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ORIGINAL ARTICLE

Printing a patient-specific instrument guide for skull osteoma management

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Abstract

Background: To surgically remove osteoma and to keep an optimal cosmetic profile would be very challenging. To solve the difficulty, we utilized the three-dimensional (3D) printing technologies in generating a patient-specific instrument guide (PSIG) for the safe removal of a skull bone tumor.

Methods: The preoperational brain computed tomography (CT) provided the digital imaging with thin slices, and then images were reconstructed into a 3D skull model. Based on the model, we designed a PSIG to make landmarks on the osteoma to avoid excessive removal of the skull bone. During the operation, the surgeons could remove the osteoma piece by piece by using the landmark as a reference point.

Results: The PSIG was successfully applied to remove an osteoma that measured 60 × 48 × 40 mm^3 over the left frontoparietal skull of a female patient. The 3D CT reconstruction taken both before and 4 months after surgery showed a significant change in the appearance of the osteoma.

Conclusion: The PSIG was able to guide the surgeon in the safe removal of the skull osteoma, as well as in maintaining the cosmetic skull profile.

Keywords: 3D Printing; Image Reconstruction; Patient-Specific Instrument Guide (PSIG); Skull Image Osteoma

1. INTRODUCTION

Three-dimensional (3D) printing, also known as additive manufacturing, has significantly changed object production methods.[1] The traditional method for making an object involves machining parts from material blocks and then screwing or welding them together. With 3D printing technique, a product can be designed on a computer and printed on a 3D printer. The 3D printer, which basically creates the object by building upon successive layers of material, can produce numerous objects that are even too complex for a traditional factory to handle.[2]

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Given that 3D technology provides additional information, such as accurate patient-specific anatomy, both treatment planning and surgical simulation have demonstrated promising results.[2] Surgeons have demonstrated that 3D printing surgical guides are feasible and promising for complex surgical procedures.[3–7] Moreover, possibly in the near future, patient-specific implants would represent the result of direct manufacturing and fabricating of end-use products with 3D printers.

The purpose of this report is to describe the use of 3D printing technologies to generate a patient-specific instrument guide (PSIG) for safely removing a skull bone tumor. The osteoma was relatively big in size so that simple resection without proper guide may affect skull contour and further risking proper thickness of skull. Therefore, we designed a customized surgical instrument guide for the operation to make sure a proper resection procedure.

2. METHODS

2.1. Patient

A 32-year-old female noticed a protruding mass on her left frontoparietal skull at the age of 22. The skull routine images from a local hospital revealed a bony lesion on skull. Since the tumor was barely visible initially and no symptoms such as headache, nausea, or vomiting were noted, the neurologist suggested conservative observation. However, the mass had been increasing in size and obvious visible since then. On January 2018, she visited a medical center for help again and received brain computed tomography (CT). An osteoma over left frontoparietal skull in the size of 60 × 48 × 40 mm^3 was noted.

Following the diagnoses, she visited our Neurology Clinic for second opinion and then was referred to our Plastic Surgery Outpatient Department for surgical evaluation Because the osteoma was considered as a relatively large tumor[8] and should be surgically removed with respect to best aesthetic outcome and safety,[9] we would introduce the 3D printing technology to assist the surgical procedures.

2.2. 3D modeling and PSIG design

The preoperational brain CT provided the digital imaging and communications in medicine (DICOM) with thin slices (<1 mm CT brand). Then, we used Mimics 19 Medical (Materialise Company, Leuven, Belgium) to reconstruct the DICOM images into a 3D skull image model (Fig. 1A). The surface of the 3D skull model without osteoma (Fig. 1B) was further reconstructed by excluding the osteoma part in each DICOM image. We utilized image processing software, Meshmixer (Autodesk Inc., San Rafael, CA, USA), to smooth the skull model without osteoma (Fig. 1C).

The osteoma was firmly fixed to skull, and there was no ideal reference for differentiation. To avoid excessive removal of skull bone and preserve an ideal shape, we designed a PSIG to make landmarks on the osteoma. The landmarks were created by drilling multiple holes from the osteoma surface and down to the surface of the cranial bone under the assistance of the PSIG. The depth of the holes was decided according to the corresponding thickness of the osteoma (Fig. 2). The landmarks served as indicators while contouring the osteoma. As long as there were visible holes, the surgeons could keep on contouring.

A 4.5-mm diameter surgical drill (Hall Mirco 100; Zimmer, Warsaw, IN, USA) was used to make holes for the landmark. The drill bit could maximally protrude for 19 mm from the drilling protective sleeve (Fig. 2). The PSIG was designed as a hood covering the osteoma, with multiple preset holes on it. A counter bore was designed to be applied on the top of every hole. Drilling from the holes with the 19-mm protrusion will reach the surface of the cranial bone (Fig. 3). The PSIG also has a 7.5-mm wide and 3-mm-thick surrounding rim, so that the PSIG could be fixed on the skull with guide wires. The PSIG further had two locating indicators so that the plastic surgeon (the first author) could accurately put the PSIG on the skull by positioning the indicators related to the sagittal suture (Fig. 4).

2.3. 3D printing

Our 3D printing center used "Form 2" 3D printer (Formlabs, Inc., Somerville, MA, USA) and self-assembly printers to print the models. It took approximately 580 minutes to print the PSIG using Dental SG resin (Formlabs, Inc., Somerville, MA, USA), which is a biocompatible resin met with ISO 10993 and US Pharmacopeia VI standards.[10,11] The produced PSIG can be steam sterilized using an autoclave, allowing it to be used directly in the operating room. For safety concern, we further printed the skull model for simulation surgery. The self-assembly 3D printer and polylactic acid was used for printing. We performed simulation surgery with the PSIG on the skull model to evaluate its effectiveness and safety.

2.4. Surgical procedures

The patient was under general anesthesia and the surgical space was created. The surgeons fixed the PSIG on the skull by positioning the indicators related to the sagittal suture. While drilling holes on the osteoma, surgical navigator[12] (Kolibri; Brainlab Navigation System, Feldkirchen, Germany) was used to confirm the path and depth of drilling. In total, 18 holes were created on the osteoma. Reciprocal saw was used to cut for bone biopsy (Fig. 5), and a cutting burr (Hall Mirco 100; Zimmer) was used to gradually remove the osteoma. The holes on the osteoma surface were marked with blue dye for indicating the depth of tumor. During the operation, the surgeon grounded out the osteoma piece by piece by referring 18 holes as landmark. The surgical procedure should stop at the depth where the blue dye indication almost disappeared (Fig. 6). Thus, we would remove the osteoma as well as maintain the cosmetic profile of the skull.

3. RESULTS

The postoperative course was quite smooth. The patient was discharged under stable condition 5 days later. The pathology report was compatible with osteoma. The 3D CT reconstruction taken before (Fig. 7A) and 4-month after surgery (Fig. 7B) showed the significant change in the appearance. It should be noted that Fig. 7A is exactly the same as Fig. 1B; we duplicated it here to demonstrate the change before and after the surgery. The patient was quite satisfied with her postoperative outcome. It should be mentioned that we selected cone beam CT for lower dose of radiation and cost[13] since the postoperation CT would not be clinical necessary.

4. DISCUSSION

The most common benign skull bone tumor,[14] osteoma, is a slow-growing osteogenic lesion typically composed of well-differentiated mature bone tissue. To surgically remove the hard tissue as well as keep the cosmetic profile would be of great challenge. Young et al[15] proposed a synthetic cranioplasty that includes an enlarged craniectomy and then using hydroxyapatite bone cement, a dural prosthetic and a resorbable plate to repair the dural defect. Other than the risk of craniectomy, the technique would also introduce foreign body and biomaterials. For resuming the natural curvature of the skull, especially for

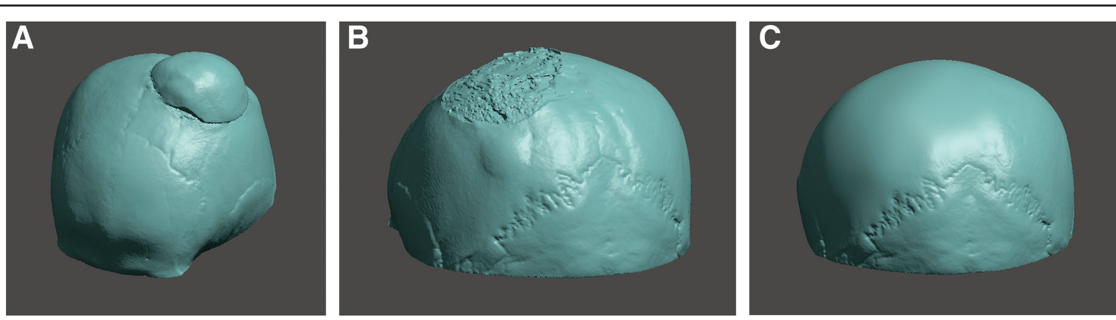

Fig. 1 The reconstructed three-dimensional (3D) skull model with osteoma (A), without osteoma (B), and model smoothing (C).

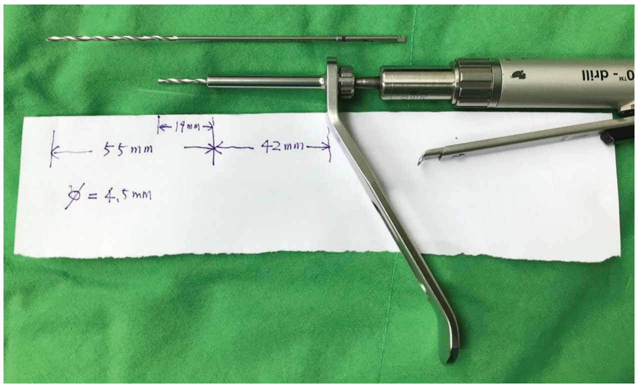

Fig. 2 The surgical drill and protective sleeve.

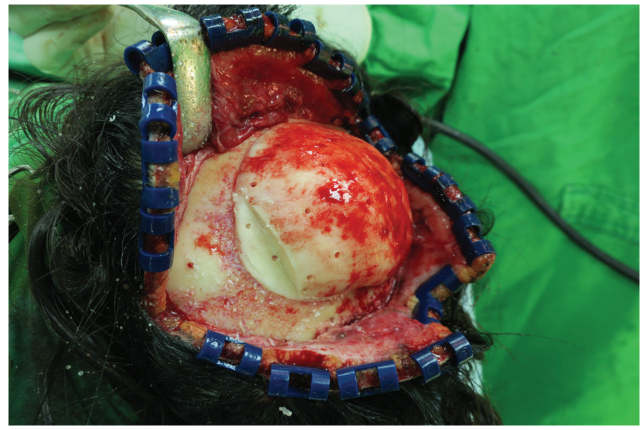

Fig. 5 A cutout of the osteoma with surgical saw.

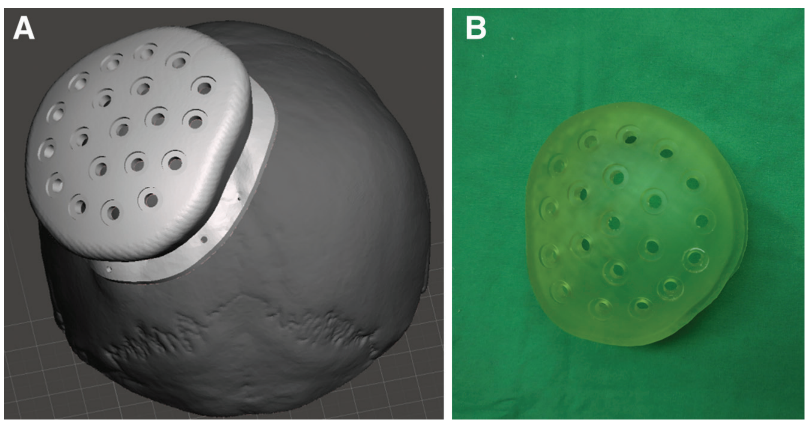

Fig. 3 The patient-specific instrument: A, computer model and B, printed with resin.

Fig. 4 The surgical site and the SPI for drilling landmark holes.

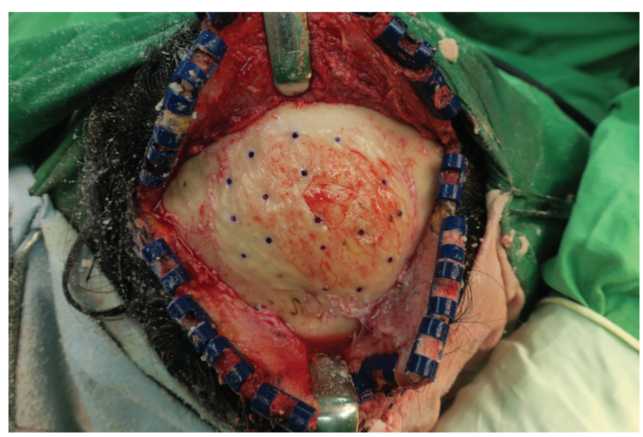

Fig. 6 The osteoma was grinded to the landmark almost without blue dye indication.

large defects, a well-prepared presurgical plan and a useful PSIG is important.

For surgeons, who do not have 3D printing technology to deal with giant skull osteoma, they have to remove the tumor piece by piece very carefully. Especially without good reference, an operator may only slowly use powered saw or burr to keep the natural curvature of skull and not to make the skull too thin to induce intracranial hemorrhage. The removal of giant osteoma was done via craniectomy and followed by cranioplasty using methyl methacrylate or titanium mesh.[8] Furthermore, a surgeon may also use the surgical navigation system to keep their surgical tools in decent positions. However, the operator still has to frequently check the navigation monitor for safety reason, which would be tedious and time-consuming.

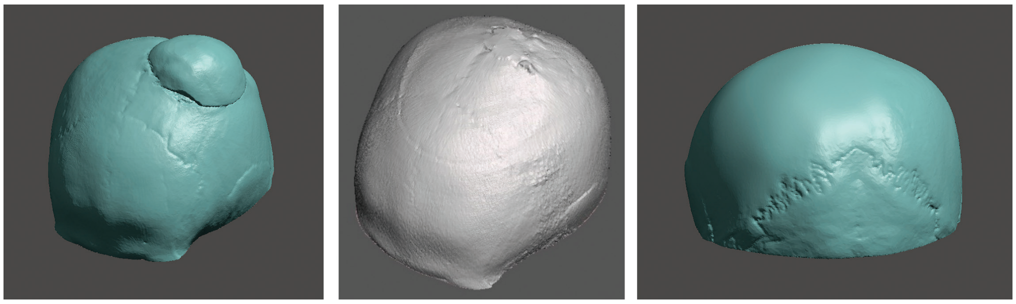

Fig. 7 The three-dimensional (3D) reconstruction models of the subject (A) before and (B) after surgery.

For safety, effectiveness, and quality concerns, the application of 3D printing technology in medical fields further requires regulatory compliance, such as the US Food and Drug Administration (FDA). Thus, it was not until 2006 that the first 3D-printed titanium skull implant was applied.[16] This type of application has been employed successfully ever since. Indeed, the 3D printing does open the world of research[2,17] in medical fields. Medical staffs reconstruct routine medical images, such as CT or magnetic resonance imaging (MRI), into 3D models. Then, the 3D model can be either manipulated in virtual reality or printed for treatment planning or surgical simulation.[18–20]

The 3D reconstruction technology and 3D printing technology share some similarity and can be of help in different ways. The 3D reconstructed CT images can provide stereo-form information to the viewers and further be reviewed at different places by cloud technology.[21] Moreover, a surgeon would perform virtual surgery for practice via computer programs.[22] Instead, printing out a 3D model based on 3D reconstructed CT images can provide a real object to a surgeon even though the printing process is time-consuming and may cost.[2,23] By appreciating a real model, the operator has real tactile feedback and gets better control of the important structures of the patient. For example, the surgeon can do simulating surgery on a 3D printing facial bone fracture model by direct cutting, drilling, and reduction for surgery rehearsal. Therefore, we believe that, by adopting the 3D reconstruction and printing technologies, a surgeon can drastically improve the surgical outcome and offer more patient safety.

Since 3D printing technology has been applied in surgical simulation and planning,[6,7,24–26] we would like to add a PSIG for skull osteoma. The purpose of using the PSIG is to create landmarks for safety and keep cosmetic profile. The landmarks were created by drilling holes on the surface on the osteoma. Thus, the landmark could guide the plastic surgeon not only safely remove the hard tissue but also keep preserve the natural curvature of the skull.

In this case demonstration, we also utilized surgical navigator to valid the PSIG. However, we believed that this time-consuming procedure would be saved. Instead, we would make surgical simulation by using the PSIG to drill landmarks on the model before surgery. During the process of removing the osteoma, the drilled holes with blue dye could guide us to go further or just to hold on. We then examined the skull model profile after removing the mass to valid the PSIG.

The greatest advantage of the 3D printing technology in medical applications is the ability to produce patient-specific devices.[27] For example, the application of 3D printing to customize prosthetics and implants represents significant value for both patients and physicians.[28–30] In this case, 3D printing technology offers benefits in terms of safety and cosmetic outcomes. However, a 580- and 1140-minute production time for PSIG and skull model, respectively, represents a limitation of 3D printing PSIG. If any events interrupted the process, the whole printing should be repeated again. Fortunately, numerous outsourced professional 3D printing companies are available worldwide. A 3D model can be saved and transmitted as a stereolithographic file. Using this file, a professional company can print the model and deliver the 3D printout. Furthermore, 3D printing hardware is also progressing. We may expect more precise and rapid 3D printers in near future.[31]

In conclusion, this article, we demonstrated the application of 3D printing PSIG for plastic surgery. Using 3D printing technology, we reconstructed the patient's skull model from the CT images, designed a PSIG for surgery, printed these models, and then validated the PSIG before clinical application. The entire process was smoothly performed. The PSIG would guide the surgeon to remove the skull osteoma safely as well as maintain the cosmetic skull profile.

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