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Mandibular reconstruction using stereolithographic 3-dimensional printing modeling technology

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Mandibular reconstruction can be challenging for the surgeon wishing to restore its unique geometry. Reconstruction can be achieved with titanium bone plates followed by autogenous bone grafting. Incorporation of the bone graft into the mandible provides continuity and strength required for proper esthetics and function and permitting dental implant rehabilitation at a later stage. Precious time in the operating room is invested in plate contouring to reconstruct the mandible. Rapid prototyping technologies can construct physical models from computer-aided design via 3-dimensional (3D) printers. A prefabricated 3D model is achieved, which assists in accurate contouring of plates and/or planning of bone graft harvest geometry before surgery. The 2 most commonly used rapid prototyping technologies are stereolithography and 3D printing (3DP). Three-dimensional printing is advantageous to stereolithography for better accuracy, quicker printing time, and lower cost. We present 3 clinical cases based on 3DP modeling technology. Models were fabricated before the resection of mandibular ameloblastoma and were used to prepare bridging plates before the first stage of reconstruction. In 1 case, another model was fabricated and used as a template for iliac crest bone graft in the second stage of reconstruction. The 3DP technology provided a precise, fast, and cheap mandibular reconstruction, which aids in shortened operation time (and therefore decreased exposure time to general anesthesia, decreased blood loss, and shorter wound exposure time) and easier surgical procedure. **(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:661-666)**

Mandibular reconstruction is often needed after partial resection and continuity defect. The aims for reconstruction are the maintenance of proper esthetics and symmetry of the face and the achievement of good functional result, thus preserving the form and the strength of the jaw and allowing future dental rehabilitation.

Reconstruction poses a challenge for the maxillofacial surgeon for a number of reasons, such as complicated geometry of the mandible, muscles attached to the mandible which act in different directions, form and position of condyles in the glenoid fossa, and occlusion.

Reconstruction of the mandible can be achieved by a bridging titanium locking bone plate. Many studies report a high complication rate, up to 70%, owing to plate and screw fracture, screw loosening, plate exposure, and infection. Current literature mentions this method as temporary until bony reconstruction of the gap is accomplished.[1,2] Additional use of the reconstruction plate is when predicted life expectancy is low and when medical conditions preclude prolonged general anesthesia.[1-3]

Further rehabilitation of the mandible can be performed using autogenous bone grafting, a reliable standard procedure.[4-9] Incorporation of the bone graft into the mandible allows for the continuity and strength necessary for its proper function, with the possibility for dental implant rehabilitation.[7-10] Bone tissue can be harvested during the first surgical procedure or at a

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second stage for recurrency detection. There are 2 types of autogenous bone grafts. Vascularized bone grafts are considered to be the "standard of care" for mandibular reconstruction, with reports of a high success rate, up to 95%, of bone incorporation and dental implant osseointegration. Nonvascularized bone grafts can be used reliably in a delayed reconstruction procedure, after a few months, for defects up to 9 cm, with the advantage of better ability to shape its contour.[10]

These procedures can be significantly optimized with the use of 3-dimensional (3D) anatomic models. Unlike standard computerized tomography (CT)–derived imaging, in which the surgeon views images on a monitor or sheet of film, it is possible to physically interact with these 3D models, making it easier to understand morphology and to perform hands-on surgical planning. Such a method helps in surgical planning improvement, and reduced operating time.[11] These models are generated by a process known as rapid prototyping (RP).

Rapid prototyping is a class of technologies that can construct physical models from computer-aided design via 3D printers. Although RP has been used in the field of industrial design for over 3 decades, only in the last decade have applications been developed for medicine.

Although there are numerous RP technologies, those most commonly used for medical applications are stereolithography and 3D printing (3DP).

Stereolithography is a process by which liquid polymer media contained in a vat is "cured" via laser into solid resin, which comprises both the 3D model and support pillars (which help maintain the structural integrity as the model) is being created. The model is then rinsed in alcohol and again "cured" in a UV chamber. Afterward, the support pillars must be separated from the model by hand. These models are accurate to 0.1 mm, and the build time is dependant on the complexity of the structure being printed.

The 3DP technology works by jetting photopolymer materials in ultrathin layers onto a build tray, layer by layer. Each layer is cured by UV light immediately after it is jetted, producing fully cured models that can be handled and used immediately, without postcuring. The gel-like support material, which is specially designed to support complicated geometries, is easily removed by hand and water jetting. The 3DP models are accurate to 0.016 mm, and the build time is 1 cm in height per hour.

In comparison, although stereolithography is widely considered to be the "gold standard" for medical RP applications and is typically the more efficient process for larger parts, it is significantly more labor intensive and costly. The 3DP models, while arguably less compelling, are more quickly and easily produced and the cost is approximately one-third that of stereolithography models. Furthermore, 3DP is superior in printing smaller and more complex structures compared with stereolithography.

The present article presents 3 cases demonstrating the use of 3DP technology in mandibular tumor reconstruction with a precontoured reconstruction plate, including 1 case in which we attempted to exploit the same technology to facilitate reconstruction of the gap with iliac crest bone graft in a second stage.

DESIGN PROCESS

Overview

Once acquired, CT source data must undergo postprocessing to isolate the mandible. Once isolated, the resulting 3D volume must be saved in a format suitable for RP printing (STL file). Until recently, this was a painstaking process which required CT data to be imported into a third-party software program and edited on a slice-by-slice basis. However, this can now be performed on a commercial 3D workstation (EBW 4.0, Philips Medical, Cleveland, OH, USA). This is a major improvement, because a once tedious 2-hour job now requires ≤5 minutes.

Mandibular model fabrication—first stage

The CT imaging was performed on a 64-slice multidetector CT scanner (Brilliance 64; Philips Medical). Volumetric data was acquired (1 mm slice thickness, 0.5 mm increment, 0.75 second rotation time, 120 kVp, 250 mAs). The DICOM-format data was postprocessed and converted to STL format (EBW 4.0). A photopolymer jetting device (PolyJet Technology Eden500V; Objet Geometries, Rehovot, Israel) "printed" super-thin layers (down to 16 μm) of hard plastic and a gel-like support material at 600 × 600 dpi to create the model.

Negative template of the gap after resection—second stage

Postoperative CT was performed and the DICOM-format data converted to STL format. Before printing, the STL file was imported into a rapid prototyping software program (Magics; Materialise, Leuven, Belgium) in which a new model was created using a "mirror image" function using the contralateral side of the mandible as a reference. This "positive" model of a "negative" space was then printed and sterilized for the operating room.

CASE PRESENTATION

Case A

A 27-year-old man was referred to our institute for treatment of left mandibular swelling and an indurative lesion on

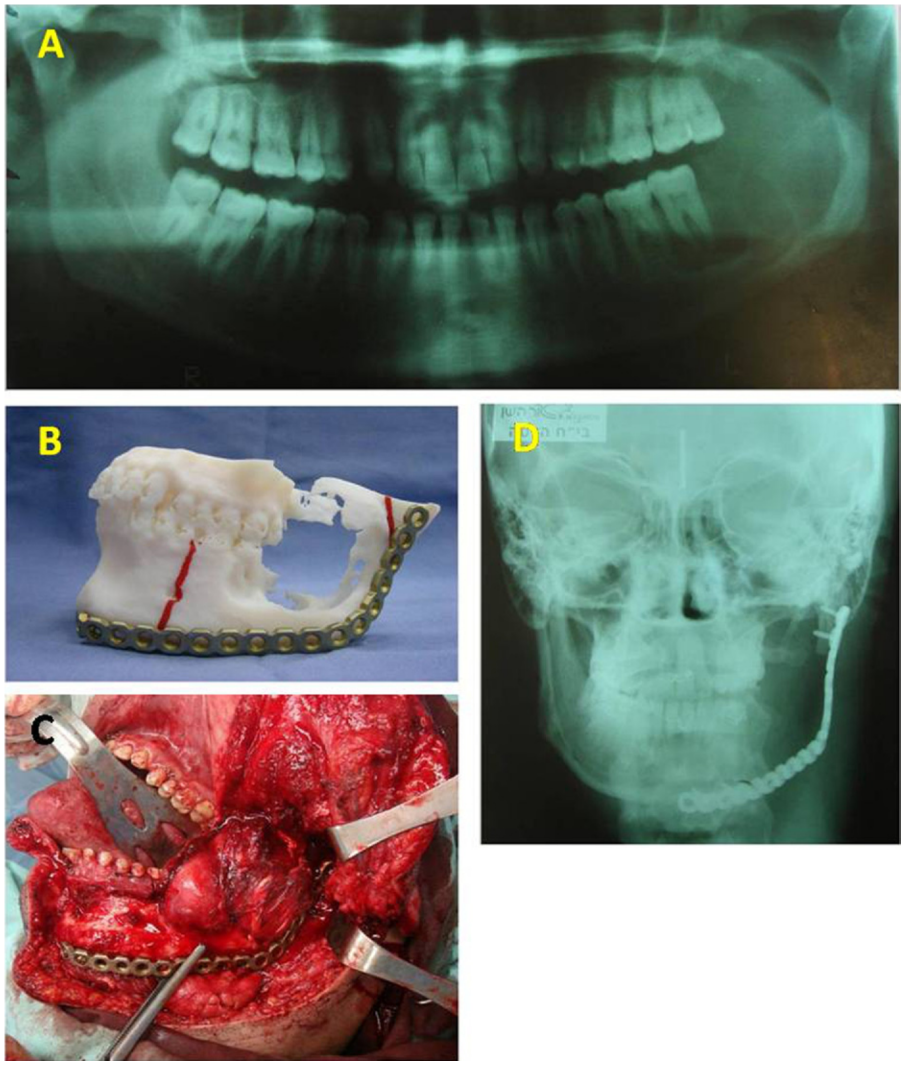

Fig. 1. **A,** Panoramic radiograph showing a multiloculated lesion, approximately 5.3 × 4.3 cm in size, in the left mandible. Note the extension from the distal root of tooth no. 36 up to the sigmoid notch. **B,** Precontoured mandibular reconstruction plate according to the streolithographic model. **C,** Under general anesthesia, a lower buccal cheek flap was raised, exposing the tumor. Reconstruction plate positioned before tumor resection. **D,** Postoperative posteroanterior cephalometric x-ray demonstrating excellent symmetry.

the left mandibular retromolar area. Panoramic radiograph showed a multiloculated lesion that was approximately 5.3 × 4.3 cm in size in the left mandible, extending from the distal root of tooth no. 36 up to the sigmoid notch (Fig. 1, *A*).

Biopsy of this lesion yielded the diagnosis of plexiform ameloblastoma. An 8 cm (not compatible with the size previously mentioned, i.e., 5.3 × 4.3 cm) resection was planned with titanium plate reconstruction in the first stage and delayed reconstruction of the defect with iliac crest bone graft in the second stage.

Before surgery, a mandibular reconstruction plate (2.4-mm Mandible Locking Plate System; Synthes Maxillofacial, Paoli, PA) was bent to span the gap using the streolithographic model as a reference (Fig. 1, *B*).

Intraoperatively, a lower buccal cheek flap was elevated, exposing the tumor. The reconstruction plate was positioned perfectly and rapidly and holes were drilled in healthy bone. Plate removal and segmental mandibulectomy, including soft tissue excision, according to plan was performed, followed by repositioning of the plate and fixation to the predrilled holes (Fig. 1, *C*).

A postoperative cephalometric radiograph exhibited the. reconstruction and achievement of symmetric mandibular result (Fig. 1, *D*).

One year later, iliac crest bone graft reconstruction was performed. Again, a 3DP model was fabricated, and a negative imprint of the missing bone was prefabricated (Fig. 2, *A*). During the operation, bone harvesting from the

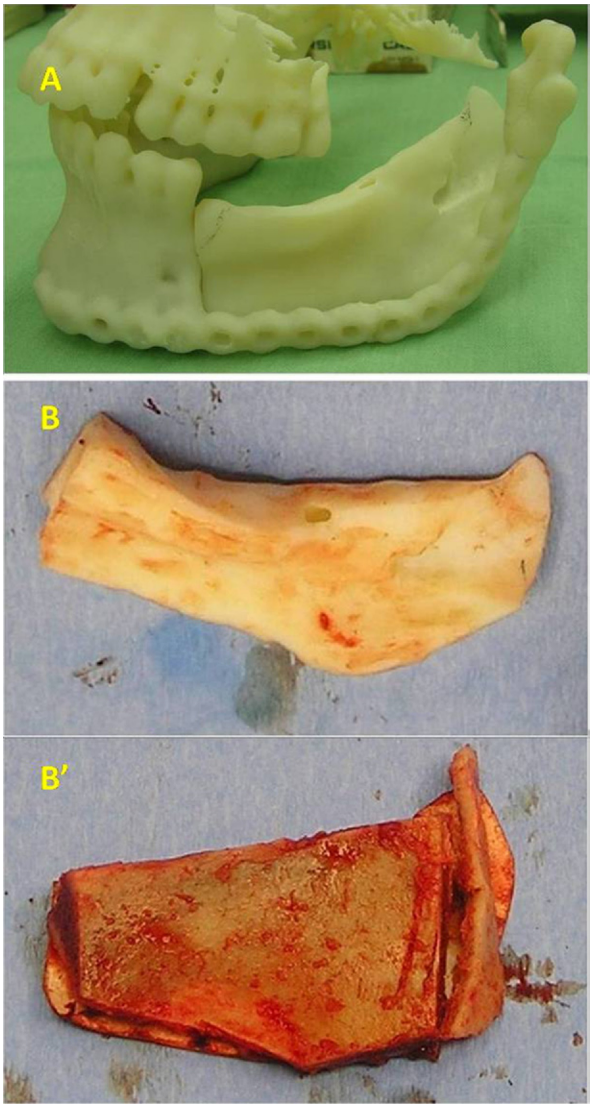

Fig. 2. **A,** Negative imprint of the missing bone was prefabricated before mandibular reconstruction. Bone harvesting from the ileum (**B′**) was done according to the negative template (**B**).

iliac crest was done according to the negative template (Fig. 2, *B* and *B′*).

A comparison between the bone graft and the template revealed that a short bone graft block was harvested. Therefore, adaptation to the gap could not be achieved with the graft as a monoblock, and a fixation of a few bone fragments to the bridging plate was done.

Case B

A 28-year-old man was suffering from plexiform ameloblastoma of the right mandible. The lesion extended from the sigmoid notch to the body of the mandible. A segmental resection was performed with a reconstruction by a precontoured plate, as described in case A. Good facial symmetry was achieved (Fig. 3).

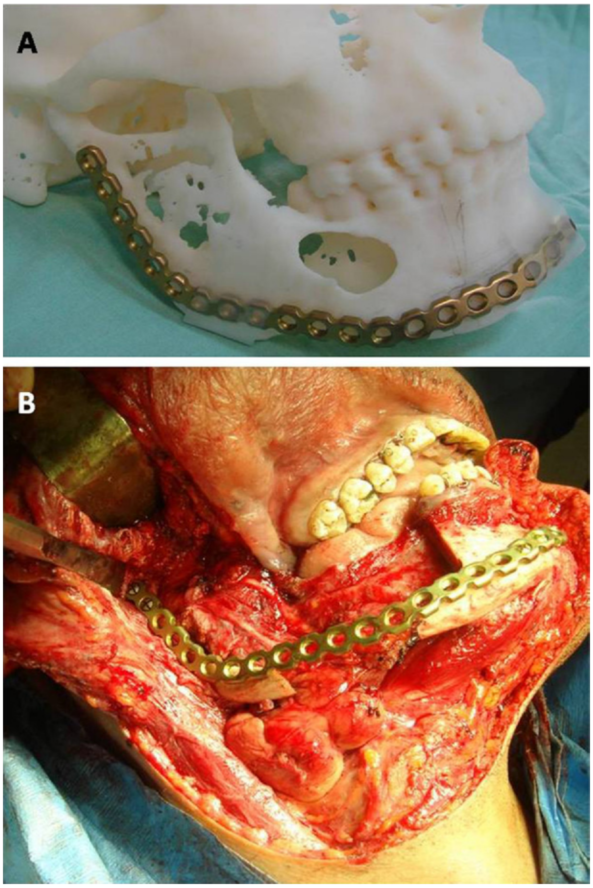

Fig. 3. **A,** Precontoured mandibular reconstruction plate placed over the right mandible consisting the ameloblastoma **B,** Reconstruction plate bridges the gap following tumour resection.

Case C

A 60-year-old woman, sufferring from mural ameloblastooma in the upper border of her right mandible, underwent marginal mandibulectomy, leaving a thin cortex in the lower border of the mandible. A prebent reconstruction plate was adapted to the mandible to strengthen the jaw. A precise adjustment of the plate to the mandible was achieved by precontouring only (Fig. 4).

DISCUSSION

There are several etiologies for bone defects of the mandible, such as tumors (benign or malignant), trauma, infections, osteoradionecrosis, and osteochemonecrosis. In many cases, part of the treatment requires segmental mandibulectomy and reconstruction of the bony defect.[7-9,12,13] The commonly used reliable alloplastic material for mandibular recon-

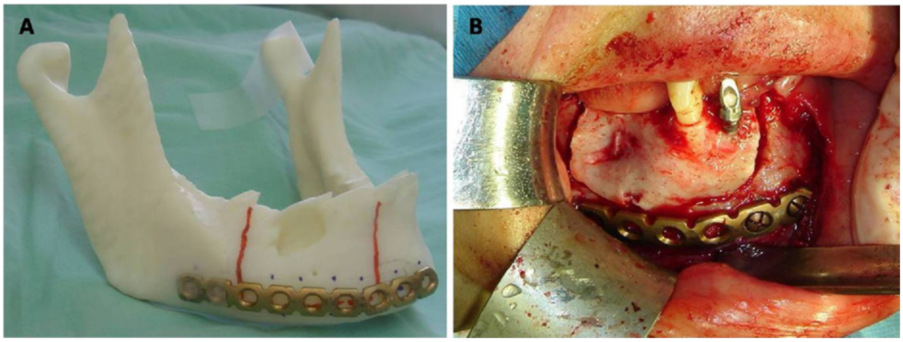

Fig. 4. **A,** Precontoured reconstruction plate before marginal mandibulectomy aiming to reinforce the remaining thin mandibular lower border. **B,** Note the physiologic alignment of the precontoured plate to the lower mandibular border.

struction is titanium reconstruction plate.[14] It is biocompatible and adaptive to bone surfaces, but, because of expected mechanical failure, it can serve only as a temporary reconstruction material to bridge the gap.[1,2]

In the present study, we present 3 clinical cases in which mandibular reconstruction was addressed using 3DP technology. In all 3 cases, partial mandibular resection was performed owing to ameloblastoma. Reconstruction was performed in the first stage with 2.4 mm Locking Plate precontoured according to the 3D model. Precise adaptation of the plate and excellent symmetry was achieved in a considerably short operation time. Plate handling in the operating theater was minimal, thus preserving its strength. Other benefits which should be mentioned include decreased exposure time to general anesthesia, decreased blood loss and shorter wound exposure time.[15-17]

Autogenous bone graft is a reliable standard method for further functional rehabilitation of the mandible. It can be harvested during the first surgical procedure, or at a second stage which would give time for recurrence detection. The exact amount of bone needed for harvesting is usually made by estimation of the gap and direct measuring. In 1 case, a 3D negative template of the created gap was printed. Bone harvesting from the iliac crest was made accordingly. This method has not been documented in the literature so far, and it is important for precise planning of the shape and size of the graft in addition to exact placement of the graft in an acceptable prosthodontically position for future dental implant rehabilitation.

CONCLUSION

The advantages of the 3D model techniques include the special understanding of the bone morphology, an accurate and easier planning of plate preoperative bending, and a much more accurate bone harvesting by using the negative imprint of the gap to be reconstructed.

The 3DP technology is a reliable method for precise mandibular reconstruction using bone plates and bone grafts. This method, compared with other 3D methods, is more quickly and easily produced and cost-effective. Furthermore, it is superior in printing smaller and more complex structures.

Future use of this new technology is recommended and might even serve in other fields in oral and maxillofacial surgery, such as dental implants treatment, temporomandibular joint surgeries, orthognathic surgery, and distraction osteogenesis of the jaws.

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