Autogenous Calcaneal Bone Graft Repair of a Closing Base Wedge Osteotomy Nonunion

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The authors present a case report showing successful autogenous calcaneal bone graft stabilization of a first metatarsal closing base wedge osteotomy nonunion. The authors discuss the complications and clinical sequelae associated with first metatarsal base wedge osteotomy nonunions. The patient’s clinical presentation, surgical procedure, and postoperative course are discussed. Comparative preoperative and postoperative objective gait analyses are presented. This approach to first metatarsal nonunion salvage appears to be clinically successful with a 15-month follow-up period.

First metatarsal base wedge osteotomies for hallux abducto valgus were first proposed by Loison in 1901. He described a laterally based, transverse closing wedge osteotomy of the first metatarsal for an elevated intermetatarsal angle. In 1903, Balacescu first performed the procedure described by Loison. In 1919, Juvara described an oblique, laterally based closing wedge osteotomy. In 1983, Smith advocated the hinge-axis concept in an attempt to control one of the factors associated with the development of elevation of the first metatarsal following closing base wedge osteotomies. Prior to this time, the osteotomy was oriented perpendicular to the long axis of the metatarsal. This design allows for motion in both the frontal and transverse planes during closure of the osteotomy. Smith recommended that the osteotomy be performed perpendicular to the weightbearing surface. This leads to motion in only the transverse plane during osteotomy closure.

In 1988, Palladino studied closing base wedge osteotomies performed both perpendicular to the weightbearing surface and the long axis of the metatarsal. He concluded that the hinge-axis concept theory is biomechanically sound; however, the change in orientation amounts to little or no clinical significance.

Various types of fixation have been used in an attempt to stabilize closing base wedge osteotomies. A review of the literature revealed that no consistent form of fixation has provided optimal stability. Despite the relative stability of the type of fixation used, internal fixation cannot withstand the unsupported stresses of weightbearing. Therefore, the use of a short leg cast and strict nonweightbearing are recommended to avoid complications following closing base wedge osteotomies.

Ruch compared different forms of fixation used in transverse and oblique osteotomies and the stability provided by each. Osteotomies were performed on plastic bone models and the individual fixation techniques stressed by applying a dorsiflexory force to the metatarsal head. He concluded that two 2.7-mm compression screws and right angle loop orthopedic wire provided the strongest fixation.

Landsman and Vogler assessed the stability of oblique base wedge osteotomies with different modes of internal fixation. Juvara-type osteotomies were performed on fresh, previously frozen cadaveric specimens. The osteotomy was fixated with either one 3.5-mm cancellous screw, two 2.7-mm cortical screws, or two crossed 0.062 Kirschner wires. The
specimens were attached to an Instron® tensiometer and a dorsiflexory force applied to the distal metatarsal. They concluded that the two-screw fixation was less stable than either the single screw or crossed Kirschner wire configurations. No statistical difference was noted between the stability of the one screw or crossed Kirschner wire fixation types.7

Christensen et al8 evaluated the stiffness of screw fixation and the role of the cortical hinge in oblique closing base wedge osteotomies. Oblique closing base wedge osteotomies were performed on fresh, previously frozen cadaveric first metatarsals with and without an intact cortical hinge. The osteotomies were fixated with either one or two 3.5-mm fine thread cortical screws. The specimens were tested for axial loading, valgus torque, and cantilever bending. They determined that osteotomies with an intact cortical hinge showed superior stiffness. Fixation with two screws and an intact hinge had increased axial stiffness as compared with one screw with an intact hinge; however, cantilever bending and torsional stiffness were not statistically significant.8

Complications following closing base wedge osteotomies are most commonly related to first metatarsal elevation and shortening. According to the literature, elevation and shortening can be attributed to two critical factors: surgical technique, including osteotomy design and fixation, and postoperative management. Schuberth et al9 reported an average elevation of 6.679° and shortening of 3.187 mm in a study of 159 closing base wedge osteotomies. Zlotoff10 noted an average shortening of 2.6 mm of the first metatarsal in 38 patients undergoing closing base wedge osteotomies. Jeremin et al11 noted that 50% of the 24 closing base wedge osteotomies they studied developed postoperative first metatarsal elevation. Nigro et al12 reported postoperative elevation in 34% (21/61) of the closing base wedge procedures they analyzed.

There exists no universal agreement as to the precise definition of a nonunion. It is generally understood that a nonunion is present when bone has failed to heal and all evidence of the reparative process has ceased. The Food and Drug Administration defines a nonunion as osseous discontinuity of 9 months’ duration, in which there has been no evidence of osseous healing for 3 consecutive months.13

There are several local and systemic etiologic factors associated with the development of a nonunion. Local factors associated with nonunion tend to be more common than systemic factors. These include disruption of vascular supply to the bone, which may be caused by poor surgical technique and location of the osteotomy in diaphyseal bone. Improper or unstable reduction and fixation will lead to motion at the osteotomy site and prolong proper revascularization. Premature weightbearing, especially in combination with unstable fixation, can lead to delayed union, malunion, and nonunion.

Systemic etiologic factors, although less common, need to be considered primarily during preoperative planning. These include medications such as chronic corticosteroids, which have been implicated in the development of osteoporosis and a decreased ability to mobilize osteoprogenitor cells. Disease processes such as diabetes mellitus, hypothyroidism, anemia, and hypovitaminosis C and D have all been proven to disrupt normal bone healing. Systemic or local infection during the postoperative period may cause disruption of fixation and concomitant instability.14, 15 Often the development of the nonunion is multifactorial.

Nonunions have been classified as either hypertrophic or hypervascular or atrophic or avascular. Hypertrophic nonunions are capable of healing. However, because of unstable fixation, poor reapproximation of the bone, and early weightbearing, they are unable to result in osseous union. Atrophic nonunions are not capable of osseous healing. This may be caused by severe commination, increased gapping between fragments, or development of fibrous tissue between fragments.16

Nonunion diagnosis requires the clinician to evaluate subjective complaints of the patient and to correlate them to physical findings and medical imaging studies as necessary. The clinical sequelae associated with closing base wedge osteotomy nonunion include severe first metatarsal deformity with resulting elevation and shortening of the metatarsal. This creates disruption of first metatarsal biomechanics and an apropulsive gait pattern. In an attempt to reestablish normal weightbearing function across the metatarsal parabola, secondary complications such as second metatarsal stress fractures, transfer lesions beneath the second metatarsal head, and lesser metatarsalgia may develop. The patient may also have proximal complaints such as knee, hip, or lower back pain. Nonunions produce chronic inflammation at the osteotomy site often resulting in local pain, edema, and calor.

Medical imaging studies are clinically important to follow the postoperative treatment course and aid in the diagnosis of nonunion. When delayed or nonunion is suspected, plain radiographs are the first imaging study recommended. Sclerotic borders or an osseous void seen on plain radiographs at the osteotomy site indicate nonunion. A bone scan such as technetium-99m can be used to distinguish between a hypertrophic and atrophic nonunion. Hypertrophic nonunions will display persistent uptake at the os-

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81Intron Corporation, Canton, MA.
Osteotomy site, whereas atrophic nonunions will appear as areas of diminution or a cold spot. Computer tomography can also be used to visualize a persistent osseous defect at the site of the osteotomy.

The treatment of nonunions is dependent on vascularity and the alignment of the osseous fragments. Hypertrophic nonunions with acceptable alignment may be treated with prolonged immobilization, non-weightbearing, or an electrical bone stimulator.

Fukada and Yasuda showed that bone has piezoelectric properties. Friedenberg and Brighton observed negative bioelectric potentials at fracture sites. Bone stimulators, either invasive, semi-invasive, or totally noninvasive, have shown that osteogenesis occurs around the negative electrode (cathode). Osteonecrosis has been observed around the positive electrode (anode). Bone stimulator usage relies heavily on patient compliance in the noninvasive model. Bone stimulators are contraindicated in the presence of active infection or if the nonunion gap is greater than one half of the diameter of the bone.

In cases of atrophic nonunion or malposition, surgical intervention is warranted. Surgical resection of the nonunion, followed by insertion of bone graft and internal fixation, is standard of care to maintain adequate alignment and aid in osteogenesis. Concomitant usage of a bone stimulator may be of additional benefit. Once again, the patient must be immobilized with strict nonweightbearing following the procedure.

The incidence of nonunion associated with closing base wedge osteotomies of the first metatarsal could not be ascertained in the literature. Although the incidence of nonunion may be relatively rare, this complication poses a significant dilemma to the podiatric surgeon in regard to surgical options available for reconstruction.

Case Report

A 42-year-old female presented to the Foot and Ankle Institute with a chief complaint of right foot pain. She related a history of a bunionectomy 7 months prior. Following surgery, she remained nonweightbearing in a short leg cast for 6 weeks. After cast removal, she began full weightbearing. She reported having significant discomfort while walking and weightbearing around the first metatarsal and beneath the ball of her foot. The patient said that her big toe could not rest on the ground (Fig. 1). She also complained of limited range of motion in the first metatarsophalangeal joint and continued swelling primarily at the end of the day. She underwent two courses of physical therapy following her procedure. The rehabilitation provided little improvement in range of motion, strength, and functional ability of her right foot.

The patient’s medical history was significant for mitral valve prolapse. Her surgical history included tubal ligation and prior right bunion surgery. At the time of presentation, she was not taking any medications. She reported an allergy to penicillin.

The physical examination revealed a well healed surgical incision on the dorsomedial aspect of the right first metatarsal. There was significant restriction in the available range of motion in the right first metatarsophalangeal joint with primarily no available dorsiflexion. The first metatarsal was in an elevated attitude with respect to the second metatarsal. Mild edema was noted in the right midfoot region. In comparison, the left foot showed a moderate hallux abducto valgus deformity with approximately 70° of available dorsiflexion of the first metatarsophalangeal joint. Vascular examination revealed palpable dorsalis pedis and posterior tibial artery pulses bilaterally with immediate capillary filling time. Her sensation was grossly intact, however slightly diminished on the medial aspect of her right hallux. Gait analysis revealed external leg rotation and lateral weight shift to compensate for lack of right first metatarsophalangeal joint range of motion.

Radiographic examination revealed a probable non-union in the proximal one third of the right first metatarsal, at the site of the previous surgery. The distal aspect of the metatarsal was noted to have an elevated attitude with concomitant shortening. Remaining cerclage wire fixation around the

Figure 1. Clinical photograph revealing inadequate hallux purchase.
osteotomy site was noted (Fig. 2). Computer to-
mography of the right foot was obtained with find-
ings consistent with a hypertrophic or hypervascu-
lar nonunion affecting the middle one third of the 
right first metatarsal (Fig. 3).

An objective gait analysis was performed using a 
Musgrave Footprint® system to ascertain pressure 
of the plantar aspect of the patient’s foot. Maximum 
barefoot pressures of the plantar aspect during 
stance revealed pathologic focal pressures greater 
than 10 kg/cm² beneath the second metatarsal. It 
revealed also that the first metatarsal was bearing no 
weight. The center of pressure reading indicated overpronation with weight transfer through the sec-
ond metatarsal and digit caused by the elevatus de-
formity of the first metatarsal (Fig. 4).

After discussing conservative and surgical treat-
ment options, the patient requested surgical repair 
of the nonunion. This involved an autogenous cal-
caneal bone graft placed into the first metatarsal 
with rigid internal fixation to restore length and 
alignment and to improve first ray biomechanics 
and promote osseous union.

Operative Technique

An 8-cm dorsolinear incision was made through the 
previous incision site. After dissecting through the sub-
cutaneous tissues, a peristeal incision was performed. The peristeal tissues were reflected at the level of the 
previous osteotomy site. The retained internal fixation 
was identified and removed. The nonunion site was 
identified and resected with a power bone saw until 
healthy, bleeding bone was visualized.

A second, slightly curved 3-cm incision was per-
formed over the superior lateral aspect of the right 
calcaneus. The incision was centered halfway be-
tween the posterior edge of the posterior facet of the 
subtalar joint and the anterior edge of the Achilles ten-
don. Dissection was carried through the superficial

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Figure 2. Dorsoplantar and lateral radiographs re-
vealing closing base wedge osteotomy nonunion re-
sulting in first metatarsal elevatus and shortening.

Figure 3. Computer tomogram revealing nonunion in 
proximal one third of the first metatarsal.

Figure 4. Preoperative gait analysis showing dimi-
ished weightbearing beneath the first metatarsal and 
pathologic pressures of the plantar aspect beneath 
the second metatarsal.
fascia to the superior aspect of the posterior calcaneus. Care was taken to avoid the posterior calcaneal branch of the sural nerve. The periosseum was reflected off of the calcaneus, and a pie-shaped cortical-cancellous graft was procured using a power bone saw measuring approximately 1.8 × 1.0 cm. A 8 mm × 1.5 cm piece of allogeneic iliac crest was then fashioned and placed into the remaining calcaneal defect.

The calcaneal bone graft was placed into the first metatarsal nonunion site and temporarily fixed with a 0.062 Kirschner wire. After ensuring adequate osseous correction, a 4.0-mm cannulated screw was used to stabilize the graft and osteotomy site. A six-hole Synthes©3 one-quarter tubular plate was then placed on the dorsomedial aspect of the first metatarsal. One 2.7-mm cortical screw was placed into the bone graft, and the remaining five holes were filled with 2.7-mm cortical screws with two proximal to the graft and three distal to the graft. The Kirschner wire used for temporary fixation was then removed (Fig. 5).

Attention was then directed to the first metatarsal head where osteophytic spurring was noted, and using a power bone saw, a dorsal exostectomy was performed. An open Z tendon lengthening was performed on the contracted extensor hallucis longus tendon. The incisions over the first metatarsal and lateral calcaneus were then reapproximated in a layered fashion. During wound closure of the lateral calcaneus, a closed suction drain was placed to control hemostasis. After application of a sterile dressing, a Jones compression dressing and a posterior splint were applied.

Postoperatively, the patient remained nonweight-bearing for 7 weeks. Serial radiographs of her right foot revealed graft consolidation, and she progressed to partial weightbearing with a surgical shoe and crutches (Fig. 6). Throughout the postoperative course, the patient was encouraged to perform daily range of motion exercises of her first metatarsophalangeal joint. At 13 weeks' postoperatively, the patient was progressed to full weightbearing. Approximately 6½ months postoperatively, the patient began to complain of discomfort over the plate with weightbearing. The internal fixation was removed 9½ months after nonunion repair without complication. Following this last procedure, the remainder of the patient's postoperative course was uneventful with a return to full activity without limitation (Fig. 7).

Using the Musgrave Footprint system, objective gait analysis was repeated 15 months after nonunion repair. Analysis of static pressures of the plantar aspect revealed improved first metatarsal weightbearing of approximately 5 kg/cm². The pathologic pres-
sures of the plantar aspect noted preoperatively beneath the second metatarsal have been significantly reduced. The center of pressure study indicated weight shift to the medial column with transfer of the weight through the first metatarsal head (Fig. 8).

Discussion

Prior to establishing a treatment plan for this malaligned hypertrophic nonunion, it is important to establish the etiologic causes that lead to the condition. The patient’s past medical history did not reveal any underlying systemic conditions or current medications that could increase the incidence of nonunion. There are several local etiologic factors that could account for development of a nonunion following closing base wedge osteotomy of the first metatarsal. One example would be the location of the osteotomy within the diaphyseal bone of the first metatarsal. Nigro et al concluded that the optimum distance for osteotomy placement is 0.5 to 1.0 cm from the metatarsocuneiform joint. Oloff related that metaphyseal bone heals better than diaphyseal bone by virtue of its blood supply.

The patient’s osteotomy was fixated with a single dorsal loop of cerclage wire and a horizontal loop of cerclage wire. Schuberth et al concluded that monofilament wire resulted in an average of 8.5° of elevation when used to fixate closing base wedge osteotomies. It appears from the radiographs that the medial cortical hinge of the osteotomy failed. The medial cortical hinge offers greater stability to the osteotomy site. When the cortical hinge fractures, it is more difficult to maintain proper fixation and alignment. The patient reported that she remained in a short leg cast, nonweightbearing for 6 weeks, following her closing base wedge osteotomy procedure. However, despite radiographic evidence of incomplete consolidation of the osteotomy, she began unrestricted weightbearing; this contributed to the gross malalignment of the nonunion.

The treatment for first metatarsal base osteotomy nonunion can be extremely challenging to the podiatric surgeon. Conservative treatment for hypertrophic or hypervascular nonunion often involves prolonged immobilization, nonweightbearing, and a bone stimulator. If structural malposition is present, as in this case, then surgical intervention is warranted to realign the osseous segment and restore function.

The most important aspect of this reconstruction is to restore normal first ray biomechanics. Preoperative and postoperative gait analyses were obtained to assess first ray biomechanics. The preoperative gait analysis revealed the functional loss of the first ray during walking as a result of the nonunion. Structural metatarsus primus elevatus along with inadequate hallux purchase, leads to subtalar joint pronation, resulting in an apopulsive

Figure 7. Clinical photographs revealing improved first ray position.

Figure 8. Postoperative gait analysis showing improved pressures of the plantar aspect.
gait.\textsuperscript{24} Postoperatively, first metatarsal weightbearing is improved and plantar pressures beneath the second metatarsal have normalized (Table 1). Since the patient continued to overpronate, she was referred for fabrication of custom-molded orthoses.

Restored first ray biomechanics are obtained by fashioning the calcaneal autogenous bone graft to lengthen and plantarflex the first metatarsal. It is imperative that the nonunion be resected back to healthy bone and that the graft be placed in close apposition to the resected bone margins. Rigid internal fixation of the bone graft and nonweightbearing will promote osteogenesis and prevent the development of delayed union, nonunion, or malalignment following the reconstructive procedure.

Using bone grafts to repair nonunions is not a new concept. Calcaneal autogenous bone grafts have been successfully used for procedures such as revisional digital arthrodesis and in repair of brachymetatarsia.\textsuperscript{25, 26} For several reasons, autogenous bone is considered superior to allogeneic bone grafts for repair of nonunions. Autogenous grafts provide the properties of osteogenesis, osteoconduction, and osteoinduction. As with all autogenous grafts, immunologic incompatibility is not a concern.\textsuperscript{27} The corticocancellous bone structure of the calcaneus makes it suitable material for grafting in metatarsals; however, the size of the calcaneus limits the amount of graft that can be harvested for grafting. The relative ease of procurement, accessible location, and low complication rate also make this technique an excellent alternative for the podiatric surgeon.\textsuperscript{28}

Hemostasis following graft procurement is crucial for preventing hematoma, wound dehiscence, and possible neuritis. A piece of allogeneic bone graft was placed into the calcaneal donor site deficit following graft harvest to assist in hemostasis. Also, a closed suction drain was used postoperatively to prevent hematoma formation. The use of coralline hydroxyapatite, collagen, and hydroxyapatite or tricalcium phosphate, and topical hemostatic agents such as topical thrombin, gel foam, or bone wax have been reported in the literature to assist with hemostasis.\textsuperscript{28}

Another serious complication is the possible development of calcaneal fracture. This risk is reduced by 1) being careful not to violate the medial calcaneal cortex during graft harvesting, 2) biasing the corners of the osteotomy to reduce stress riser formation, 3) packing the graft donor site as mentioned previously, and 4) maintaining nonweightbearing with a short leg cast postoperatively.\textsuperscript{28}

**Summary**

The development of a nonunion in basal osteotomies for hallux abducto valgus poses a significant concern to the foot and ankle surgeon. Revisional surgery is indicated if first ray malalignment with shortening and elevation are clinically apparent. The use of calcaneal autogenous bone when grafting has been shown to be a reliable, safe, and effective treatment for iatrogenic and congenital deformities in the foot. This procedure for salvage of first metatarsal nonunion has yielded nonunion consolidation and improved first ray biomechanics, enhancing the functional ability of the affected lower extremity. The calcaneal bone grafting procedure should be a surgical consideration for the podiatric surgeon when malaligned nonunions of the first metatarsal are encountered.

**References**

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