



Three-dimensional printed calcaneal prosthesis following total calcanectomy[☆]



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ABSTRACT

INTRODUCTION: The majority of patients with extremity sarcoma can be surgically treated without amputation. However, limb-salvage surgery for foot sarcomas including the calcaneus remains challenging.

PRESENTATION OF CASE: A 71-year-old man presented with a 5-year history of right heel persistent pain. Imaging studies revealed an osteolytic, destructive and highly metabolic lesion in the right calcaneus. Computed tomography guided core needle biopsy confirmed the diagnosis of grade 2 chondrosarcoma. A total calcanectomy was performed, and the defect was reconstructed with a patient matched three-dimensional printed titanium calcaneal prosthesis. Intra-operatively, ligaments including the Achilles tendon, and plantar fascia were reattached. The post-operative course was uneventful, and at the 5-month clinical follow-up, the patient was fully weightbearing, with a mobile ankle without pain.

DISCUSSION: This case is the first to use additive manufacturing to create a prosthetic calcaneus. The complex peri-calcaneal articular surfaces and reattachment of tendinous structures facilitate efforts to stabilize the prosthesis in situ.

CONCLUSION: Three-dimensional-printed prosthesis of the calcaneus is a viable alternative to amputation.

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1. Introduction

Approximately 90% of the sarcomas arising in extremities can be successfully treated with limb-salvage surgeries [1]. However, for sarcomas of the foot including calcaneus, below-knee amputation has been the standard choice of operative treatment due to its poor compartmentalization [2]. Only a limited number of limb-salvage procedures has been reported for sarcomas arising in the calcaneus [3–11].

Methods reported for calcaneal reconstruction following tumor resection include bone allografts, vascularized or pedicled bone autografts, composite allografts with vascularized fibula, and custom-made calcaneus prosthesis. These procedures may be asso-

ciated with complications requiring long-term immobilization, non-weightbearing and the potential for subsequent amputation.

In recent years, three-dimensional (3D) additive printing technology has become the focus of attention in the field of medicine. This technique has been utilized in various situations, such as customized operative instruments [12]. Although some cases with 3D-printed prosthesis, such as tailor-made hip replacement, have been reported via mass media, no case has been published by medical journals to date.

We describe the surgery and outcome following total calcanectomy that was reconstructed with a 3D-printed titanium calcaneal prosthesis.

2. Presentation of case

A 71-year-old man presented with a five-year history of right heel pain. Radiographic studies revealed an abnormal lesion in the right calcaneus, and thallium scintigraphy showed a high metabolic activity (Fig. 1). Computer tomography (CT) assisted core needle biopsy confirmed the pathological diagnosis of chondrosarcoma, grade 2. At the time of diagnosis, no distant metastasis was detected.

Total calcanectomy followed by prosthetic reconstruction was performed. The prosthesis, which is mirror image of the left

[☆] This study was conducted at St. Vincent's Hospital Melbourne, in accordance with the World Medical Association Declaration of Helsinki. The patient in this case report was informed that data, radiographs, and photographs from the case would be submitted for publication and gave his written consent. We declare that we have no conflicts of interest.

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Fig. 1. Pre-operative imaging. Radiographs (A and B) show an osteolytic lesion in the right calcaneus. Computed tomography (C) shows expansion of bone remodeling of the lateral wall as well as stipple calcification and popcorn type appearance in the right calcaneus, where a high accumulation of thallium is observed (arrow) (D).

calcaneus, was custom made (Anatomics Pty., Ltd., Australia) by an Electron Beam Melting 3D printer (CSIRO High Performance Metals Technologies, Australia) based on helical CT DICOM data. The prosthesis weighed 280g, and its strength was thought enough (Fig. 2). Through a Cincinnati incision, the Achilles tendon was detached, and the plantar fascia was released from the calcaneus. Then, medial neurovascular structures were retracted, and the peroneus longus tendon was dissected out of its sulcus, which enabled access to the ligaments between the calcaneus and surrounding tarsal bones (Fig. 3). After resection, having engaged the various



Fig. 2. A prototype of the calcaneal prosthesis showing an ability to sustain a load of over 6t.

articular surfaces the prosthesis perfectly fit the defect and was stable even before soft tissue reconstruction. The prosthesis was tightly sutured to the Achilles tendon, plantar fascia, and spring ligament using anchor points on the prosthesis (Fig. 4). Post-operative radiograph showed the perfect fit of prosthesis (Fig. 5).

Post-operative course was uneventful. The right ankle was plaster-casted in plantar flexion for two weeks after surgery. Two weeks post-operatively, plaster was switched to CAM walker boot and held in plantar flexion for a further four weeks. No weightbearing was permitted on the right foot for six weeks after surgery. Then, weightbearing was allowed, gradually increased to fullweight over the next three months. At the latest clinical follow-up, five months after surgery, the patient was free of pain without medication, and could walk unsupported on bare feet (Video 1). He also could continuously walk more than six blocks with the CAM walker boot. Ranges of motion of the right ankle remained restricted mainly in inversion and eversion, with 5° of dorsiflexion, 25° of plantarflexion (Video 2), and 5° of both inversion and eversion, but the ankle was stable both anteroposteriorly and laterally. The American Orthopaedic Foot and Ankle Society (AOFAS) Ankle–Hindfoot Scale score for this patient was 82 points.

3. Discussion

Limb-salvage surgery for sarcomas and aggressive benign tumors in the calcaneus remains challenging, with only 18 cases reported to date (Table 1) [3–11]. Allograft and autograft reconstructions have been the preferred modality in the majority of cases. The use of allografts for calcaneal tumors was first published by Ottolenghi and Petracchi in 1953 and one more case was reported in 2000, but both resulted in collapse [8,10]. High rates of infection, non-union, and collapse related to allografts have been also reported by others [13]. If extensive multilayer defects are expected, vascularized or pedicled osteofasciocutaneous flaps, such as iliac crest and fibula, are preferable [5,6,11]. However, these flaps also have some issues; while a vascularized iliac crest flap is difficult to combine with sensory nerve reconstruction, a pedicled fibular

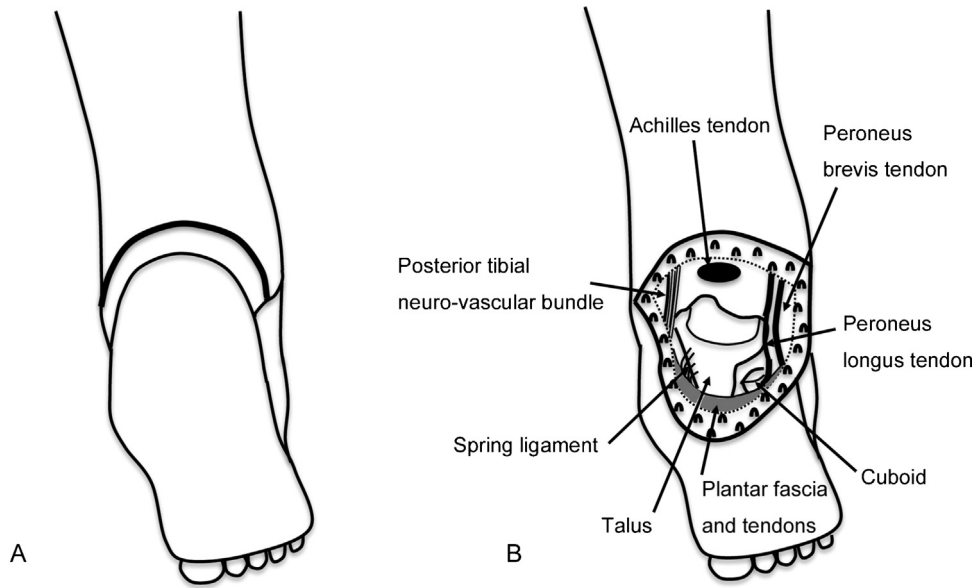


Fig. 3. (A) Transverse posterior skin incision along the skin crest. (B) Scheme illustrating intra-operative field after calcaneectomy.

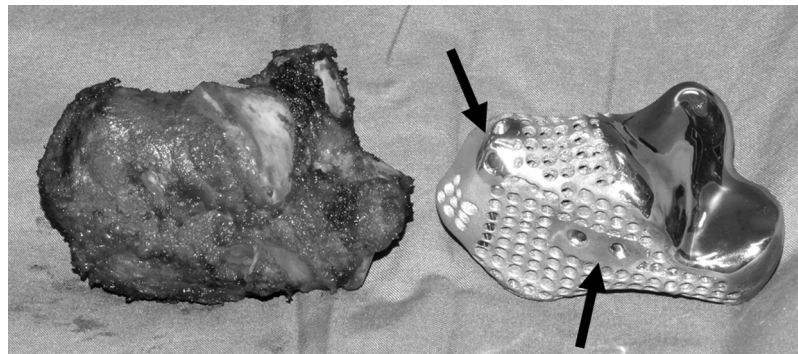


Fig. 4. A photograph showing the resected specimen and prosthesis. The prosthesis was partially polished for the talocalcaneal and calcaneocuboidal joints. Anchor points (arrows) were used to attach ligaments to the prosthesis.

graft cannot provide enough space for reconstructing the Achilles tendon apparatus. For these reasons, Li et al. modified their strategy and reported the combined method of vascularized fibular osteo-fasciocutaneous flap and allogenic bones (Capanna technique) in 2012 [7]. Although all these past cases of allografts or autografts have obtained acceptable functional results, there still remain problems. One common issue among the past bone graft cases is the



Video 1. A movie showing the patient walking on bare feet at the 5-month follow-up.

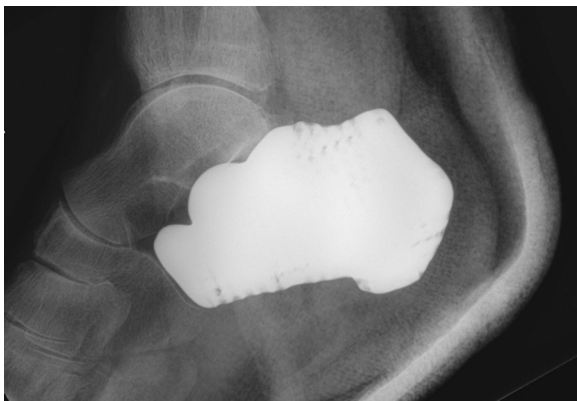


Fig. 5. Post-operative lateral radiograph showing the perfect fit of calcaneal prosthesis in relation to the talus and cuboid.

Table 1
Past literature of various reconstructions after calcaneectomy for tumors.

Study (year)	No.	Reconstruction	AOFAS score	Features	Follow-up
Chou (1998, 2007) [3,4]	1	Prosthesis and arthrodesis	67	Shoe limitation Moderate persistent pain	12 years
Ottolenghi, Muscolo (1953, 2000) [8,10]	1	Allograft and arthrodesis	N/A	Grafted bone collapse Plaster cast for 7 months	32 years
Muscolo (2000), case 2 [8]	1	Allograft and arthrodesis	N/A	Grafted bone collapse ROM limitation	9 years
Woźniak (2007) [9]	3	Allograft and arthrodesis	N/A	ROM limitation	6 months
Kurvin (2008) [5]	1	Vascularized iliac bone and arthrodesis	N/A	WB limited for 4 months	8 months
Scoccianti (2009) [11]	2	Vascularized iliac bone and arthrodesis	N/A	Fracture (one case) Plaster cast for 11 weeks WB limited for 6–8 months	79–93 months
Li (2010) [6]	5	Pedicled (osteocutaneous) fibula	80–95	WB limited for 8.6 months Difficulty re-suturing the Achilles tendon	32–76 months
Li (2012) [7]	4	Composite allograft with pedicled (osteocutaneous) fibula	80–95	Two revision cases WB limited for 6.5–8 months	13–37 months

AOFAS: American Orthopaedic Foot and Ankle Society, N/A: not applicable, ROM: range of motion, WB: weightbearing.



Video 2. A movie showing almost the same active dorsiflexion and plantarflexion range of motion among both ankles.

lengthy period of immobilization and weightbearing limitation for bone union. In plastic reconstruction cases, a long operation time and prolonged hospitalization to protect the soft tissue reconstruction can be another problem.

Custom-made prosthesis reconstruction was first reported by Chou et al. [3,4]. This prosthesis was fixed to the talus via a posterior approach including plantar skin incision. The ankle was plaster-casted for the first two months, but the details of weightbearing were not described. Even though the prosthesis was specially designed for the patient, the 18-month-post-operative radiograph revealed some gap between the prosthesis and the cuboid. At the 12-year clinical follow-up, the patient could walk eight to ten blocks but suffered from persistent pain in the planter heel pad. Bare foot walking was not possible and different shoe wear was required for the operated foot.

In our case, we used a patient matched 3D-printed titanium calcaneal prosthesis, which had several advantages. First, the availability of software to acquire and then transfer computer tomographic data allowed an accurate reproduction of the prosthesis which would not have been previously possible. Second, the ability to differentially print different parts of the prosthesis

allowed selective polishing of parts of the calcaneal prosthesis that corresponded to the articular surfaces. Third, anchor points were printed into the prosthesis to allow attachment of the Achilles tendon, the plantar fascia, the spring ligament and also soft tissue on the medial and lateral sides of the prosthesis. Fourth, small round holes of 3-mm diameter were designed (mesh structure) to promote tissue integration. Fifth, titanium was chosen because it is light, strong, and biocompatible. Sixth, 3D printing allowed the prosthesis to be hollow on the inside except for specifically designed weightbearing struts to reduce the overall weight of the implant compared to a solid titanium block with the same shape. Seventh, the availability of a ready-made anatomically matched prosthesis may reduce the intra-operative refashioning of allograft or autograft material. Finally, this technique required only several days from order to clinical use, including designing (approximately two days), design reviewing by surgeon (depending on the surgeon), 3D printing (one day), and post processing (two days).

At the five-month clinical review, the patient had satisfactory clinical results without any major complication or pain, which may be partially attributed to the choice of skin incision. Surgery to the hindfoot can be associated with high rates of complications including prolonged wound healing, sural nerve injury, and ugly scar formation [14–16]. However, the Cincinnati incision, which was initially described by Crawford et al. in 1982 preserves the neurovascular and lymphatic supply of the foot, has the advantages of almost invisible scar formation and fairly low risks of complications [17,18]. One possible issue associated with this skin incision applied to calcaneectomy is difficulty approaching the entire circumference of talocalcaneal joint, but we could dissect its ligaments via this approach by retracting medial neurovascular structures and peroneal tendons.

The limitation of our report is the short term of follow-up, which is too early to draw any definitive conclusion. However, we can report that this method is less invasive without donor-site problems and can promote earlier rehabilitation and discharge from hospital. If a calcaneal sarcoma or aggressive benign tumor is localized in the calcaneus and no soft tissue coverage is required, 3D-printed calcaneal prosthesis may be a viable option, along with below knee amputation, allografts, and vascularized or pedicled bone grafts.

4. Conclusion

We report the first 3D-printed calcaneal prosthesis reconstruction case. Short-term clinical outcomes were satisfactory and early rehabilitation was possible. This prosthesis can be a promising option for calcaneal tumors.

Conflict of interest

No conflicts of interest to declare.

Source of funding

None.

Ethical approval

The quality assurance sub-committee of Human Research Ethics Committee (HRES) – A approved our project as a quality assurance activity at St. Vincent's Hospital Melbourne, with the reference number of QA: 112/14.

Consent

Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

Author's contribution

Mr. Jungo Imanishi, MD: assisted the surgery, wrote the draft for case report, carried out the literature search, and wrote up the literature review.

Professor Peter F.M. Choong, MBBS, MD, FRACS, FAOrthoA: planned and performed the surgery, edited the draft, and helped to analyze the literature review results.

Guarantor

Mr. Jungo Imanishi and Professor Peter F.M. Choong.

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