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Case Report

Three-dimensional printing technology facilitates customized pelvic prosthesis implantation in malignant tumor surgery: a case report

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Abstract: This report presents a case of the application of a customized three-dimensional (3D) printed pelvic prosthesis for the treatment of pelvic malignant tumor in one patient. The pelvic mass was scanned by computer tomography (CT) to obtain two-dimensional data and a 3D digital model was reconstructed using Mimics software. The physical model was then printed using a 3D printer. The tumor resection procedure was pre-designed with the personalized pelvic prosthesis prefabricated. After the tumor was removed, the pelvic prosthesis was successfully implanted and an artificial total hip replacement and pelvis and hip joint reconstruction were performed to restore the shape and function of the patient's pelvis and hip joint. At the 6-month follow-up, the X-ray results indicated that the prosthesis and the pelvis matched well. The application of computer-aided design and 3D printed custom-designed pelvic prosthesis for the treatment of pelvic tumors may be a viable method for a more accurate, reliable, convenient surgery, with a better clinical outcome.

Keywords: Computer-aided design, pelvic tumor, custom-designed prosthesis, 3D printing, pelvic prosthesis

Introduction

The surgical procedure for removing a pelvic tumor is challenging, due to the size and unique location of the tumor, the complex anatomic relationships, and invasion of the tumor into the acetabulum [1, 2], resulting high postoperative complication rates [3]. However, currently no guidelines are available regarding the removal of such tumors, the reconstruction of the bone, or the restoration of joint function. Traditional reconstruction of the pelvis using an allograft or artificial prosthesis [4] is rarely used these days, due to the narrow indication, high complication rate, and poor function of allograft-based reconstruction of the pelvis. With 3D printing technology, an individualized pelvismodel can be printed and the location of the tumor, the range of the bone erosion, and the adjacent relationships can be observed from multiple angles and directions to determine the scope and level of the osteotomy. This facilitates the complete removal of the tumor, while maximally preserving normal tissue.

With 3D printing technology, a personalized titanium alloy metal prosthesis can be designed and printed according to the pelvic morphology and residual bone. Using the physical model of the pelvis and the personalized prosthesis, surgeons can simulate the operation in advance tounderstand better the osteotomy plane, acetabular depth, placement of the prosthesis, how well the prosthesis matches, and the direction and length of the fixed screws. Theoperation may be simulated repeatedly to familiarize the surgeons with the procedure, shorten the operative time, minimize bleeding and injury, and prepare for potential problems.

In this report, we describe the application of 3D printing technology in the treatment of pelvic tumor in one patient. This modality aided preoperative planning, predesign and manufacture of a personalized prosthesis, successful resec-

Figure 1. Preoperative X-ray (A), CT (B) and MRI (C) confirmed the left pelvic tumor as chondrosarcoma.

tion of the tumor, and accurate installation of the prosthesis [5].

Case report

A 65-year old man with a gradually enlarging mass in the left hip for half a year was admitted. Upon admission, the patient had been immobilized for 2 months with lower limb numbness. Physical examination found an oval mass measuring 15 cm × 10 cm, in the left inguinal region of the left groin area. The muscle strength of the lower limb was grade 1. Preoperative X-ray film and CT suggested that the left pelvic tumor was a chondrosarcoma (**Figure 1**). Written informed consent was obtained for participation in this study.

The lesion site was scanned using a Philips 256-layer Brilliance iCT (Philips) before the operation with the following parameters: 120 kV, thickness of the layer was 1 mm. Data was output in the DICOM format and input into Mimics software (Materialise's Interactive Medical Image Control System). The bone was extracted from surrounding soft tissues using the command "Thresholding", and then both sides of the hips and sacrum were separated from other tissues using "Edit Masks". The 3D pelvic model was reconstructed using the commands "Edit Masks and Region Growing" and "3D Calculate", then saved in STL format and printed using an Objet24 3D Printer (Stratasys; **Figure 2A**).

Before the surgery, the imaging data and the 3D pelvic model were analyzed, the range of the osteotomy was determined, and the osteotomy was simulated with the Mimics software. To retain enough of the acetabulum to support the prosthesis and femoral head, the main cutting plane was the anterior inferior iliac spine, perpendicular to the acetabular rim (**Figure 2B**). The sciatic branch plane was made parallel to the osteotomy plane of the acetabulum. The sciatic body plane was made perpendicular to these two parallel planes. After determining these planes, the pelvis was divided into the

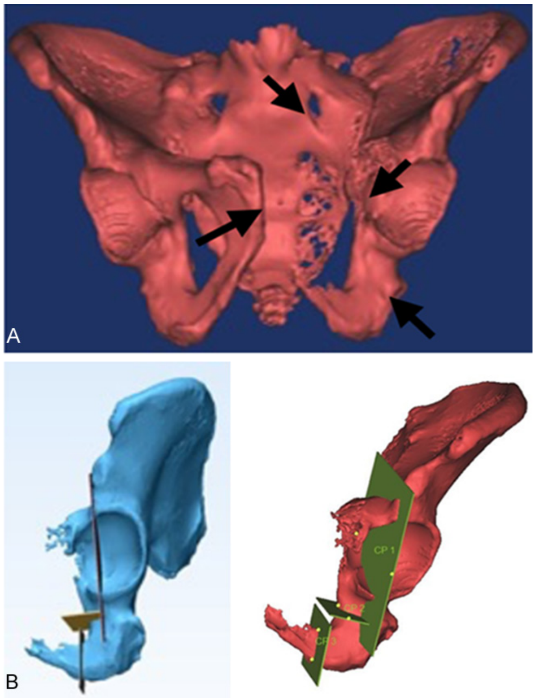

Figure 2. Three-dimensional reconstruction of the lesion (A) preoperatively, and (B) illustration of preoperative simulation osteotomy on the Mimics software.

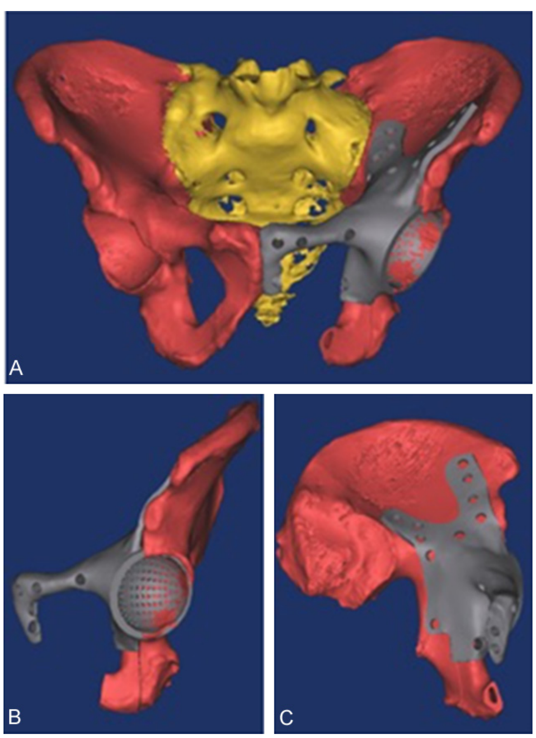

Figure 3. Preoperative simulation of the prosthesis from different angles in Mimics software.

normal pelvic region and the pelvic tumor resection region. The surface characteristics of the residual acetabular osteotomy were extracted and the operative osteotomy plate was determined.

A personalized pelvic prosthesis was designed to match the normal pelvic region. The prosthesis included the acetabulum, the upper pubic branch, the pubic union surface, and the connection to the normal pelvic region. The portion of the prosthesis that contacted the normal pelvis was completely matched. As shown in **Figure 3A**, this mainly included the osteotomy surface of the pelvis, the pubic joint, and the fixed handle. The thickness of the contact portion of the prosthesis and the non-bone supporting portion was 2 mm and 6 mm, respectively (**Figure 3B**). The diameter of the anchorage hole of the inner surface of the acetabulum was 3 mm, which was favorable for the infiltration of the bone cement. The upper branch of the pubic bone retained the original shape to allow a smooth transition between the bone and the prosthesis.

Two fixed holes of the sagittal plane were arranged for the joint surface of the prosthesis, which was perpendicular to the surface of the pubic bone. The Y-type fixed connecting handle was designed on the inner upper part of the prosthesis, which was matched with the contour of the iliac wing, and a screw hole was arranged on the fixed handle. The diameters of all screws were 7 mm, to ensure that the cancellous bone screws (6.5 mm in diameter) could go through.

The designed prosthesis was then saved as an STL file and input into an EOS M290 3D metal printer (Germany). The printing of the titanium alloy personalized prosthesis was completed in about 20 hours. Meanwhile, finite element method analysis and biomechanical analysis were performed and the osteotomy plate was printed using an Objet30 3D Printer (**Figure 4A**). Then, the acetabulum was ground to fit, the personalized prosthesis was installed into position with appropriate adjustments. The electric drill and boring tools were used on the arranged fixed holes of the prosthesis, and the length of the screws were measured and recorded for the operation. The entire simulated installation process went smoothly.

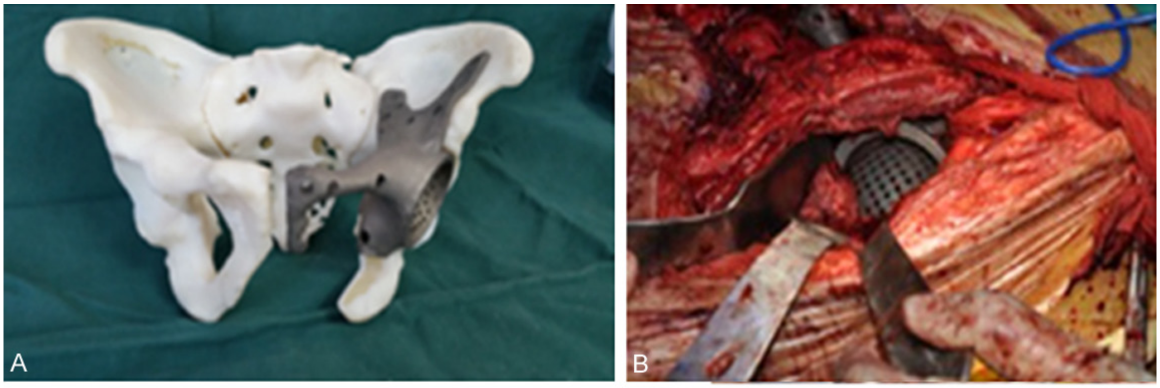

Figure 4. The successful reconstruction (A) and installation (B) of pelvic 3D model and titanium alloy metal prosthesis preoperatively and confirmation with postoperative X-ray (C).

To perform the left-side extension of the groin approach along the femoral anterior lateral incision, the femoral head was removed and the hip joint was dislocated to fully expose the acetabulum and separate along the tumor boundary. The tumor was located in the peritoneum, which posteriorly compressed the lumbar sacral nerve trunk. The tumor invaded into the left side of the pubic bone, partial sciatic nerve branches, and acetabulum.

Based on the preoperative design of the osteotomy plate, the left ramus of the pubis, part of the ramus of ischium and medial acetabular, and the tumor with a 2-cm margin were removed. The wound was debrided thoroughly, the acetabulum was smoothed by grinding, and the 3D-printed titanium alloy semi-pelvic prosthesis was installed. The appropriate position of the prosthesis was confirmed by radiographic view, the surrounding tissues were closely joined, and screws were drilled in and fixed.

To make the lateral straight incision of the hip joint, the osteotomy was 2 cm above the small rotor. The medullary was extended for preparation. The 3D-printed semi-pelvic prosthesis with total hip joint acetabular model was 50#. The 46# acetabular polyethylene prosthesis was fixed with bone cement, then a 2# femoral prosthesis and 28 XL femoral head prosthesis were installed and the joint was reduced and stabilized in all directions. Negative pressure drainage was placed and the incision was closed (**Figure 4B**). The destruction of the left pubis branch and part of the acetabulum bone, together with a significant mass around the acetabular margin and upper femur medial muscle group suggested chondrosarcoma (**Figure 1**). The whole body bone scan suggested malignant lesions.

The surgical procedure took about 4 hours and the amount of bleeding was about 4000 mL. No tumor was found in the lungs, abdomen, thoracic vertebrae, or lumbar vertebrae. The patient recovered well, and the wound healed with

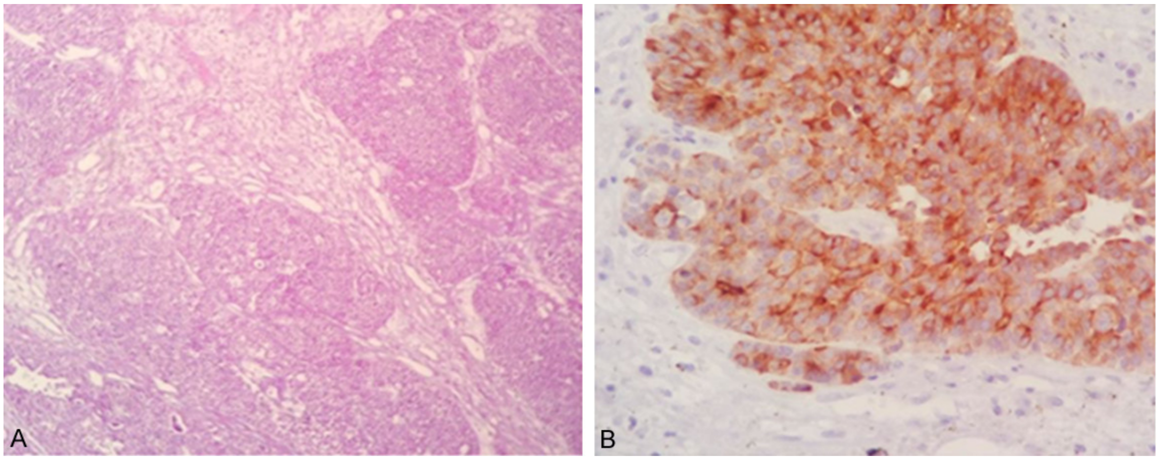

Figure 5. Pathological examination suggested a pelvic metastatic poorly differentiated carcinoma using (A) hematoxylin and eosin staining at 10×; and (B) immunohistochemistry at 20×.

no postoperative complications. The postoperative X-ray results indicated that the range of the tumor resection was consistent with the preoperative planning and that the personalized prosthesis matched the pelvis well (**Figure 4C**). The pathological examination confirmed the tumor as a pelvic metastatic poorly differentiated carcinoma (**Figure 5**). At the 6-month follow-up, the passive range of motion of the left hip was normal without dislocation. Active flexion of the hip was 30 degrees, back extension was 10 degrees, and abduction was 10 degrees. The muscle strength of both lower extremities had recovered to grade III.

Discussion

In this study, we used computer-aided design and 3D printing technology combined with a traditional total hip arthroplasty for the treatment of pelvic tumor resection and functional reconstruction. The early stage of the prosthetic design was mutually supported by both the digital design and the simulated operation using the physical model. Potential problems were foreseen and addressed by the software, and the simulation could be repeated as necessary to determine the optimal prosthetic design and treatment options.

The personalized 3D printed prosthesis has certain advantages over the traditional prosthesis. First, through computer-aided design, the prosthesis fits better to the contour of the remaining structure, and the mechanical strength of the integrated prosthesis is guaranteed by the mechanical analysis. In addition, because of the simulated surgery with the prosthesis beforehand, surgeons are familiar with the operative process and the fixed position of the screws; knowing the angle and length parameters increases the accuracy of the operation and reduces the installation time. Furthermore, the shape of the personalized prosthesis is consistent with the excised bone and the original physiological anatomy.

There remain considerations regarding the design and installation of a 3D-printed personalized prosthesis. The surgeons must be familiar with the design of the prosthesis, although this extends the preoperative preparation time. In addition, the fabrication of the prosthesis is limited by the 3D printers and manufacturers, and time must be allowed for production.

There have not been many successful cases of application of a custom-designed prosthesis, and most of them lack long-term clinical observation and functional follow-up. However, we believe that as the technology advances, computer-aided design and 3D printing will have broader application in the treatment of pelvic tumors or even orthopedic diseases.

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Disclosure of conflict of interest

None.

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