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CALCANEAL HYBRID RECONSTRUCTION WITH FEMUR HEAD ALLOGRAFT ENRICHED WITH BONE MARROW AND ALT FLAP

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Summary

Open calcaneal fractures with bone and soft tissue loss often require complex reconstructive strategies aimed at restoring the hind-foot anatomy and physiologic ambulation. Although there is no established gold standard for treatment, the techniques utilized include bone autografts and allografts, composite flaps, and prosthesis. We report the case of a 43-year-old healthy man, who suffered an open fracture of the right calcaneus with bone loss and a wide soft tissue defect, following a motorcycle accident. After the emergency management, a reconstruction with a femur head allograft and free anterolateral thigh flap (ALT) was planned. The allograft was shaped with the aid of 3D-printed models of the defect and residual calcaneal bone. Concentrated bone marrow aspirate (cBMA) was utilized as a biological adjunct to promote osteointegration by enhancing new bone formation. The soft tissue defect was reconstructed with an anterolateral thigh flap (ALT), harvested from the contralateral thigh, and anastomosed with the posterior tibial vessels. Off-label treatment with Teriparatide was initiated postoperatively, to further boost the healing process. The reconstruction was successful, with full weight bearing reached at 6 post-operative months, and no reported complications over the 8 months follow-up.

Key words: calcaneus, reconstruction, bone, allograft, ALT, cBMA, teriparatide

INTRODUCTION

Calcaneal fractures constitute 1-2% of all fractures and typically result from high-energy traumas, such as falls from height and traffic accidents. While uncommon, open calcaneal fractures with bone loss pose a reconstructive challenge. The calcaneus plays a pivotal role in weight-bearing and load transfer while standing and walking; thus, impairments of the heel anatomy might hamper ambulation, substantially restricting patients' activity and quality of life. Moreover, open fractures exhibit an increased risk of infectious complications

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Chair of Plastic Surgery, Department of Surgical Sciences, School of Medicine and Surgery, Tor Vergata University of Rome, via Montpellier 1, 00133, Rome, Italy. Tel. +39 06 23 18 85 14. E-mail: benedetto.longo@uniroma2.it

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This is an open access article distributed in accordance with the CC-BY-NC-ND (Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International) license. The article can be used by giving appropriate credit and mentioning the license, but only for non-commercial purposes and only in the original version. For further information: https://creativecommons.org/licenses/by-nc-nd/4.0/deed.en and osteomyelitis, potentially necessitating extended patient care and more complex reconstructive procedures ^{1,2}. Despite various techniques described for open calcaneal fractures reconstruction, there is currently no universally accepted gold standard of treatment. Tailored approaches are often employed, taking into consideration the defect type and size, the presence of post-traumatic complications, and patients' comorbidities ³⁻⁵. In cases involving calcaneal bone loss requiring bone augmentation, reconstructive strategies might encompass the use of bone autografts or allografts, vascularized or pedicle bone autograft flaps, and composite allograft with vascularized fibula or medial femoral condyle flap 6-9. This report details a successful case of calcaneal defect reconstruction, utilizing a femur head allograft enriched with autologous bone marrow and a free anterolateral thigh flap, performed in a 43-year-old man who suffered a severe injury following a motorcycle accident.

CASE REPORT

We report the case of a 43-year-old healthy man, who sustained a severe trauma involving the right hindfoot following a motorcycle accident. The patient presented with an open Gustilo IIIB fracture of the right calcaneus with bone loss (6 x 2.5 cm) and a wide soft tissue defect (12 x 9 cm), involving the calcaneal area, and extending to the lateral malleolus (Fig. 1). The emergency management included intravenous antibiotics, wound irrigation, thorough debridement of devitalized tissues, and VAC therapy. Six wound debridement procedures and change of VAC therapy were performed over the first month following the trauma. Wound swabs, taken and sent for microbiological examination at regular intervals during hospitalization, did not show the presence of infection and no radiographic signs of osteomyelitis were detected. At one month from the injury, the patient was evaluated by the orthopedic and plastic surgery teams, and a combined reconstruction of the bone and soft tissue defect with a bone allograft and a free anterolateral thigh (ALT) flap was planned. Before surgery, 3D-printed models of the residual and contralateral healthy calcaneal bone were realized based on threedimensional CT reconstructions to study and assess the shape and size of the calcaneal defect. Following the request to the local musculoskeletal bone bank, a nonirradiated proximal femoral epiphysis was assigned to the patient for the reconstruction (Fig. 2).

The surgery started with the harvesting of the anterolateral thigh flap from the left lower limb, with the patient in the supine position. The perforator flap included a skin island of 14×9 cm, based on a single perforator of the descending branch of the lateral circumflex femoral artery (Fig. 3). The flap vessels were not divided until preparation

Figure 1. A pre-operative photograph of the right foot taken one-month post-trauma shows the exposed calcaneal bone. Additionally, a substantial soft tissue loss is evident, encompassing the weight-bearing region of the foot and extending towards the lateral malleolus.



Figure 2. Intra-operative photograph showing the femur head allograft and the 3D-printed models of residual calcaneal bone and calcaneal bone defect.





Figure 3. Intra-operative photograph showing the harvested anterolateral thigh (ALT) flap based on a single perforator of the descending branch of the lateral circumflex femoral artery and its comitant vein (flap dimension: 14 x 9 cm; pedicle length: 13 cm).

of the recipient vessels and debridement of the defect area was completed. Simultaneously, the orthopedic team performed a surgical debridement of the recipient area and residual calcaneal bone. A 60 ml svringe of blood and bone marrow aspirate was taken percutaneously with the BioCUE® Blood and Bone Marrow Aspiration (bBMA) Concentration System, from the right anterior iliac crest. After completion of the debridement procedure, the bone allograft was molded according to the defect size and shape with the aid of the 3D printed models, positioned at the defect site and enriched with autologous bone marrow. Fixation of the bone allograft was performed with custom-made calcaneal plating system with cortical and Herbert screws (Figs. 4-5). An intra-operative x-ray was performed to confirm the correct positioning of the bony allograft. After reconstruction of the osseous defect, a small incision was performed posterior to the right medial malleolus, to isolate and prepare the posterior tibial artery and veins, chosen as recipient vessels for the ALT flap. A subcutaneous tunnel in the posterior calcaneal region was



Figure 4. Graphic illustration of the calcaneal bone-allograft osteosynthesis (lateral view).



Figure 5. Graphic illustration of the calcaneal bone-allograft osteosynthesis (posterior view).

prepared, to allocate the pedicle vessels. The flap's pedicle was then divided and the flap transferred to the defect site. The pedicle was positioned in the prepared tunnel, to reach the medial aspect of the foot (...) (Fig. 6). Two suction drains were placed in the right foot, one beneath the ALT flap, and one at the site of the microvascular anastomoses. Off-label treatment with Teriparatide was started the first postoperative day (20 mcg subcutaneously per day) and continued for six months. Thromboembolic prophylaxis with 4000 U.I. of low molecular weight heparin, started during hospitalization, was continued after surgery. The patient was monitored with hand-held doppler ultrasound for 5 days, and the post-operative follow up was uneventful. Weight bearing was avoided for the



Figure 6. A) site of anastomosis between the recipient vessels, posterior tibial artery and vein, with the flap pedicle vessels; **B**) posterior view of flap pedicle vessels located in the prepared tunnel underlying the Achille's tendon; **C**) calcaneal bone defect reconstructed with the femur head allograft.

first 8 weeks and the patient was placed in a splint. Follow-up controls showed viable flap and stability of the soft tissues; a post-operative CT performed at 8 weeks from surgery showed signs of bone healing, and the patient was allowed to begin partial weight bearing, with wedges (Fig. 7). After a new CT performed at 12 weeks, showing increased callus formation, the patient was advised to progressively increase weight-bearing, with the guidance of a physical therapist. At 6 months from surgery complete weight bearing was reached, and the patient was able to walk with no limping and without supports without supports (Fig. 8; <u>Video 1.</u> Post-operative video recorded at 6-month follow-up showing physiologic ambulation without supports). The patient did not refer pain during ambulation and every-day activities.

DISCUSSION

Reconstructing open calcaneal fractures with bone loss presents a challenging task, and there is currently no universally accepted gold standard treatment for such defects. Our patient presented with an open calcaneal fracture, with bone loss affecting the inferolateral calcaneus and a substantial soft tissue defect of the right hindfoot and lateral malleolar area. Considering the composite nature of the calcaneal region's defect, the reconstructive plan was customized to both restore sufficient structural support to the heel for a stable surface for load transfer and provide vascularized soft tissue coverage to ensure the stability of the reconstructed bone and minimize the risk of infectious complications. Different surgical approaches have been described for the reconstruction of calcaneal bone



Figure 7. Post-operative photograph taken at 2-month followup showing signs of bone healing at the allograft-calcaneal bone interface.



Figure 8. Post-operative photograph taken at 6-month followup showing the aesthetic outcome of the reconstruction (lateral and posterior views).

defects, including composite flaps, autografts, allografts and custom synthetic implants ^{6,10,11}. Considering the presence of a partial defect of the calcaneal bone without involvement of the articular surfaces, the use of a prosthetic implant was ruled out. Defect reconstruction with autologous bone grafts or osteocutaneous flaps was considered, but to minimize donor site morbidity, we opted for the use of a non-irradiated femur head allograft provided from the local bone and musculoskeletal tissue bank, combined with a free anterolateral thigh flap (ALT). Bone allografts have long been used as structural frameworks to provide bone reconstruction in the foot and ankle, following traumas, post-traumatic sequelae and corrections of deformities, with overall good outcomes in terms of healing and integration ¹². The femur head allograft is a corticocancellous structural bone graft, and among the most used bone allografts. Its application in foot and ankle surgery has been reported mostly for arthrodesis procedures, whereas literature is sparse as regards its use for the reconstruction of calcaneal bone loss ¹²⁻¹⁵. Loder et al. and Weiss et al. reported successful delayed calcaneal reconstructions with femur head allografts in two patients who developed post-traumatic osteomyelitis following ORIF treatment requiring calcaneal resections. Restoration of full weight bearing was observed at 12 weeks and 4 months, respectively, with overall good outcomes in the long-term follow-up and no major complications. Plateletrich plasma (PRP) was utilized as a biological adjunct to improve early allograft integration and osteogenesis in the case reported by Loder et al., whereas Weiss et al. utilized demineralized bone matrix (DBM), bone morphogenetic protein 2 (BMP-2) and concentrated bone marrow aspirate (cBMA) to promote an osteoconductive and osteoinductive environment at the bone-allograft interface. Hsu et al. and Metha et al. described an innovative approach for calcaneal bone reconstruction utilizing femur head allografts revascularized by medial femoral condyle (MFC) flaps, which was successful for the bone reconstruction following traumatic calcaneal avulsion and post-traumatic ostomyelitis of the calcaneus respectively.

When assessing bone defect reconstruction, allografts are recognized for their benefits in minimizing donor site morbidity and pain, as well as their ease of handling. However, despite serving as effective osteoconductive scaffolds, allografts lack osteogenic and osteoinductive properties, which play a pivotal role in bone healing. Considering this, biological adjuncts are increasingly used to enhance new bone formation, thereby enhancing the overall healing process. In our case concentrated bone marrow aspirate (cBMA) was utilized to enrich the allograft with adult mesenchymal stem cells (MSC), which have the potential to differentiate into osteoprogenitor cells. Studies have shown that the BMA used with allografts, demineralized bone matrix, or synthetic materials, promotes new bone formation, and the results are in some cases comparable with the use of autografts alone ¹⁶⁻¹⁹. In a study conducted on revisions of hip surgery with acetabular grafting, Hernigou et al. observed a higher concentration of bone marrow-derived mesenchymal stem cells (BM-MSCs) in allografts previously loaded with MSCs, compared to autografts, and increased new bone formation in MSCs loaded allografts, compared to uncharged allografts and autografts ¹⁸. Besides the use of cBMA, in our case, off-label postoperative treatment with teriparatide was applied to promote allograft osteointegration. Teriparatide is a recombinant form of the bioactive component of the parathyroid hormone (PTH), mostly used in postmenopausal women for its demonstrated effects of increased bone mass, and fracture prevention. The promising results of preclinical studies have expanded teriparatide use as offlabel treatment of delayed fracture union, and non-union, with evidence, although still limited, supporting its safety and beneficial effects on callus formation and bone healing. Reynolds et al. have shown a remarkable potential of Teriparatide as adjuvant therapy for allograft repair in mice, with substantially improved osteointegration, and a 2-fold increase in callus volume and union-ratio, compared to controls ²⁰. In the presented case bone reconstruction was combined with the use of a free ALT flap, which served as an optimal tissue coverage, to reduce the risk of infections.

CONCLUSIONS

In the detailed case of a complex calcaneal defect with bone and soft tissue loss, the planned reconstruction with femur head allograft enriched with cBMA and anterolateral thigh flap yielded a complete restoration of physiological ambulation and pre-injury activities with no limping nor pain at the 6 months follow-up. No complications were observed over the post-operative course and the patient was satisfied with the aesthetic and functional outcomes of the reconstruction.

CONFLICT OF INTEREST STATEMENT

We, hereby certify, that to the best of our knowledge no financial support or benefits have been received by author or any co-author, by any member of our immediate family or any individual or entity with whom or with which we have a significant relationship from any commercial source which is related directly or indirectly to the scientific work which is reported on in the article. None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this manuscript.

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AUTHOR CONTRIBUTIONS

BL: A, W MG: S, W RI: A, W GD'O: D, DT EG: D, DT LV: D, DT TG: D, DT UT: A, W VC: A, W

Abbreviations

A: conceived and designed the analysis
D: collected the data
DT: contributed data or analysis tool
S: performed the analysis
W: wrote the paper
O: other contribution (specify contribution in more detail)

ETHICAL CONSIDERATIONS

Not applicable.

DISCLOSURES

The patient gave written consent to the drafting of the article, and the use of images.

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