis is present. Grimes and Coughlin reported thirty-three cases in which a failure of hallux valgus surgery was treated with arthrodesis of the metatarsophalangeal joint. Four nonunions resulted, three of which were asymptomatic. Radiographic correction was excellent in all cases. Although the patients with failed bunion surgery had improvement following the arthrodesis, the final results were worse than the final results of successful primary bunion surgery. Kitaoka and Patzer noted that, compared with successful primary procedures, arthrodeses done to revise failed bunion surgery resulted in similar improvements in scores but less patient satisfaction.
These authors also observed that the results of the arthrodeses were slightly better than those of resection arthroplasties for salvage following failed bunion surgery. Myerson et al. described staged arthrodesis for the management of failed bunion surgery associated with osteomyelitis. Several studies have shown that arthrodesis of the first metatarsophalangeal joint will correct an even substantially increased inter-metatarsal angle, and metatarsal osteotomy is typically not necessary (Figs. 5-A and 5-B).

Biomechanical studies may help surgeons to select the appropriate technique for arthrodesis of the metatarsophalangeal joint. A more stable construct theoretically allows a higher fusion rate and permits earlier weight-bearing. Joint preparation is usually done through a dorsal or medial incision. Preparation with matched cuts made with a straight or crescentic saw or a “cup-in-cone” arthrodesis bed prepared with a high-speed burr or with matched conical reamers has been reported. In cadaveric models of arthrodeses of the first metatarsophalangeal joint, Curtis et al. noted that machined conical reaming followed by fixation with interfragmentary screws provided more strength than preparation with matched planar cuts regardless of the fixation technique, including the use of a dorsal plate. In a study involving mechanical testing of five fusion models in cadavers, Politi et al. similarly noted that conical reaming provided improved strength compared with that provided by planar excision. The strongest construct in this study was created by matched conical reaming and use of a dorsal compression plate and a single oblique lag screw. A review of the available biomechanical data shows plate-and-screw fixation to be the most stable, followed by interfragmentary or intramedullary screw fixation, both of which are superior to compression plate and a single oblique lag screw. The strongest construct in this study was created by matched conical reaming and use of a dorsal compression plate and a single oblique lag screw. A review of the available biomechanical data shows plate-and-screw fixation to be the most stable, followed by interfragmentary or intramedullary screw fixation, both of which are superior to compression staples.

**Authors’ Preferred Technique: Cup-in-Cone Arthrodesis with Crossed Screws**

Our preferred technique is based on an attempt to balance the available biomechanical data with current constraints imposed by implant cost and the operative time required for the procedure. The costs of specialized plates, compression staples, and cannulated screws must be balanced against the surgeon’s ability to achieve successful results with less expensive, generic solid screws and fracture plates. It has been our experience that even the use of precontoured plates substantially increases operating room time and can be associated with incorrect alignment of the arthrodesis. At least three commercially manufactured conical reaming systems are currently available for this procedure, but they must usually be rented or purchased or are paired with an implant system. Surgeons must take care when learning to use these systems as we have seen fractures of both the metatarsal head and the proximal phalanx with use of these reamers. The cup-in-cone preparation described by Myerson is done through a dorsal incision and with use of a standard inexpensive 5-mm burr (Fig. 6). The first metatarsal head is denuded of any remaining cartilage and subchondral bone until the underlying cancellous bone is exposed. The proximal phalanx is similarly prepared to create the recipient “cup,” following removal of cartilage and subchondral bone. Final adjustments are made with the burr for positioning, and the metatarsophalangeal joint is stabilized with a Kirschner wire and checked for alignment. The arthrodesis site can be secured with two 4.0-mm cannulated or noncannulated cancellous screws. If stability is poor secondary to osteoporosis or bone loss, a contoured one-third tubular plate will substantially improve fixation.

Final positioning should consist of 10° to 20° of hallux valgus, but care must be taken to allow clearance of the second toe by 1 to 2 mm. Dorsiflexion should be 15° to 30° from the first metatarsal, or 5° to 10° from the floor. A good way to assess the final position intraoperatively is to press the foot flat on a sterile plate (an instrument case lid) (Fig. 7). The hallux should not impinge on the second toe, rotation should be neutral with the axis of the floor, and there should be approximately 5 mm of space between the plate and the pulp of the hallux. Malpositioning is the most...
common complication associated with this surgery. Plantar flexion and malrotation are associated with secondary arthritis of the interphalangeal joint. Excessive dorsiflexion may cause difficulty with shoe-wear and transfer lesions at the lesser metatarsophalangeal joints. After the surgery, the patient wears a postoperative shoe with weight-bearing on the heel for four to six weeks or until fusion is evident radiographically.

**Overview**

Hallux valgus correction with distal soft-tissue release and proximal metatarsal osteotomy is the procedure of choice for most patients with a symptomatic moderate or severe hallux valgus deformity. Complications can be avoided by selecting a procedure that provides adequate correction of the intermetatarsal angle and ensuring proper balancing of the first metatarsophalangeal joint through lateral soft-tissue releases and medial joint plication. Arthrodesis of the first metatarsophalangeal joint should be considered when revision of failed bunion surgery is planned or when degenerative joint disease is present. Arthrodesis should also be considered if the likelihood of failure of a standard bunion procedure is high, such as in elderly individuals with osteoporosis, patients with severe deformity and substantial involvement of the lesser metatarsophalangeal joints, and those with neuromuscular spasticity.

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