Current Trends in Fixation Techniques

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KEYWORDS

• Hallux valgus • Forefoot malalignment • Fixation • Osteotomy • Arthrodesis

KEY POINTS

- The correction of all components of a hallux valgus deformity is of paramount importance for treatment success.
- Reliable fixation is very important for maintaining surgical corrections.
- Advances in internal fixation are a major factor in improved surgical results.

INTRODUCTION

Hallux valgus is the most common deformity in the adult forefoot, and, for a long time, its correction was considered a challenge due to the high frequency of treatment failures. Any hallux valgus deformity involves varying degrees of varus of the first metatarsal, valgus of the hallux, and pronation of the first ray. The rotational component (pronation), which has been studied more intensely in recent years, is present in up to 87% of hallux valgus cases.[1] First-ray realignment osteotomies have undoubtedly been responsible for more complete corrections and lower rates of deformity recurrence. Since realignment osteotomies became established in hallux valgus treatment, better fixation methods have developed that maintain surgical corrections, accelerate consolidation, and allow earlier rehabilitation.

A complete understanding of the deformity is of utmost importance for determining the appropriate type of surgery. Choosing an ideal technique for a particular deformity involves analyzing several parameters. In the same patient, different techniques are frequently indicated for each foot. At least one surgical technique exists for each type of hallux valgus. Most of the corrective techniques can be classified as distal osteotomy (including those of the proximal phalanx and the head and neck of the first metatarsal), diaphyseal osteotomy, proximal osteotomy, metatarsocuneiform joint

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arthrodesis, and metatarsophalangeal arthrodesis. Fixation techniques and implants differ for each procedure.

The main complications of hallux valgus surgery are related to the osteotomy's location, its inherent stability, the alignment obtained, and the type of fixation. This article focuses primarily on the last item.

OSTEOTOMY OF THE PROXIMAL PHALANX FOR HALLUX VALGUS

Osteotomy of the proximal phalanx, more commonly called the Akin procedure, although may be performed alone in cases of interphalangeal hallux valgus, is usually associated with a more proximal procedure, first metatarsal osteotomy or metatarsocuneiform joint arthrodesis. It is estimated that 10% of surgeons use Akin osteotomy to supplement distal osteotomy of the first metatarsal, whereas 30% use it when correcting major deformities.[2,3] The technique can add angular and rotational correction to the procedure, and the degree of additional correction depends on the size of the resected wedge. Although a single screw is the most commonly used method of fixation, crossed screws, Kirschner wires, staples, and binders are also recommended. Liszka and Gadek investigated the influence of fixation type on the results of osteotomy of the proximal phalanx in 138 patients and found no significant differences in the degree of angular correction; American Orthopaedic Foot and Ankle Society (AOFAS) score improvement; or incidence of complications between groups of patients fixed with staples, screws, or transosseous suture stabilization. These investigators concluded that the suture fixation technique is as good as the more expensive (and potentially more complicated) techniques.[4]

Complications often arise during traditional Akin technique when the saw blade reaches the lateral cortical margin and completes the osteotomy, making fixation a challenge. In the author's experience, performing an oblique osteotomy, from the proximal medial to the distal lateral, decreases the chance of this complication, making the correction less abrupt while still facilitating fixation, because it allows the screw to cross the osteotomy line almost perpendicularly (Fig. 1).

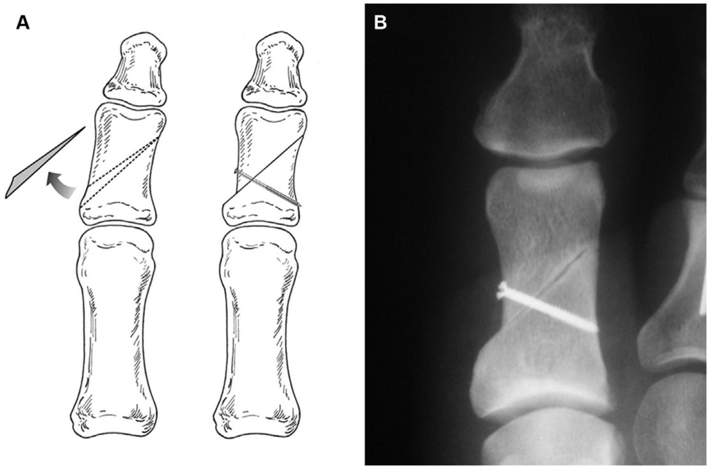

Fig. 1. (*A*) Modified Akin osteotomy. The obliquity of the cut increases the osteotomy area, smoothing the correction, allowing almost perpendicular screw fixation, and possibly speeding bone healing. (*B*) Radiograph of the phalanx after modified Akin osteotomy. (*From* Sanhudo JA. Clinical tip: modified Akin osteotomy. Foot Ankle Int. 2005; 26(10): 901-902; with permission.)

DISTAL FIRST METATARSAL OSTEOTOMIES

Distal first metatarsal osteotomies are indicated for mild deformities, but the limits of the angle used to classify the deformity as mild are highly debated among specialists. When choosing the most appropriate technique, the angulation between the first and second metatarsals, the angle between the first metatarsal and the proximal phalanx, and the distal articular angle of the metatarsal are usually taken into consideration. However, studies show low intra- and interobserver agreement regarding the measurement of these variables, and, moreover, these measurements do not take into account the thickness of the first metatarsal, foot length, or pronation of the first ray, factors that influence the magnitude of the variables and deformity correction.[5,6]

Distal chevron osteotomy is the most common procedure performed by specialists to correct mild deformities in the foot and ankle.[2] Internal fixation was not performed in the first publications on the chevron technique.[7,8] To accelerate consolidation and decrease the risk of correction loss, implants have been gaining acceptance; internal fixation is now preferred by most investigators, despite the intrinsic stability of this type of osteotomy. The most commonly used implant for distal osteotomy fixation is a noncannulated headed screw.[2]

However, Crosby and Bozarth compared the results of 3 groups of distal chevron osteotomy patients: without fixation, Herbert screw fixation, and temporary Kirschner wire fixation. No differences were observed in the results or degree of satisfaction among the patients, although the costs and surgical time were higher in the Herbert screw group than the other 2 groups.[9] Trost and colleagues[10] found no difference in distal chevron osteotomy fixation stability between fixation with a 3.5-mm cortical screw and fixation with two 1.6-mm Kirschner wires. In a retrospective study, Armstrong also found no differences between distal chevron osteotomy patients with Kirschner wire fixation or cortical screw fixation.[11]

The boldness of some investigators and the possibility of more robust internal fixations have allowed osteotomies in the distal region to achieve greater correction due to the greater displacement of the distal fragment, which not only allowed the correction of mild deformities but also contradicted the historical concept that larger deformities must be treated with proximal osteotomies.[12–15] As recommended by Sanhudo, modifying the distal chevron osteotomy angle from 60° to 30° makes the upper arm of the osteotomy reach the proximal metaphyseal region, increasing the contact area between the fragments and the procedure's stability. In fact, this modification transforms a distal osteotomy into a distally centered diaphyseal osteotomy (**Fig. 2**).[12,13] Using this modified distal chevron technique on 50 feet, Sanhudo obtained hallux valgus angle (HVA) and intermetatarsal angle (IMA) corrections of 22.70° and 10.40°, respectively, with a high degree of patient satisfaction.[13] Murawski and colleagues obtained a similar correction with a similar technique and a 60% mean lateral translation of the metatarsal head.[14] Palmanovich and Myerson[15] described the correction of major deformities using the same principle of increased translation of the distal fragment, but with transverse osteotomy and fixation with an intramedullary fixation plate (Orthohelix Mini MaxLock Extreme ISO).

PROXIMAL OSTEOTOMIES OF THE FIRST METATARSAL

Because the bone mineral density of the proximal region of the first metatarsal is less than that of the distal region, osteotomies in this region require more robust internal fixation to minimize correction losses, malunion, and/or recurrence of the deformity.

Many orthopedists perform medial opening wedge osteotomies in the region of the metatarsal base. The technique, which was described in 1960 for treating hallux

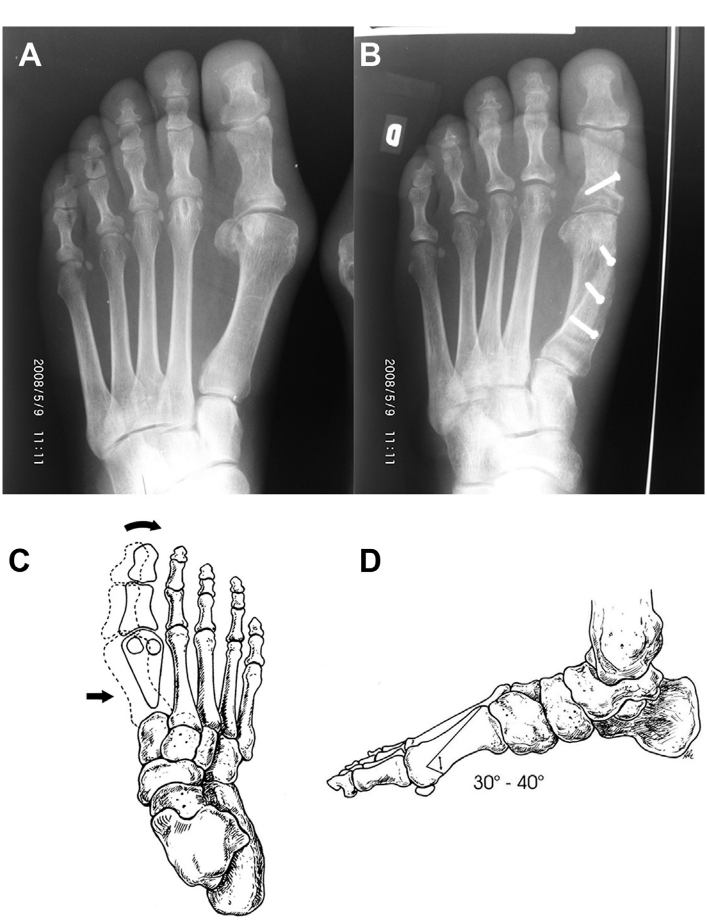

Fig. 2. (*A*, *B*) Radiographic examinations of severe hallux valgus deformity corrected with the modified chevron technique. The apex is distal, but the upper arm of the osteotomy reaches the proximal metaphysis, traversing the entire diaphysis. (*C*, *D*) The technique. ([*C*,*D*] *From* Sanhudo JA. Correction of moderate to severe hallux valgus deformity by a modified chevron shaft osteotomy. Foot Ankle Int. 2006; 27(8):581-5; with permission.)

valgus in adolescents, has recently gained popularity with the advent of more efficient internal fixation and, consequently, more predictable results.[16] Smith and colleagues[17] published the results of 49 metatarsal osteotomies performed to correct moderate and severe hallux valgus deformity using wedge plate fixation. The mean correction of the IMA was 7°. Complications occurred in 14 cases, including hardware irritation, nonunions, and delayed unions.

Proximal chevron osteotomy is inherently unstable because the angulation at the osteotomy site causes a medial gap, and if supination is added to the distal fragment for rotational correction, the gap becomes even wider. The long lever arm at the level of the osteotomy is also a cause for concern, because a loss of correction during the initial recovery period is not uncommon with this type of procedure. Park and colleagues[18] found a 4.6-fold higher recurrence rate in wedge plate fixation than Kirschner wire fixation (33.3% vs 9.8%). The investigators ascribed the higher failure rate of plate fixation to the fact that they were not premolded.

Bending the plate prevents some locked screws from being used and correction loss can occur when the plate is compressed close to the bone. This risk can be minimized by using premolded plates or a more recent development: customized implants.

Based on the high frequency of a rotational component in the first ray, Wagner and colleagues[19,20] developed a proximal osteotomy that can correct deformity in the coronal and rotational planes, that is, metatarsus varus and pronation of the first ray. The investigators published the results of proximal rotational metatarsal osteotomy for hallux valgus in 30 feet, with a mean prospective follow-up of 1 year. The mean IMA improved from 15.5° before the procedure to 5° at follow-up, whereas the mean HVA improved from 32.5° to 4°. Lower Extremity Functional Scale scores improved 17 points. All of the patients were satisfied and no recurrence of the deformity or other complications was observed.[21] The technique requires consulting a specially developed table to determine the angulation of the osteotomy, which is performed using specially developed guides. Fixation involves a wedge plate and lag screw, which, according to the investigators, provides great stability.

Wu and Lam used osteodesis without osteotomy to treat mild to moderate hallux valgus.[22] The procedure consisted of realigning the first and second metatarsals with double stranded # 1 PDS sutures (Ethicon Inc., Somerville, NJ, USA). Opposing cortices of the first and second metatarsal were fish-scaled with an osteotome to induce postoperative fibrous bonding ingrowth. In 110 feet treated with the technique, the investigators obtained a mean IMA decrease from 14° to 7° and a mean HVA decrease from 31° to 18°. The patients' mean AOFAS score improved from 68 points before surgery to 96 points at a mean follow-up of 12 months, but a fatigue fracture in the second metatarsal occurred in 5% of the cases. Using a similar principle, Cano-Martínez and colleagues[23] described correcting hallux valgus by realigning the first and second metatarsals with a mini TightRope. In a sample of 36 feet, the AOFAS score improved from a mean of 47.7 points before surgery to a mean of 88 points after 24 months of follow-up. The mean IMA and HVA corrections were 4.8° and 10°, respectively. As in Wu and Lam's study, stress fractures of the second metatarsal were a problem, occurring in 5.5% of the cases.

DIAPHYSEAL OSTEOTOMIES

In a recent study, Ludloff diaphyseal osteotomy was found to be the most commonly performed orthopedic procedure to correct severe deformities.[3] Because of its low intrinsic stability, the technique requires efficient internal fixation to ensure stability in the correction.

The scarf osteotomy is another popular diaphyseal osteotomy for correcting moderate to severe hallux valgus. The results of the technique are hampered by a high incidence of complications, with the most common being the collapse of the correction, called troughing. This complication occurs due to loss of cortical contact after correction, which occurs in the scarf osteotomy but not in the modified chevron osteotomy (**Fig. 3**). Murawski and colleagues[24] developed a modified scarf osteotomy to reduce this complication, which occurs in up to 35% of the cases.[25,26] The modified procedure, called rotational scarf osteotomy, aims to maintain cortical contact between the fragments after correcting the deformity. Through this technique, the investigators obtained an IMA reduction from 18° to 8°, HVA improvement from 37° to 12°, and, most importantly, without the occurrence of troughing.[24]

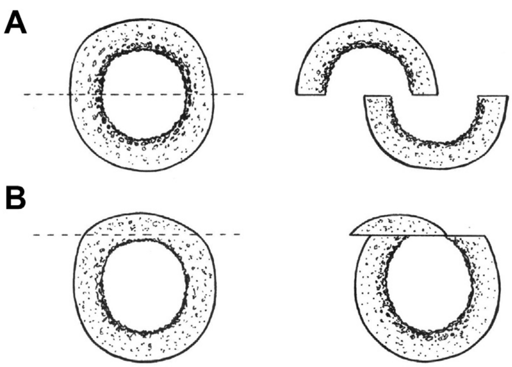

Fig. 3. An axial cut of the metatarsal after correcting the deformity, comparing classic scarf osteotomy (*A*) and modified chevron osteotomy (*B*). Note that cortical contact is lost after scarf osteotomy, a factor that predisposes to troughing.

Jung and colleagues[27] published a study demonstrating the mechanical benefit of supplemental osteotomy fixation with 2 Kirschner wires introduced longitudinally at the first metatarsal. In biomechanical tests on cadavers, the investigators observed an increase in load to failure in Ludloff and proximal crescentic metatarsal osteotomies with 2 supplementary 0.062-inch Kirschner wires compared with fixation with screws only. In the authors' experience, using a 1.5-mm Kirschner wire longitudinally in modified chevron osteotomies, especially in patients with low bone density, adds great stability to the fixation and, because of the resilience of the Kirschner wire, the alignment of the first ray is maintained even in cases that develop a fracture at the level of the diaphysis due to exaggerated effort in the postoperative period (**Fig. 4**).

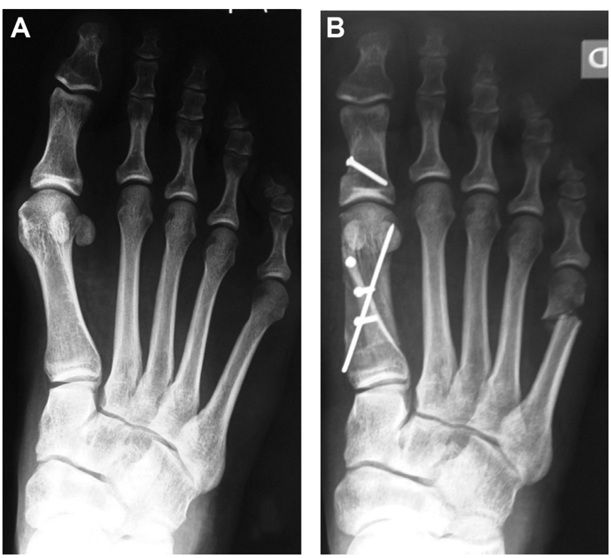

Fig. 4. (*A*) Severe hallux valgus deformity. (*B*) Supplemental fixation with longitudinal Kirschner wire adds rigidity to the hallux valgus correction, decreasing the chance of fracture in the metatarsal. Sponsel osteotomy of the fifth ray was also performed.

METATARSOPHALANGEAL ARTHRODESIS

Metatarsophalangeal joint (MTPJ) arthrodesis is an alternative treatment of severe, recurrent, or arthritic hallux valgus, especially in older and less active patients. The technique is also a great option for patients with neurologic disorders, such as cerebral palsy or stroke sequelae. The success of the procedure depends on 4 main factors: joint preparation, arthrodesis position, fixation method, and postoperative management. The ideal procedure, in turn, should be reproducible, involving a high rate of consolidation and a low incidence of complications. Several studies have found that MTPJ arthrodesis effectively corrects deformities, including the IMA, without the need for osteotomy at the base of the first metatarsal.[28–34]

Combining a dorsal plate and a compression screw has already shown greater stability than other forms of fixation for MTPJ arthrodesis.[35] Pinter and colleagues[36] compared the results of 36 patients who underwent MTPJ arthrodesis of the hallux whose fixation consisted of a dorsal plate plus a lag screw versus 63 patients who underwent the same procedure but received only a dorsal plate. The fusion rate was 89% in the dorsal plate plus lag screw group and 84% in the dorsal plate only group, which was not considered significantly different. However, the mean change in dorsiflexion angle in the immediate postoperative period versus the end of follow-up was much lower in the dorsal plate plus lag screw group (0.57°vs 6.73°). This difference was significant and demonstrated greater sagittal stability in the lag screw group.

Hunt and colleagues[37] used biomechanical testing to compare the feet of cadavers whose MTPJ was fixed with a compression screw and either a locked or an unlocked dorsal plate. The locked plate group had greater mean stiffness and demonstrated less plantar gapping during fatigue endurance testing. No significant difference in load to failure was observed between the 2 groups. The same investigators observed higher nonunion rates (23%) in 73 patients who underwent MTPJ arthrodesis with a precontoured locked titanium plate than in 107 patients who underwent the same procedure with a nonlocked stainless steel plate (11% nonunion rate), possibly due to exaggerated stiffness from the wedge implant and the lack of contact or compression at the bone interface.[38] Studies have hypothesized that the rigidity provided by wedge plate fixations suppresses interfragmentary mobility at one level, which impairs consolidation.[39,40] This scenario is even more likely in cases of wedge plate fixation where compression between the fragments and/or bone contact was insufficient.

In these investigators' experience, for patients with severe hallux valgus with or without arthrodesis, MTPJ arthrodesis fixed with cerclage or crossed Kirschner wires has presented high levels of radiographic consolidation and patient satisfaction. In 23 patients (29 feet) who underwent the procedure, the fusion rate was 100%. After an average follow-up of 35 months, the AOFAS score improved from a mean of 27.3 points before the procedure to 77.3 points at follow-up, showing an improvement of 50 points. A secret to the procedure in such cases is preserving the integrity of the adductor tendon, because the resilience of the hallux valgus deformity associated with intramedullary fixation with Kirschner wires and the action of the adductor tendon promote compression at the level of the arthrodesis and the approximation of the first and second metatarsal, correcting the IMA. The technique's greatest disadvantage in this group of patients was the high rate of reintervention to remove the implants. Although no nonunion occurred, a second procedure was required in 65% of cases due to hardware irritation. Despite presenting low stability indexes in biomechanical studies, MTPJ arthrodesis with Kirschner wires might present a high consolidation rate due to the benefits of micromobility at the arthrodesis, provided that the construction is associated with an adequate area of bone contact (**Fig. 5**).[35]

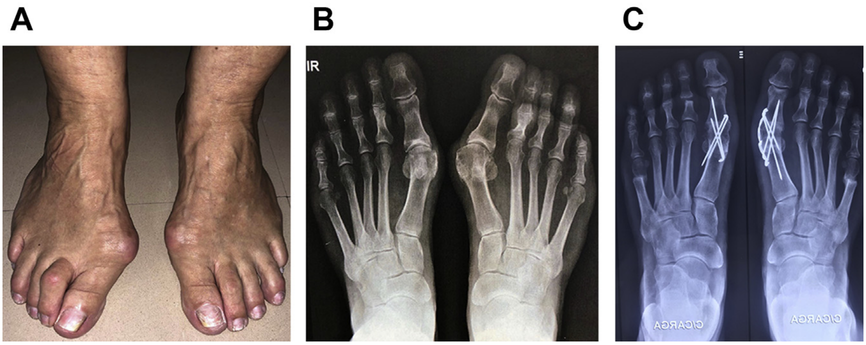

Fig. 5. (*A*) Clinical aspect of severe hallux valgus deformity. (*B*) Radiographic examination of the deformity. (*C*) Correction of severe hallux valgus deformity through MTPJ arthrodesis fixed through crossed Kirschner wires with and without cerclage. Note the intermetatarsal angle correction.

METATARSOCUNEIFORM JOINT ARTHRODESIS

Since Lapidus first described the procedure in 1934, metatarsocuneiform joint arthrodesis in the first and second rays to correct hallux valgus has undergone certain modifications, and today many investigators perform the procedure by fixing only the first ray.[41] The procedure is indicated in cases of metatarsocuneiform joint instability, which is often difficult to prove clinically or through imaging tests. Coughlin and Grebing demonstrated that the degree of mobility of the first ray is altered by the position of the ankle during the clinical examination.[42] An increased inclination angle of the metatarsocuneiform joint in radiographs has been associated with instability, but this finding is influenced by the angle of the beam during the examination and thus cannot be an isolated determinant. Doty and colleagues[43] observed that the median inclination of the metatarsocuneiform joint in the first ray was 15.8° in 10° anteroposterior radiographs, whereas it was 2.6° in 20° anteroposterior radiographs.

Many modifications of the original Lapidus technique have been described, such as the inclusion or not of the second ray in the arthrodesis and different types of fixation. Recently, traditional screw fixation has been replaced with special locking plates, as they show superior stability to screw fixation alone.[44,45] Fixing the plate on the tension side of the arthrodesis, that is, the plantar region, has biomechanical advantages over fixation in the medial region or dorsomedial, although there is concern that it could interfere with the anterior tibial and peroneal longus tendon insertions, because both occur in this region. Klos and colleagues[46] demonstrated in a cadaver study that plates fixed in the plantar region are stiffer and have better load to failure than plates placed in the medial dorsal region. These results are supported by clinical studies demonstrating low rates of nonunion in patients who underwent metatarsocuneiform joint arthrodesis with plantar plate fixation.[47] The main drawback of placing the plate in this region is interference with the peroneus longus and anterior tibial tendon insertions, which could explain the high reintervention rate to remove the hardware.[48] Anterior tibial tendon rupture due to this technique has been previously described.[47]

However, Plaass and colleagues[49] demonstrated in a cadaver study that there is a “safe zone” in which plantar placed plates in the metatarsocuneiform joint do not interfere with the anterior tibia or the long fibular tendon insertions.

To avoid irritation of local tissue and preserve the periosteum, an intramedullary fixation technique was developed for first-ray metatarsocuneiform joint fixation. Roth and colleagues,[50] in a biomechanical study performed on cadavers, showed that fixation with a plantar plate plus a compression screw provided a stronger and stiffer construct than fixation with an intramedullary device plus a compression screw.

Burchard and colleagues[51] compared first-ray metatarsocuneiform joint fixation in synthetic bones using a dorsal locking plate, a plantar locking plate, and fixation with an intramedullary device. Although the intramedullary device had the highest initial compression force, fixation with a plantar plate produced higher stiffness than the other forms.

Attention has also been given to rotational correction of the first ray during metatarsocuneiform joint arthrodesis. Klemola and colleagues[52] demonstrated that correcting varus and pronation of the first metatarsal can correct the entire deformity without touching the MTPJ. According to these investigators, rotational correction realigns the head of the first metatarsal and the sesamoids, bringing the relationship between the structures to a more horizontal and stable position, possibly decreasing the chance that the deformity will recur.

PERCUTANEOUS TECHNIQUES

With the introduction of internal fixation in osteotomies, procedures performed with burs have gained popularity with a greater number of practitioners, given that better results were obtained. In a recently published systematic review, the Reverdin-Isham procedure was found to have less potential for valgus hallux angle correction than a Chevron-Akin osteotomy, which is also performed percutaneously. The Reverdin-Isham procedure was also found to be less able to correct the IMA than the technique that uses the Endolog device, a curved titanium endomedullary nail that serves to push the metatarsal head laterally after a percutaneous osteotomy.[53] The development of cannulated screws with beveled heads for fixing percutaneous osteotomies has facilitated the procedures, reducing the chance of postoperative correction loss and allowing for accelerated rehabilitation.[54]

THREE-DIMENSIONAL PRINTING TECHNOLOGY

The advantages of precontoured implants for adjusting fixation and reducing surgery time, coupled with the emergence of 3-dimensional printing technology, has led to customized implants to match an individual's anatomy. Although not yet widely used, customized printed implants have already proved useful in syndromic patients and those with highly compromised bone structure. As this technology advances, large-scale production of custom implants in stainless steel, titanium, nitinol, ceramics, etc. will drive costs less than current levels, and the possibility of producing sterile implants in the operating room could completely change current material supply logistics.[55,56]

DISCLOSURE

The authors have nothing to disclose.

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