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Technical note

Contribution of 3D printing to mandibular reconstruction after cancer

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ABSTRACT

Three-dimensional (3D) printing is booming in the medical field. This technology increases the possibilities of personalized treatment for patients, while lowering manufacturing costs. To facilitate mandibular reconstruction with fibula free flap, some companies propose cutting guides obtained by CT-guided moulding. However, these guides are prohibitively expensive (€ 2,000 to € 6,000). Based on a partnership with the CNRS, engineering students and a biomedical company, the authors have developed cutting guides and 3D-printed mandible templates, deliverable in 7 days and at a lower cost. The novelty of this project is the speed of product development at a significantly lower price. In this technical note, the authors describe the logistic chain of production of mandible templates and cutting guides, as well as the results obtained. The goal is to allow access to this technology to all patients in the near future.
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1. Introduction

Segmental mandibulectomy is a common head and neck surgical procedure. When mandibular reconstruction is performed by titanium plate, conformation of these plates is usually performed intraoperatively. The limitations of this technique are the considerable duration of plate modelling depending on the defect to be repaired and modelling that remains only approximate. Various companies, such as KLS Martin Group or Synthes, propose preformed plates adapted to the morphology of the defect, at prices ranging from € 700 to 1300. When mandibular reconstruction is performed with fibula free flap, which constitutes the reference technique, the long bone must be reconfigured into a three-dimensional (3D) angular structure, making this a complex technique. In order to facilitate free flap modelling, several companies propose various solutions, ranging from virtual planning to cutting guides with or without screw plates. The cost of these solutions varies between € 2500 and 6000, depending on the option selected, i.e. cutting guides with or without 3D-printed template, with or without preformed plates. Manufacturing times are at least 21 days. At the present time, French national health insurance does not reimburse preoperative planning, and these additional costs remain at the charge of healthcare institutions.

3D printing is a rapidly growing technology in the medical field, which can provide adapted solutions, but can the production chain be simplified in order to reduce delivery times and simultaneously limit costs? Based on a partnership between a head and neck surgery department, a CNRS biomaterial laboratory and an engineering school, the authors have demonstrated that personalized 3D-printed mandible templates can be produced by using only free software and an open source BCN3D+® printer costing € 1500 (BCN3D Technologies). These templates allowed planning of operations and conformation of titanium plates. In the light of these preliminary results, the authors contacted AnatomikModeling, which designs custom-made 3D implants and masters the digital chain. 3D-printed cutting guides for fibula free flap conformation were jointly developed. In this technical note, the authors describe the logistic chain and perspectives of this study in order to allow, in the near future, access to 3D modelling prior to mandibular reconstruction for all patients.

2. Technique

Neck and chest CT scan was performed in all patients and CT angiography of the lower limbs was performed before fibula free flap reconstruction.

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2.1. Manufacture of mandible templates and preformed screw plates.

3D printing of objects requires generation of an STL (STereoliLhography) format file that can be used directly by the printer. In the field of medical imaging, the set of 2D images (Digital Imaging and Communications in Medicine format, i.e. DICOM) obtained from the patient's CT scan in various planes (coronal, axial and sagittal) are compiled to reconstitute a virtual 3D view of the patient's tissues and isolate a view of the mandible, which is then exported in STL format to be optimized (correction of imperfections and creation of a support) before 3D printing.

In order to demonstrate the feasibility and potential cost reduction, we preferred to use a free access software suite (3D Slicer, Blender, 3D Builder) (Fig. 1A).

2.1.1. Generation of the STL file

After importing the DICOM file into 3D Slicer software, volume rendering functions are initially used to display a 3D image of all tissues and then isolate the bony part of the patient's skull before exclusively extracting the mandible. Residual artifacts are partly corrected by the software (removal of parts of the maxilla remaining on the image, filling of certain internal defects of the mandible). The file obtained is in STL format.

2.1.2. Preparation of the print file

The new file contains certain residual imperfections derived from CT image acquisition (diffuse white zones related to the patient's dental fillings) and 2D-to-3D image transformation (non-smooth surface of the mandible). These various artifacts are eliminated with Blender software (Fig. 1B). The first types of defects are therefore selected and eliminated one by one, while the smoothing function smoothes the bone surface, resulting in acceptable, slight, 5 mm maximum undersizing of the mandible.

For 3D printing by layer-by-layer extrusion of polymer filament, the first layer must be flat, which is not the case for an object like the mandible. 3D Builder software easily optimizes spatial positioning of the mandible and adds a flat support allowing printing under suitable conditions. The total duration to obtain a printable mandible file is 1.5 hours.

2.1.3. 3D printing of the mandible template

3D printing was performed on a BCN 3D+ open source modular printer (BCN3D Technologies, Spain) using PLA polymer filament melted at 205 °C (printing speed: 160 mm/s). The mandible printing time is 3 hours (Fig. 1C).

Mandible templates were scanned and superimposed onto the patient's preoperative CT images, revealing a difference in dimensions of less than 2 mm.

The initial data processing learning time was 3 hours, and the initial 3D printer learning time was 1.5 hours.

2.1.4. Conformation of the titanium plate

For each patient, 72 hours before the surgical operation, the titanium screw plate was conformed onto the mandible template (Fig. 1D) adapted to the future mandibular resection. The plate was then sterilized according to the usual procedures. The mandible template was then also sterilized according to the Sterrad process (UV irradiation + H_2O_2 plasma) in order to be available for the surgical procedure.

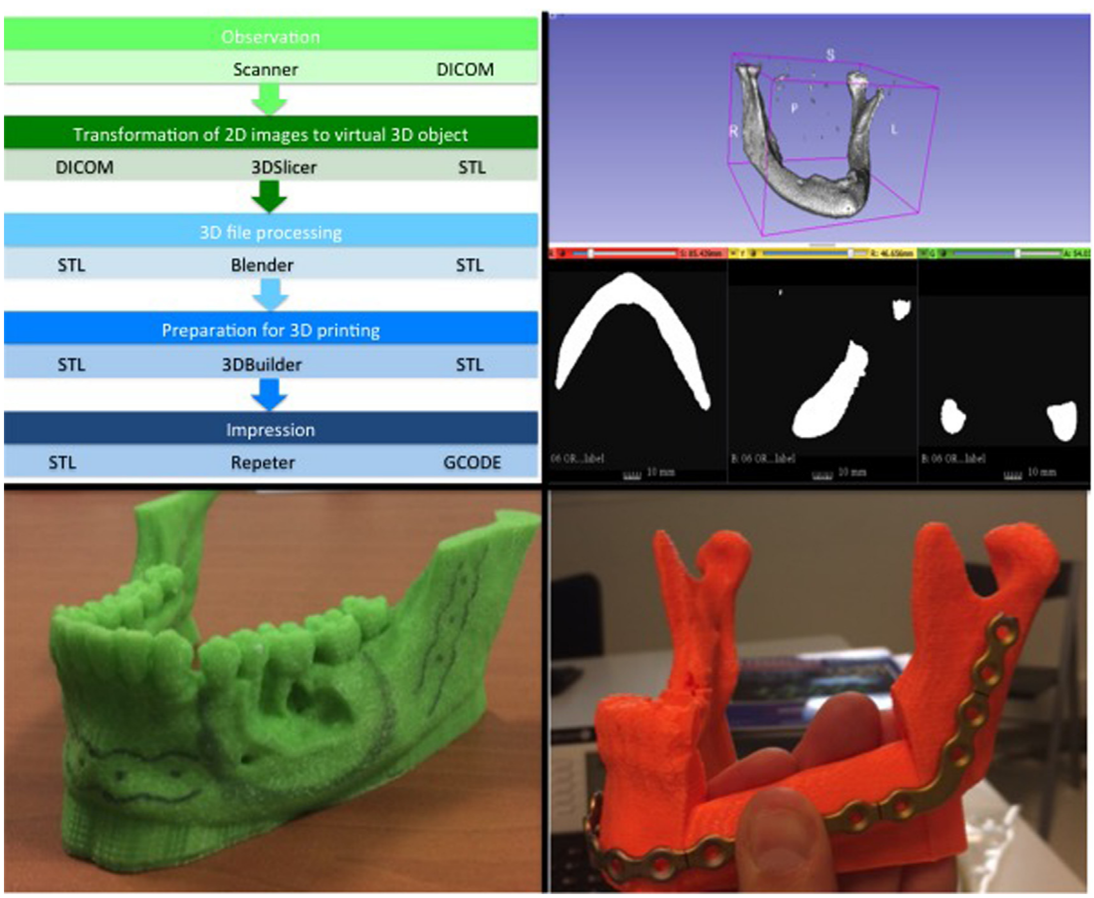

Fig. 1. A. Free digital chain allowing 3D printing of mandible templates from DICOM files. Use of 3D Slicer for image processing. C. PLA printed mandible template with osteosarcoma impression. D. Titanium plate preoperatively conformed onto the mandible template with printed fibular segment replacing the body of the mandible.

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