Three-dimension correction of Charcot ankle deformity with a titanium implant

Gang Wang, Junhao Lin, Hong Zhang, Yantao Pei, Lei Zhu and Qingjia Xu

Department of Hand and Foot Surgery, Department of Orthopedics, Qilu Hospital of Shandong University, Jinan, P.R. China

ABSTRACT

Background: Charcot neuroarthropathy of the ankle is an extremely challenging clinical dilemma, and its surgical management can be highly complicated. The goal of Charcot ankle treatment is to restore a plantigrade and stable foot, and thus to avoid ulceration with subsequent infection. This report aims to introduce a method of correcting ankle deformity using a novel 3D printing technique.

Patient and methods: One patient with Charcot ankle deformity was operated in this study. The ankle deformity of this patient was quantified in three dimensions through computed tomography. On the basis of the computed tomography scans, a new titanium implant was designed and manufactured using 3D printing. The implant was applied in the surgery of tibialo-calcaneal arthrodesis to restore local anatomy of the affected ankle of the patient with Charcot neuroarthropathy.

Results: Evaluation of the post-operative radiography indicated union in the affected ankle. After surgery, the planar foot in this patient was restored. The patient was satisfied with the post-operative course, and joint fusion was successful as indicated by 2-year post-operative evaluation. The results of post-operative follow-up showed that the lower limb length of the patient with Charcot neuroarthropathy was salvaged, and the patient retained the plantigrade foot.

Conclusion: Three-dimensional printing technique combined with tibialo-calcaneal arthrodesis may help to correct ankle deformity in patients with Charcot neuroarthropathy.

KEYWORDS
Charcot neuroarthropathy; talus defect; CT 3D reconstruction; 3D printing technique

Introduction

Charcot neuroarthropathy (CN) of the foot and ankle is still a poorly understood destructive disease that presents an extremely clinical challenge for foot and ankle surgeons [1,2]. The most common location for CN is the midfoot (59%), followed by the ankle (29%), and then in other locations [3].

The best treatment timing for CN is currently unknown. The treatment includes conservative non-operation treatment, and surgical treatment. At any period, the main purpose is to restore a plantigrade and stable foot, and thus to avoid ulceration with subsequent infection. If surgery is necessary, many options include osteotomy, open reduction internal fixation of neuropathic fractures, external fixation, multiple joints fusion, Achilles tendon lengthening and amputation [3,4]. However, the clinical effects of the surgical methods for CN treatment are unsatisfactory [3,4].

Since Charcot destruction of the foot is often complex, planning the surgery is challenging. Three-dimensional printing (3DP) may help the surgeons to fully understand the deformity and thus to better plan the surgery. Besides, 3DP technique can manufacture products of various sizes from the smallest nanoparticles to large buildings [5]. In medical field, 3D printed implants with good biological tissue compatibility have been widely used such as dental implants [6], neurosurgery [7], orthopedics and maxillofacial surgery [8]. Many pros encouraged the application of 3DP techniques in reconstructing or storing local anatomy of the joint. Dekker et al. [9] study reported the advantages of 3DP implants with arthrodesis for complex foot and ankle restoring, limb salvage, deformity correction. In their report, 13 of 15 cases
were shown as radiographic fusion verified by CT scan. Hsu et al. [10] reported one case report of tibio-talo-calcaneal (TTC) arthrodesis using a patient-specific 3D printed titanium cage in combination with a retrograde TTC nail to treat an open tibial plafond fracture with nonunion. Therefore, we hypothesize 3DP technique with arthrodesis could be a good attempt in correcting Charcot deformity as well as preoperative planning.

This a case report, we introduced a surgical method using 3D printed implant combined with arthrodesis in order to correct Charcot ankle deformity and restore stable and plantigrade foot in one patient. We made preoperative planning to measure bone defect by reconstructive CT scanning. Based on the data of constructive CT scanning, we designed and produced a patient-specific titanium cage using 3DP technique placed in the anatomic region to support massive bone autografts. Then, arthrodesis were performed via retrograde interlocking nails and headless compressing screws in this case.

Patient and surgical methods

Case description

A 54-year-old female patient presented with a varus deformity (Figure 1) in her right ankle. One year before, her right ankle became swollen without any deformity and other complaints. She felt numbness in the affected ankle occasionally, but which did not bother her. Her medical history showed type 2 diabetes mellitus, hypertension and hyperthyroidism. She received long-term medication to maintain normal blood pressure and thyroid function before the operation. Clinical examination showed no pain, restricted flexing and extension in the ankle. She was diagnosed with CN by surgeons, and she asked for surgical solution for the improvement of life quality. The surgery was approved by hospital medical ethics committee.

Preoperative planning

Radiographic examination was assessed by the whole surgeon team in our department of the hospital. The radiograph showed a large osteonecrosis of the talus, which influenced peripheral joints in the hind foot and tibia-talus joint (shown in Figure 2(a)). The dislocation around the talus was found posterior of the right ankle.

Reconstructive CT scans of the defective lower limbs contained the tibia, fibula and foot (Figure 2(a)). DICOM files obtained from the CT scan were used to segment target bones via the software Mimic Medical 20.0. The bony regions were labeled manually in all slices of the CT images based on the gray values for the bones. The automated segmentation of the bone started by gray values and was followed by manually editing the slices to obtain more accurate regions. Thus, the bones of interest with the pathologic fragment were separated from the surrounding bones using a region growing algorithm. The analysis result via software demonstrated that the target space of damaged talus was 3.4 cm × 3.2 cm × 2.8 cm, which was approximately the shape of a sphere. Then, the digital cloud data in STL Files with 3D model and STEP files which containing the information of the sites and the reference lines for the implant, was used to make preoperative plans and the design of the implant by the 3D software UG 12.0.

Four surgeons in our department consulted with one engineer and three technicians who were involved in 3DP team for the preoperative planning from the manufacture (Shenshi Medical Device, Shanghai). The 3DP product meets CFDA standards (ID: YY/T 0640-2016). A final decision was made to operate TTC arthrodesis, using nail fixation method after debridement. The damaged talus was replaced by a printed spherical implant filled with ilium crest autografts. Retrograde interlocking intramedullary nail and other screws were used to strengthen new TTC compound. After making the decision, the manufacture triggered the design process under the surgeons’
supervisor. Once the design was approved by surgeons, the schematic diagram was sent to technicians for the production of titanium implant and then the final product was delivered to surgeons for the final evaluation. It took a total of ten days to design and produce the titanium cage for the operation. The cost of R&D was about 12,000 RMB yuan. The implant design was represented in the schematic diagram in Figure 3. The spherical implant (Figure 3(c)) was designed for the insertion of retrograde intramedullary nail (Figure 3(d)).

Surgical technique

The lateral approach was selected in the right ankle of the patient. Osteotomy was performed to remove 8 cm of distal fibula in which way clearly exposed the local tibia, talus and calcaneus. Then, the destroyed talus and distal articular surface of the tibia were removed meticulously to form a local space (around 3 cm of diameter) for the cage graft. Local bone fragment and degenerated synovium were continued to remove or scape to provide a space for the cage. Then the local debridement was executed to clear necrotic tissues and bones around destroyed talus. After the titanium implant was filled with ilium crest and the cut off fibula fragment autografts, it was inserted in anatomic place of talus. TTC fusion was executed and strengthened by the retrograde interlocking intramedullary nail and several headless compression screws. The residues of bone tissue were scattered in the space around artificial implant. Finally, the wound was sewed with absorbable and nonabsorbable suture layer-by-layer after adequate hemostasis and negative pressure drainage. A well-padded splint was placed around hindfoot in the right ankle to maintain the position of the foot at 90 degrees to axial position. Figure 4(a–c,e,f) showed the whole surgical process in the patient with CN. In Figure 4(d), two sizes of the cage, dimeter 3 and 3.4 cm respectively, were produced by manufacture, to manage the uncertainty to be sure that the cage fit well the vacuity. In practice, the bigger (3.4 cm) was used after clearly moving the destroyed bones.
Postoperative treatment and follow-up

Wound dressing was performed daily, and the drainage stopped 5 days post-operatively. No signs of infection and visible necrosis were observed, and the sutures on the skin were removed at 3 weeks post-operatively. Then, a short leg cast was applied to avoid weight bearing on the operated ankle. At 2 months post-operatively, the patient was permitted to weight partial (50%) bear in the walking brace. The functional exercise was encouraged gradually until the patient could totally tolerate the full body weight without complaints.

Results

The patient had no complications after discharge from our hospital. She presented in our hospital again at 3 and 14 months post-operatively for regular follow-up. TTC joint showed good signs of fusion from X-ray 3 months after surgery in Figure 5(a,b). Her 14-month radiographs in Supplementary Figure showed no obvious bone uptake around the hardware and no dislocation of multiple joints in the hind foot with forming bone trabecula. She presented normal appearance with her affective ankle when weight-bearing standing and walked well. Because of personal reasons, the patient did not return to the clinic at 2 years post-operatively. We talked by phone, and the patient reported no clinical complaints of fracture, infection, dislocation, deformity and other signs. She can walk with full weight-bearing pain free. The present evidence indicates the joint fusion using 3DP was deemed successful by 2 years post-operative observation. She only has decreased feeling on local surface of the right ankle, which did not bother her.

Discussion

Although early conservative treatment of Charcot joint disease can prevent or delay the development of the disease, the development of CN is still hard to control. Many types of surgical intervention correct deformity and prove the life quality of patients with CN. However, an ideal surgical method for CN disease remains lacking to date. Joint fusion surgery is usually employed by surgeons to restore local anatomy. Unfortunately, the joint fusion failure rate was high enough [11]. In the study by Eschler et al. [12], 6/7 (85.7%) patients with Charcot disease had high risk of post-operative infections and 2 cases (28.5%) had
amputations due to osteomyelitis. The choice of fixation in surgery is also controversial [13]. A previous study reported that the incidence of pin infection after external fixation was 100% [14]. In addition, intramedullary screw fixation has several advantages, but Butt and other professionals [15] believed that the risk of failure of internal fixation after intramedullary screw operation is high (80%). Autologous and allogeneic bone grafts were used in previous reports. Allografts for the treatment of ankle bone defects easily lead to a high incidence of nonunion (50%) and amputation (19%) after TTC joint fusion [16]. Therefore, we choose autografts for reconstruction-arthrodesis in the present study, and 3D printed titanium cage services as a package for autografts.

Considering our clinical experience, we believe that a stable fixation plays a key role in correcting ankle deformity. An option is to use a titanium cage, filled
with bone autografts. A stable substitute for damaged talus was formed to connect the tibia and the calcaneal. In this case, a spherical implant was designed to maximize the surface area and allow maximum contact with the surrounding distal tibia and other joints. More importantly, such a spherical structure is more linked to the preoperative planning of the bone debridement.

So far, the number of cases of Charcoal joint disease treated with 3DP is small. To the best of our knowledge, 3D printed grafts have been used for joint abnormalities of the midfoot in patients with Charcoal disease. Eric et al. [17] utilized similar ideas and surgical methods. They reported three cases of Charcot’s disease in the midfoot of the lesion and customized a 3D printed implant based on personal situation. The titanium implant successfully repaired the bone defect of the foot. However, Aubret [18] placed a non-customized trabecular metal implant for the failure of previous TTC joint replacement surgery. The square implant possibly lacked sufficient stability (insufficient construct stability) and thus was not able to fix the entire ankle joint. As a result, it did not meet the author’s original expectations. Lachman et al. supported that 3D printed titanium trusses had the ability of filling voids and providing more stable structural support to prevent collapse in bone loss/hindfoot deformity. They thought treating surgeons must adhere to principles of arthrodesis, such as stable constructs, thorough joint surface preparation, and correction of deformity [19].

Finally, there are two limitations in this report. The first is a single object. The second is that we have no long-term radiologic evidence to verify the fusion. Further evaluation should be continued, and we make a follow-up plan for this patient once per year till to postoperative five years, including radiographic analysis and physical evaluation. Further study with more cases should be performed to prove the advantages of 3DP technique in the surgical management of Charcot ankle and foot.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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