Novel exploration of customized 3D printed shoulder prosthesis in revision of total shoulder arthroplasty

A case report

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Abstract

Rationale: This paper describes the application of individual customized 3-dimensional (3D) printed macro-porous Ti6Al4V shoulder prosthesis in the revision of total shoulder arthroplasty (TSA) for the patient with severe bone defects.

Patient concerns: A 47-year-old male had been under proximal humeral resection and TSA due to shoulder chondrosarcoma 6 years ago, but a second surgery to insert a new prosthesis was then performed because the prosthesis became loose 2 months ago leaving severe bone defects which conventional prosthesis was not suitable for revision of TSA. American Shoulder and Elbow Surgeons’ Form (ASES), Neer and Constant-Murley were gradually increased after the operation. According to the X-ray, the bone healed satisfactorily without change of prosthetic position at 3rd and 12th months after the operation. The function of shoulder could meet the requirements of daily activities.

Diagnoses: The patient was diagnosed with shoulder bone defects and restriction of the shoulder movement.

Interventions: 3D printed shoulder model and computer-aided design (CAD) were used for prostheses design and surgical simulation. The novel 3D printed titanium alloy shoulder prosthesis was custom-made subsequently to be used in the revision of TSA. The patient was followed up regularly after surgery. The ASES, Neer Shoulder score and Constant-Murley Shoulder score were evaluated during pre-operation, post-operation, and follow-up.

Outcomes: Prosthesis was successfully implanted to complete anatomic reconstruction intraoperatively. The scores of ASES, Neer, and Constant-Murley were gradually increased after the operation. According to the X-ray, the bone healed satisfactorily without change of prosthetic position at 3rd and 12th months after the operation. The function of shoulder could meet the requirements of daily activities.

Lessons: The application of customized 3D printed titanium alloy shoulder prosthesis in the revision of TSA achieves satisfactory results. It provides a novel method for the similar revision surgery with severe bone defects.

Abbreviations: 3D = 3-dimensional, ASES = American Shoulder and Elbow Surgeons’ Form, CT = computed tomography, EBM = electron beam melting, STL = standardized trigonometric language, TSA = total shoulder arthroplasty.

Keywords: 3D printing, bone defects, customized prosthesis, revision shoulder arthroplasty

1. Introduction

Primary malignant tumor most often arises in the proximal humerus.\(^1\) Surgical excision is the mainstream of treatment for patients with bone malignant tumor. Many bone tumors involve resection of both the segment of tumor-bearing bone and the adjacent tissue. Therefore, bone defects are needed to be reconstructed after tumor resection depending on the extent of resection. However, the conventional therapeutic regimens including arthrodesis, artificial shoulder arthroplasty, joint transplantation, and prosthesis allograft complex are not the ideal method of reconstruction.\(^2\) Artificial shoulder arthroplasty is an effective surgical treatment for end-stage shoulder diseases, traumatic sequelae, and bone tumors,\(^3\) however, the rate of revision after shoulder arthroplasty by previous studies is approximately 5%-29%.\(^{4-7}\) Joint instability, infection, prosthesis loosening, periarticular fractures, and sports injuries are common causes of shoulder arthroplasty failure.\(^{8-13}\)

The conventional shoulder prosthesis for total shoulder arthroplasty (TSA) cannot fit the bone defects individually in revision of TSA or resection of humeral tumors due to the complexity of anatomical structure.\(^{14}\) In addition, the lack of tendon insertion and relaxation of soft tissue in the shoulder rotator cuff will lead to instability or even dislocation of the shoulder joint following the operation. Recently, the rapid
development in the technology of 3-dimensional (3D) printing has provided a new opportunity to solve such problems. Shah et al reported that 3D printed macro-porous Ti6Al4V implants could promote bone ingrowth.[15] Hence we reported a case using individual customized 3D printed macro-porous Ti6Al4V shoulder prosthesis in the revision of TSA after resection of proximal humeral tumor, and the long-term follow-up was performed to evaluate the efficacy and safety of the prosthesis.

2. Case presentation

Before the study, the “informed consent” was obtained from the patient for publication of the case details and the accompanying images. The Ethics committee of the Second Hospital of Jilin University approved this case study.

2.1. Clinical data

The patient was a 47-year-old male. Proximal humeral resection and TSA were performed for chondrosarcoma of the right proximal humerus 6 years ago. The range of motion was limited shoulder joint 6 months ago, and the X-ray showed the loosening of prosthesis (Fig. 1a and 1b) and the shoulder prosthesis was removed (Fig. 2) 2 months ago. The scarf bandage was applied to hang the limb after operation. Physical examination showed a 15...
cm surgical scar on the lateral skin of the right shoulder. Joint was empty with normal temperature, no swelling, and range of motion was not available (Fig. 1c and 1d). American Shoulder and Elbow Surgeons’ Form (ASES), Neer and Constant-Murley score were 36, 39, and 39, respectively.

2.2. Preoperative diagnosis and surgical design

2.2.1. Image data collection and processing. The X-ray of right upper limb and computed tomography (CT) (Philips iCT 256 with X-ray Tube Current 232 mA and KVP 120 kV) of bilateral upper limb were collected before operation. Then the CT data was exported in the format of DICOM, and 3D images were reconstructed by software MIMICS 19.0 (Materialise’s interactive medical image control system, Materialise, Belgium). Finally, the data were exported in the format of standardized trigonometric language (STL).

2.2.2. Auxiliary diagnosis of 3D printed model. The STL file was imported into Magics 19.0 (Materialise’s interactive medical image control system, Materialise, Belgium) to make the support structure, and then exported to 3D printing equipment (stereo lithography appearance (SLA)-450, Shining, China) in the format of magics to start printing. The 3D printed bone model was used to help surgeons evaluate the bone defects, select prostheses, and design surgical procedures.

2.2.3. Design of individual 3D printed prosthesis. According to the 3D reconstruction data of the both upper extremities, the mirror image of left humerus was obtained, and it was best fitted with right humerus image (Fig. 3a). Then the Boolean subtraction of the left image data and the right side data was used to measure the bone defects accurately. According to the result of measurement, anatomic reconstruction and bone ingrowth, the

![Figure 3](image.png)

**Figure 3.** Design and manufacture of prosthesis. a: simulation of filling bone defects with mirror image technology. b: computer aided design of prosthesis. c d: individual customized 3D printed macro-porous Ti6Al4V shoulder prosthesis.
individual customized 3D printed macro-porous Ti6Al4V shoulder prosthesis was designed and made by the Electron Beam Melting (EBM) 3D-printer (Fig. 3b, 3c, and 3d). In accordance with literature,[16,17] the pore size and porosity were set to 70 μm and 60%, respectively. Some prefabricated holes on the prosthesis were designed as parts of the soft tissue attachment.

2.3. Surgical technique

Under general anesthesia, the patient took the supine position; the right upper limb, the neck, and the anterior chest were sterilized. The incision was taken through the original scar which was from the coracoid, along the anterior margin of deltoid, to the ending point of deltoid on humerus, with a total length of 15 cm. We separated deltoid and pectoral muscles, accessing the shoulder in a largely nerve-free area to minimize nerve damage. The tendon of the short head of the biceps brachii was pulled to the medial part, and the scar tissue was loosened by the electric knife in order to expose the scapular glenoid cavity. The glenoid was ground to remove the surface cartilage before the insertion of prosthetic base. Two screws were inserted into the screw holes above and below the base, and then the glenoid ball was steadily implanted into the base. Then the broken end of the humerus was revealed to cut off the hyperplastic bone with a pendulum saw. The medullary cavity was expended by the intramedullary drill, and the bone cement was injected into the humerus medullary cavity. Subsequently, the humerus prosthesis was inserted into the medullary cavity with setting a twist angle of 30 degrees. After the hardening of the bone cement, the patch was sutured to the proximal end of the humerus prosthesis. The shoulder joint was reset, and the surrounding soft tissue was sutured to the patch and prefabricated holes of prosthesis to reconstruct the stability of the soft tissue (Fig. 4b, 4d, and 4e). Next step, the joint capsule was rinsed by iodophor solution and physiological saline. Finally, the incision was sutured layer by layer with placing drainage. The right upper extremity was fixed with abduction arm, and the patient returned to the ward safely after anesthesia recovery.

2.4. Surgical efficacy

2.4.1. Surgery. The intraoperative exposed bone defects of right shoulder were highly consistent with the preoperative 3D printed model. According to the preoperative design, the bone defects were filled with individual customized 3D printed shoulder prosthesis and the anatomical reconstruction was performed satisfactorily. The soft tissues such as ligaments were sutured to the prosthesis. The postoperative X-ray showed that the prosthesis was in accurate position (Fig. 4c, and 4f). The infection, fat liquefaction, tension blister, and other postoperative complications did not occur.

2.4.2. Follow-up. The results of ASES score, Neer score, and Constant-Murley shoulder score were showed on Table 1. The X-ray of right shoulder 3rd and 12th months after surgery showed the position and stability of prosthesis were satisfactory (Fig. 5a and 5b). The long-term complications such as chronic orthopedic

| Table 1 | ASES score, Neer score, and Constant-Murley shoulder score. |
|---------|------------------|------------------|------------------|------------------|------------------|
|         | Pre-OP | Post-OP 1months | Post-OP 3months | Post-OP 12months | Post-OP 24months |
| ASES    | 36     | 71.4            | 85.8            | 85.8             | 85.8             |
| Neer    | 39     | 54              | 72              | 77               | 77               |
| Constant-murley | 39     | 51              | 75              | 80               | 82               |

ASES = American Shoulder and Elbow Surgeons’ Form, post-OP = post-operation, Pre-OP = pre-operation.

Figure 4. revision surgery and postoperative X-ray. a b d e: surgical procedure for revision of total shoulder arthroplasty. c f: suitable position of prosthesis and reconstruction of anatomical structure.
implant-related infection, prosthesis loosening, and periprosthetic fracture did not occur until the 2 years follow-up. The range of motion (ROM) of shoulder was examined at the 12th month, forward flexion: 90°, backward extension: 40°, abduction: 80°, adduction: 15°, external rotation: 40°, internal rotation: 60°. The right arm could meet the requirements of daily activities, such as eating, writing, driving, lifting, and so on. The function of shoulder joint was well restored and the quality of life was significantly improved (Fig. 5c, 5d, 5e, and 5f).

3. Discussion

This paper reported a patient who underwent a TSA because of chondrosarcoma of the right shoulder has been suffering from prosthetic loosening which may require a revision of TSA. As has been noted, the conventional shoulder prosthesis cannot reconstruct the anatomical structure of the shoulder joint well. If using an unsuitable prosthesis for revision, it would lead to loosening of the prosthesis, peri-prosthetic fracture or even loss of bone mass, which could result in the consequence of disability of the patient. So the choice of the appropriate shoulder prosthesis was the key to the revision surgery.

In recent years, medical applications for 3D printing are increasing rapidly, especially in the process of clinical diagnosis and treatment of orthopedic diseases. It has some advantages as follow: First, 3D printing technology can be used to customize prostheses or surgical instruments based on the anatomical structure of the patient’s skeleton and the characteristics of the disease itself, which can achieve the best matching between the prosthesis and the patient. For example, the customized prosthesis described in this paper could fill bone defects, customize the appropriate size and prefabricate the soft tissue attachment holes to help achieve the perfect reconstruction of the anatomical structure. Second, some studies showed that 3D printing porous scaffolds had good effects on the induction of bone and soft tissue ingrowth. The pore size and porosity of EBM-3D-printing scaffolds in the range of 682–700 μm and 51%–73% were most conducive to bone ingrowth. At the same time, these materials also have good biocompatibility, which is the prerequisite for the 3D printing material to be implanted in the body. Thirdly, 3D printing technology can be used for preoperative diagnosis and surgical design, such as clavicle, pelvis, spine, femur and radial fractures. It not only helped surgeons to directly and clearly evaluate the condition of bone lesions but also reduced the operative time, the risk of anesthesia and the amount of bleeding. Based on the above advantages, the customized 3D printed shoulder prosthesis was selected for the revision surgery of the patient, and the preoperative design of the 3D printed model was applied.

During the first surgery to remove the loosening prosthesis, we had observed that the patient had serious bone defects with adjacent tissue adhesion. During revision surgery, bone mass was further lost and soft tissue contracture aggravated. The customized 3D printed prosthesis was implanted according to the accurate preoperative design with the suitable location and size, and passive motion of shoulder recovery. Meanwhile, patch was applied to fix the surrounding tendon and other tissue to the pre-designed holes to achieve the further anatomical fixation of the prosthesis, so as to prevent the loosening or periprosthetic fracture after operation. The scores of the shoulder joints were also gradually improved to the “superior” grade, which meant that the short-term effect of the 3D printed shoulder prosthesis was satisfactory.

3D printing prosthesis technology can be applied not only in shoulder joint tumor resection and revision surgery but also in bone defects repaired after pelvic tumor resection and maxillofacial surgery for reconstruction of maxillary and mandibular defects. In the future, individual customized 3D printed implants can be applied in irregular bone defects and special anatomical structures caused by bone tumors, complex fractures, failed arthroplasty in other parts of the body. The traditional treatment of bone defects can only rely on bone cement device implantation or autogenous bone graft, but the 3D printing technology can avoid bone injury and make anatomical and functional reconstruction better. In addition, the repair of bone defects, such as hand, foot, skull, and maxillofacial bone, is required for precise repair because of the special position and the high degree of fine function. The 3D printed prosthesis has high accuracy and could meet the requirements of precision repair. For some weight-bearing joints, such as knee and hip joints, some patients have poor soft tissue condition, while traditional prosthesis cannot provide screws or soft tissue fixation holes as required. The 3D printing technology can also implement the individual design of screw and soft tissue holes to improve the stability of the prosthesis. In summary, the individual customized prosthesis provides a new idea of treatment for patients who may...
eventually be disabled due to the absence of a suitable prosthesis.

The short-term follow-up effect of this operation is satisfac-

tory, but there is no support for long-term follow-up. For

customized 3D prosthesis, the following problems still remain
to be verified. First, compared to the traditional casting and

forging prosthesis, the durability of the 3D printing prosthesis,
such as the compression and wear resistance, is not satisfactory
due to the limitation of the manufacturing process. The shoulder

joint is not a weight-bearing joint, and for weight-bearing joints

such as hip, knee, ankle, and spine, the stress distribution of 3D

printed prosthesis and the verification of mechanical properties

are important. Second, the porous structure is beneficial to the

ingrowth of bone and soft tissue, but the metal debris produced in

its manufacture is difficult to clean due to the pores. The residual

metal debris may cause osteolysis, resulting in aseptic loosen-
ing of the prosthesis. Therefore, it is necessary to further explore

cleaning and disinfection methods. Moreover, because the
customized prosthesis cannot be produced in mass, the cost of

manufacturing is so expensive that the patient cannot afford it.

Therefore, we consider that the customized 3D printed prosthesis

should be used only in complex cases that could not be treated

with conventional prosthesis. Currently, the application of this

technology has not yet been verified by large clinical data, so we

should also keep a cautious attitude to the new technology as a

surgeon. It is still a challenge for surgeons to verify the long-term

effect of customized 3D printed prosthesis through collecting the

large clinical data in the future.

4. Conclusion

The individual customized 3D printed macro-porous Ti6Al4V

shoulder prosthesis used in the revision of TSA will help to achieve

higher precision and stability and improve the surgical outcomes. It

provides a novel method for the similar revision surgery of other

joints of the whole body with severe bone defects. However, the

result of long-term follow-up remains to be observed, and a large

amount of clinical data remains to be collected.

Author contributions

Author contributions statement: Yun Zou and Qing Han wrote

the main manuscript text, Jincheng Wang and Yongwei Zou

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