Reconstruction of the First Metatarsophalangeal Joint Following Post-cheilectomy Avascular Necrosis of the First Metatarsal Head: A Case Report

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Avascular necrosis of the first metatarsal head is a well-known, albeit rare, complication associated with hallux abductovalgus surgery. In this report, we describe the case of a 51-year-old male who developed osteonecrosis of the first metatarsal head 1 year after undergoing an isolated cheilectomy for the treatment of hallux rigidus. To our knowledge, this is the first published report of osteonecrosis following isolated cheilectomy used for the treatment of hallux rigidus. A bone graft substitute with undifferentiated stem cells was used to pack the medullary canals of the first metatarsal and the proximal phalanx. A section of autogenous calcaneal graft was used to perform a bone block distraction arthrodesis of the first metatarsophalangeal joint. Level of Clinical Evidence: 4 (The Journal of Foot & Ankle Surgery 48(1): 61–69, 2009)

Key Words: avascular necrosis, bone graft substitute, cheilectomy, hallux rigidus, Osteocel, osteonecrosis

Hallux rigidus is a common foot deformity that can be improved through surgical correction by means of arthrodesis, arthroplasty, endoprosthesis, or cheilectomy, after nonsurgical treatments have failed (1–5). Cheilectomy of the first metatarsal head has become a time-tested method for alleviating first metatarsophalangeal joint (MTPJ) arthritic pain, and is well documented in the biomedical literature (1–5). Cheilectomy, in fact, frequently serves as the foundation procedure for repair of hallux rigidus, and is often combined with other reconstructive measures, such as soft tissue release and reconstructive osteotomy. Mann and Clanton (5) documented successful results after performing cheilectomy for symptomatic hallux rigidus.

In regard to postoperative complications following cheilectomy, radiographic evidence has shown that the MTPJ commonly deteriorates over time (1, 3, 4). Other reported complications include reflex sympathetic dystrophy, neuroma formation, hallux paresthesia, prolonged swelling, superficial wound infection, cellulitis, and rapid chondrolysis (1, 3–5). If there were minimal soft tissue dissection about the first metatarsal head when the cheilectomy is performed, one would not expect to see a significant degree of vascular damage. To date, there have been no reported cases in the peer-reviewed literature of avascular necrosis (AVN) following isolated cheilectomy for the treatment of hallux rigidus. When AVN develops, reconstructive surgery to repair the necrotic bone may entail the use of bone grafting and, in the case of joint involvement, arthrodesis may be necessary. Osteocel (Osiris Therapeutics, Inc., Baltimore, MD) is a complete bone graft substitute that contains undifferentiated adult stem cells, and conveys the 3 properties of living bone that contribute to growth, namely osteoconduction, osteoinduction, and osteogenesis. As such, Osteocel is the first commercially available osteogenic product for bone repair (6). To date, no cases involving the use of this viable bone matrix containing stem cells have been reported in the foot and ankle surgical literature.

To confirm that there were no previous reported cases of AVN following cheilectomy or the use of a complete bone matrix containing stem cells in foot and ankle surgery, the following biomedical databases were reviewed: Excerpta Medica Database (EMBASE, 1980 to 2008, week 9), Cumulative Index to Nursing & Allied Health Literature (CINAHL, 1982 to February, week 5, 2008), Biosis previews (1993 to 2008, week 13), Scopus (site searched March 8, 2008), Global

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Health (1910 to February 2008), The Cochrane Library (site searched March, 8, 2008), and Medline (1950 to February, week 4, 2008).

Case Report

A 51-year-old male with no significant past medical history presented to the senior author (T.A.B.) with a complaint of pain and swelling localized to the first MTPJ of his left foot. The patient reported having undergone a cheilectomy procedure performed by another surgeon approximately 12 months prior. The clinical examination revealed increased girth localized to the first MTPJ, and there was no evidence of motion at the joint. Clinical notes and the operative report were obtained from the prior treating physician, whose operative report confirmed that periosteum had been stripped off the metatarsal, and substantial bone removed from the dorsal, medial, and lateral surfaces of the metatarsal head, as well as the dorsal aspect of the proximal phalanx. This was accomplished using a rongeur and power burr. It was noted that once the joint was debrided, 30 degrees of dorsiflexion was achieved. The patient's postoperative course was uneventful and he began range of motion (ROM) exercises a week after surgery, on his own. The patient demonstrated good compliance and no immediate signs of complications.

At approximately 8 weeks postoperative, the patient presented with painful edema and a decreased ROM at the MTPJ. No treatment was initiated and although the edema slowly subsided, pain at the first MTPJ remained. Sequential radiographs throughout the postoperative year following the initial cheilectomy had been taken (Figures 1–5). These radiographs demonstrated severe intraosseous deterioration of the metatarsal head over the course of 1 year, culminating in collapse of the first metatarsal head and degeneration of the MTPJ by 11 months post-cheilectomy. An operative bone biopsy obtained at that time was negative for osteomyelitis. Radiographs at 13 months postoperative revealed further loss of joint space, and erosion of the entire first metatarsal head with secondary hypertrophic bone formation at the MTPJ (Figures 6 and 7). Magnetic resonance images (MRI) revealed loss of signal intensity from the midshaft to the distal aspect of the first metatarsal (Figures 8 and 9).

Based on the clinical examination, the patient's medical history, bone biopsy results, and the standard radiographs and MRI images, a diagnosis of post-cheilectomy AVN was made, and a surgical course of treatment was determined to be the best course of action. The patient underwent a bone block distraction arthrodesis with autogenous graft from the calcaneus. The voids created by bone loss in the medullary canals of the first metatarsal and proximal phalanx base were packed with Osteocel. A 6-hole plate was applied dorsally to stabilize the construct.

FIGURE 1 Preoperative anteroposterior radiograph for the first surgery, demonstrating a normal contour of the first metatarsal head.

FIGURE 2 Postoperative anteroposterior radiograph 2 months following cheilectomy of the first metatarsal. Narrowing of the joint is evident in comparison to the preoperative radiographs.

The first MTPJ was exposed through a 7-cm dorsal longitudinal incision (Figures 10 and 11). After soft tissue

FIGURE 3 Postoperative anteroposterior radiograph 6 months post-cheilectomy of the first metatarsal. Continued osseous changes are identifiable along with further collapse of the metatarsal head.

FIGURE 4 Postoperative anteroposterior radiograph 8 months post-cheilectomy of the first metatarsal. Destruction of the metatarsal head with collapse of the first metatarsophalangeal joint has progressed from the previous radiographs (see Figure 3).

dissection was completed, a substantial amount of hypertrophic bone was observed to involve the residual head of the first metatarsal, base of the proximal phalanx, and the sesamoids (Figure 12). A fibrous pseudoarthrosis was ver-

FIGURE 5 Postoperative anteroposterior radiograph 11 months post-cheilectomy of the first metatarsal. Severe changes within the metaphysis of the first metatarsal, consistent with avascular necrosis, are apparent. The metatarsal head has collapsed into the metatarsal shaft, and a hollowing out of the distal metatarsal shaft can be visualized. Bone biopsy taken at this time was negative for osteomyelitis.

ified by means of probing and manipulation, and the joint was distracted using hand instrumentation. At this point, the remnants of the cartilaginous surface of the metatarsal head were located within the medullary shaft of the metatarsal (Figure 13). Remnants of the metatarsal head were removed, and the bone was inspected for signs of infection. The absence of purulence and malodor, as well as the appearance of viable bone, suggested the absence of infection, and an intraoperative Gram stain revealed no evidence of bacteria.

Using a sagittal saw, the distal aspect of the first metatarsal head was resected until consistent osseous bleeding was visualized from the bone; the base of the proximal phalanx was resected in the same manner (Figure 14). The medullary shaft was reamed with a 4.0-mm drill to the base of the first metatarsal to establish communication with good bleeding bone. The shaft of the first metatarsal, as well as the remaining portion of the proximal phalanx, were then packed with 2.5 mL of vital bone matrix containing stem cells (Figure 15). A 1.5 $\times$ 1.0 cm autogenous corticocancellous bone graft was then procured from the ipsilateral calcaneal body by means of a vertical incision situated over the lateral wall of the os calcis. This donor site was then packed with allogeneic bone chips and closed in sequential

FIGURE 6 Day of surgery anteroposterior radiograph for reconstruction of the metatarsophalangeal joint following post-cheilectomy avascular necrosis of the first metatarsal head. This was taken 13 months after the previous cheilectomy. Note the extensive collapse of the metatarsal head, and complete loss of joint space.

FIGURE 7 Day of surgery lateral radiograph (13 months following original cheilectomy) showing collapse of the metatarsal head with secondary hypertrophic bone formation.

FIGURE 8 Transverse plane image of the foot demonstrating decreased signal intensity within the distal half of the first metatarsal on a T1-weighted magnetic resonance image.

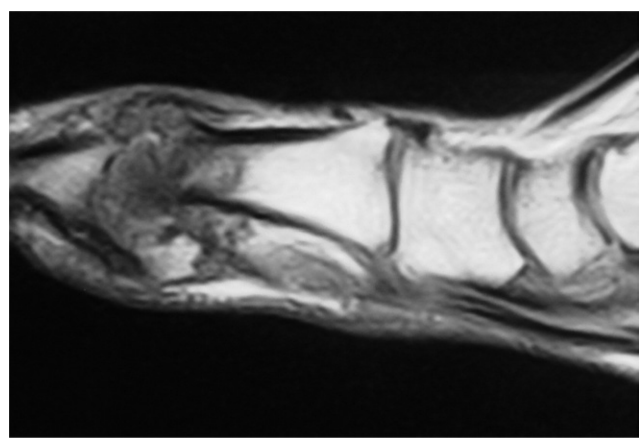

FIGURE 9 Magnetic resonance image (sagittal view) reveals loss of signal intensity from the mid shaft to the distal aspect of the first metatarsal.

layer fashion. The calcaneal bone graft was then placed within the first MTPJ complex to achieve bone apposition and length (Figure 16). A 6-hole locking plate (Synthes Small Fragment LCP Instrument and Implant Set, Synthes, Inc., West Chester, PA) was affixed across the dorsal aspect of the fusion site using five 3.5-mm fully threaded cortical screws (Figure 17). Once internal fixation was achieved and deemed stable, the wound was closed in sequential layer fashion. The patient was immobilized in a below-the-knee cast for 8 weeks and maintained non–weight bearing on the operated foot, and a low-intensity ultrasound external bone growth stimulator was applied through a window within the dorsal cast. At 8 weeks the patient was placed into a pneumatic-lined, below-the-knee immobilizing walking boot; radiographic evaluation at 11 weeks demonstrated complete incorporation and consolidation of the calcaneal graft at the first MTPJ (Figures 18 and 19). The patient has since returned to work and at 14 months postoperative, he reports no pain or limitation of motion.

FIGURE 10 Preoperative anteroposterior clinical view of a 51-year-old male with painful first metatarsophalangeal joint complex.

FIGURE 11 Preoperative lateral clinical view demonstrating significant girth of the first metatarsophalangeal joint.

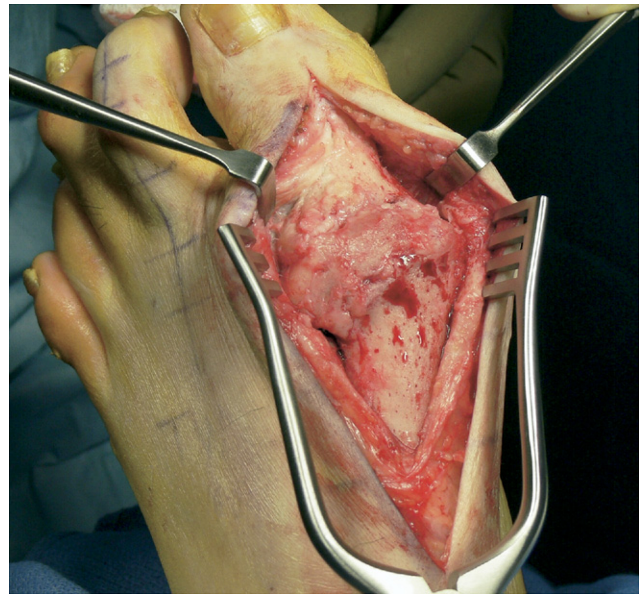

FIGURE 12 Hypertrophic bone was observed on initial inspection of the metatarsophalangeal joint complex following soft tissue dissection.

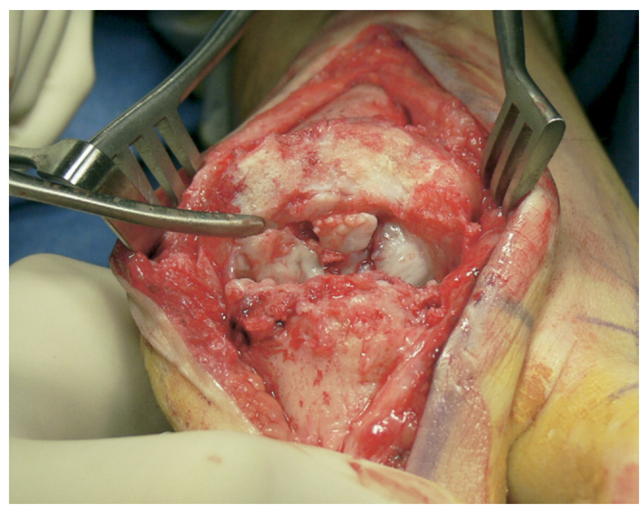

FIGURE 13 View distal to proximal with hallux plantarflexed. Note remnants of the cartilaginous surface of the metatarsal head located within the medullary shaft of the metatarsal.

Discussion

The blood supply to the first metatarsal has been elucidated in the scientific literature. Shereff et al (7) demonstrated the extraosseous and intraosseous blood supply to the first metatarsal and MTPJ by means of vascular injection techniques in cadaveric specimens. The extraosseous supply arises from the first dorsal metatarsal artery, the first plantar metatarsal artery, and the superficial branch of the medial plantar artery. The intraosseous blood supply includes a nutrient artery that penetrates the distal third of the metatarsal along the lateral aspect of the shaft, along with a network of periosteal arteries enveloping the diaphysis, and a system of metaphyseal-capital arteries derived from the extracapsular branches that penetrate the capsule (7). Furthermore, Sarrafian (8) described how the nutrient artery penetrated the middle of the lateral aspect of the metatarsal shaft and divided into 2 branches. The branch that coursed distally was smaller and connected with arteries of the metaphysis and metatarsal head. The proximal arterial branch was generally larger and, as such, considered stronger, and formed an anastomosis with epiphyseal arteries. Jones et al (9) agreed that the main arterial supply to the first metatarsal was from a combination of vessels derived from the dorsalis pedis and posterior tibial vessels. They de-

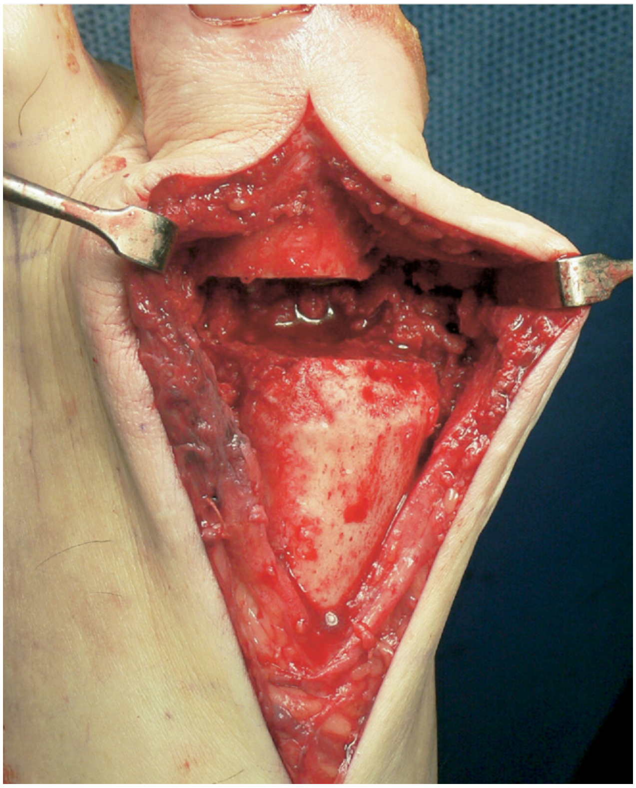

FIGURE 14 The distal aspect of the first metatarsal head was debrided of all dead bone, followed by resection of the base of the proximal phalanx.

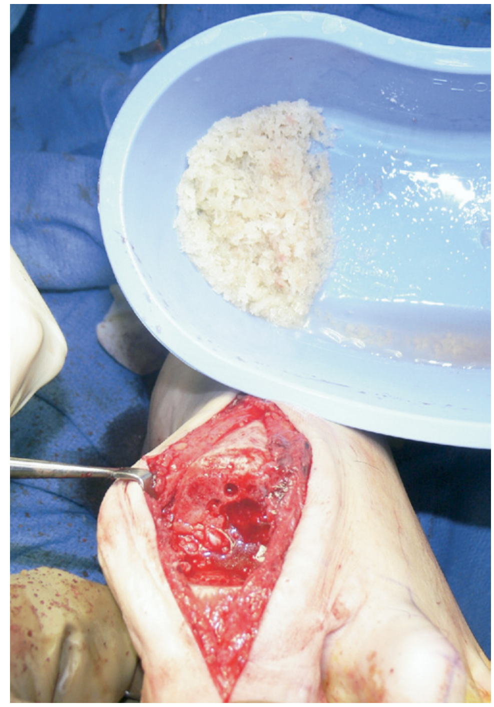

FIGURE 15 The first metatarsal with head removed and medullary canal reamed, with complete allogeneic bone graft substitute packed into the void.

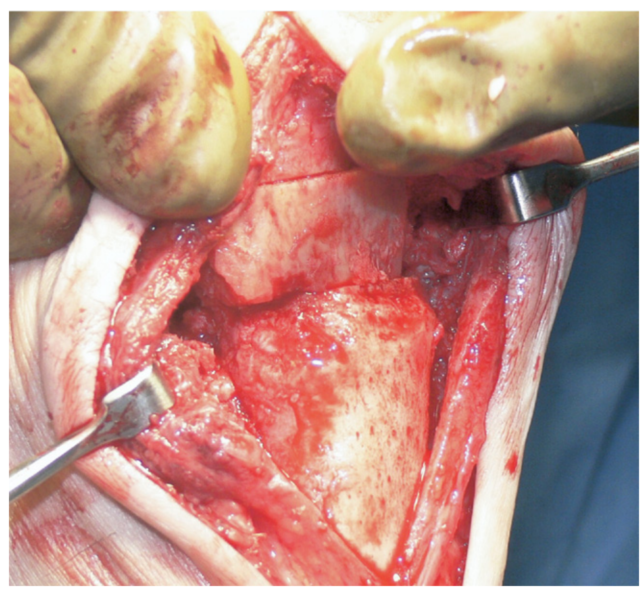

FIGURE 16 Autogenous graft located between the first metatarsal and base of the proximal phalanx.

scribed an anastomosis of branches off of the 2 main arteries that ultimately formed an arcade of vessels plantar and proximal to the metatarsal head and sesamoid apparatus, contributing to the pericapsular blood supply. They further described the nutrient artery to the metatarsal as penetrating the proximal and middle third of the metatarsal shaft. Jaworek (10) noted that the nutrient artery was located 2.7 cm proximal to the articular cartilage and 0.4 cm from the dorsal aspect on the lateral border of the first metatarsal.

In a 2004 cadaveric study, Weinraub and colleagues (11) showed that use of a standard chevron osteotomy resulted in greater disruption of the nutrient artery, in comparison to a long dorsal arm osteotomy, whereby perfusion from the nutrient artery remained intact. This suggested that a long arm chevron osteotomy carried a lower risk of vascular compromise than a distal osteotomy, because of where the nutrient artery entered the bone. Regardless of its entry point, the nutrient artery can be compromised with excessive lateral penetration with the saw blade when performing a capital osteotomy (9).

In regard to the soft tissue dissection for cheilectomy, the longitudinal capsular incision is typically centered dorsally and just medial to the extensor hallucis longus tendon, in order to reduce the risk of capsular disruption about the medial, lateral, or plantar aspects of the first metatarsal head. Given current understanding of the arterial supply to the first metatarsal, preservation of soft tissue attachments along the dorsal, lateral, and plantar aspect of the metatarsal

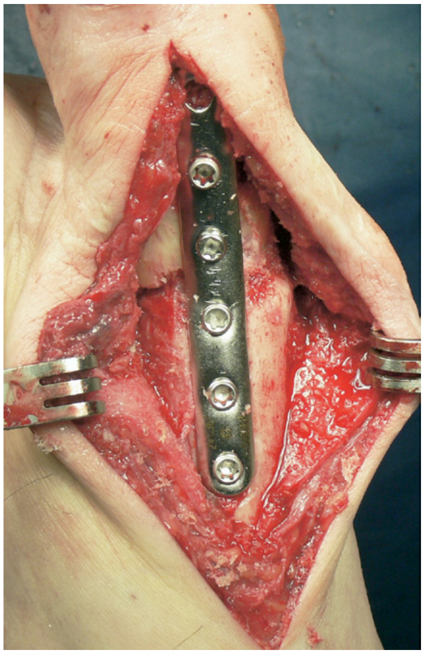

FIGURE 17 A 3.5-mm 1/3 tubular locking reconstruction plate applied to dorsal aspect of the fusion site with five 3.5-mm fully threaded cortical screws.

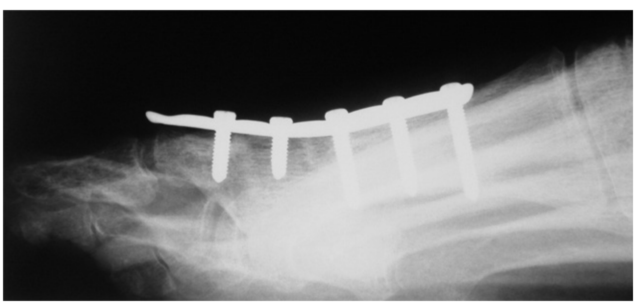

FIGURE 18 Lateral radiograph at 11 weeks demonstrating complete incorporation and consolidation of the calcaneal graft at the first metatarsophalangeal joint.

head is considered crucial to preservation of the blood supply, as described by Ruch et al (12). In conjunction with a distal chevron osteotomy, minimal disruption of the blood supply to the metatarsal head can be ensured by meticulous dissection about the metatarsal head, specifically by creating a subperiosteal collar around the neck of the metatarsal in order to preserve the capital and metaphyseal arteries that supply the metatarsal head and neck. Jones and colleagues (9) proposed distinct "safe zones" about the metatarsal head with respect to placement of the metatarsal osteotomy and capsular dissection. This preserved the proximal and lateral perforators to the first metatarsal during their cadaveric study in which a chevron osteotomy and lateral release were performed.

FIGURE 19 Anteroposterior radiograph at 11 weeks demonstrating complete incorporation and consolidation of the calcaneal graft at the first metatarsophalangeal joint.

Although uncommon, osteonecrosis of the first metatarsal head following hallux abductovalgus surgery has been documented in the literature (13–15). The insult to the vascular supply to the metatarsal head following an osteotomy, in conjunction with extensive soft tissue dissection around the metatarsal head, is theorized to be the cause. It has been suggested that aggressive capsular dissection medially, along with an overzealous interspace release, particularly involving release of the adductor tendon and any additional lateral contractures, may compromise the extraosseous vascular supply to the metatarsal head (14, 15). Kuhn et al (16) reported that 71% of the microvascular blood supply to the first metatarsal head was disrupted following a chevron bunionectomy with adductor tenotomy and lateral release. They concluded that 45% of the blood supply was lost with the medial capsulotomy. There was a 13% decrease of blood supply following the lateral release and adductor tenotomy, as well as a 13% decrease in blood supply following the chevron osteotomy. Although their results reported a high percentage of vascular disruption to the metatarsal head, they reported no cases of AVN 3 months postoperatively (16). Overall, the incidence of AVN following distal first metatarsal osteotomy combined with plantar lateral soft tissue release has been reported within the literature to range from 0% to 40% (17, 18).

In contrast to the high reported incidence of AVN following osteotomy and soft tissue release about the first metatarsal head, Banks (19) suggested that most of the radiographic and clinical findings perceived as AVN could have been caused by other processes, including osteotomy and bone resection, thermal damage, hyperemia, changes in mechanical forces, hallux limitus with subchondral cyst formation, and osteotomy stability. He also emphasized the importance of reviewing sequential radiographs to determine whether the initial changes occurred within the subchondral bone before any identifiable changes within the joint space transpired. In regard to the case described in this report, we were able to acquire sequential radiographs that were obtained during the postoperative year following the initial cheilectomy (Figures 1–7). These radiographs demonstrated severe intraosseous deterioration of the metatarsal head over the course of 1 year, culminating in collapse of the first metatarsal head and degeneration of the MTPJ by 11 months following the cheilectomy. Intraoperatively, we found a large portion of the intact cartilaginous surface of the metatarsal head impacted proximally within the metatarsal shaft, further evidence for the likelihood that the metatarsal head collapsed as a result of AVN.

A great deal of the foot and ankle surgical literature focuses on first MTPJ arthrodesis, particularly the need that sometimes arises for an interposition allogeneic or autogenous bone graft to fill large osseous deficits within the first MTPJ (20, 21). This commonly occurs following infection, nonunion, or AVN. In such cases, allogeneic iliac crest and femoral head grafts have been used because of their cortical and cancellous structural makeup. They are readily available and have the added benefit of causing less morbidity because graft procurement does not require additional surgical dissection. With a 97% union rate, Weinraub and Cheung (22) concluded that allogeneic bone grafts were a viable option for elective surgical procedures, including arthrodesis and the treatment of nonunions. One drawback to the use of allogeneic grafts is that a considerable amount of the osteoinductive and osteogenic properties are lost owing to standard methods used to sterilize and minimize the immunogenicity of allogeneic bone.

Autogenous bone grafts, on the other hand, are attractive because of their osteogenic, osteoconductive, and osteoinductive properties. The down side to autogenous grafts is the need for an additional surgical site for graft procurement, which creates additional risk on top of that already associated with the primary surgical site. Common donor sites for autogenous grafts used in the foot include the iliac crest, proximal and distal tibia, posterior superior calcaneus, and adjacent metatarsal shafts. Myerson et al (23), in 2000, reported on their experience with allogeneic and autogenous bone grafts for the restoration of length and reconstruction of the first MTPJ through arthrodesis. Nine of the 24 patients in that study suffered from AVN of the first metatarsal head that successfully achieved fusion of the first MTPJ with the addition of bone graft. Suzuki and colleagues (24) reported success with fusion of the first MTPJ following a case of idiopathic osteonecrosis without the use of bone graft.

Osteocel is a complete bone graft substitute that contains undifferentiated adult stem cells, and conveys the 3 properties of living bone that contribute to growth; namely, osteoconduction, osteoinduction, and osteogenesis. As such, Osteocel is the first commercially available osteogenic product for bone repair (6). The undifferentiated mesenchymal cells, which are attached to allogeneic cancellous chips, are cryopreserved at temperatures between −60°C to −80°C. Before they can be used, the bone graft substitute must thaw for approximately 15 minutes. Once thawed, the remaining solution is discarded and the bone substitute is inserted into the surgical site.

In regard to the case described in this report, the superior posterior aspect of the calcaneus was used as a source for autogenous bone graft, an area recommended by Mahan (25) as a site containing substantial graft tissue. Other advantages for using the calcaneus include the combined corticocancellous stability, strength, and superior options for fixation (21).

After obtaining this relatively large corticocancellous autogenous graft (Figure 16), we packed the defect with a matching contoured section of iliac crest allograft in an effort to enhance healing and decrease the risk of calcaneal stress fracture. Feeney and colleagues (26), in 2007, reported their experience with calcaneal bone grafts and replacing the donor defects with allogeneic cancellous bone cubes. They found that calcaneal donor sites with allogeneic bone replacement healed at an average of 18 months, whereas radiographic consolidation in donor sites without replacement was complete at 12 months. They also observed 2 postoperative calcaneal fractures in their study, 1 from each group, making it unclear as to whether allogeneic replacement at the donor site reduced the risk of subsequent calcaneal fracture. In our case, after 14 months of postoperative observation, no signs of a calcaneal fracture have appeared.

In summary, the case described in this article, in which AVN developed following an isolated first MTPJ cheilectomy, is both interesting and unusual. Sequential radiographs displayed severe intraosseous deterioration of the first metatarsal head with subsequent collapse of the MTPJ over the course of 1 year. Additionally, we discovered intraoperatively that at 13 months post-cheilectomy, the cartilaginous surface of the metatarsal head was still intact. Furthermore, as described in the peer-reviewed biomedical literature, first metatarsophalangeal arthrodesis with autogenous bone graft is a reliable surgical procedure for reconstruction of the joint that has been destroyed in such a fashion. Finally, in this article, for the first time in the foot and ankle surgical literature, we describe the use of a complete bone graft substitute, namely Osteocel, combined with an autogenous corticocancellous calcaneal bone graft and low-intensity ultrasound stimulated osteogenesis, for the reconstruction of a severely degenerated and shortened first ray. Although most case reports are presented with a longer duration of follow-up than we have reported here, we felt that it was important to submit this presentation because of the unusual etiology of the AVN and the novelty of the specific intervention used to repair the damaged first ray.

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