4 Emerging Technology in Reconstructive Surgery

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INTRODUCTION

In recent years, surgeons have taken advantage of various technologies to aid in microvascular free flap reconstructions. In this chapter, we discuss the use of virtual surgical planning and rapid prototype modeling for use in craniofacial reconstructions with vascularized bone flaps, which helps the surgeon to plan an idealized reconstruction with respect to restoring the facial skeleton and streamlines the creation of osteotomies. Indocyanine green (ICG) angiography and computed tomography angiography (CTA) allow visualization of flap pedicle and perforator blood vessels, which can aid in flap design, among other useful applications in reconstructive surgery. Finally, surface 3-dimensional photography is useful not only for analyzing postoperative results in terms of quantifying volumetric changes, but it holds promise as a way of more accurately planning soft tissue surgery.

VIRTUAL SURGICAL PLANNING AND RAPID PROTOTYPE MODELING

Advances in computer-assisted design (CAD) software have enabled surgeons to utilize 2-dimensional data, such as from a computed tomography (CT) scan, to generate a 3-dimensional virtual representation of a given body part. Such virtual body parts can be further manipulated, so that not only can surgical resections be rehearsed preoperatively, but various reconstructions with flaps, grafts, and implants can also be carried out on the computer to restore the missing parts in an idealized fashion (Fig. 4.1). While the applications for computer simulation of reconstructive surgeries is limitless, such technologies have become most widely applied to bony reconstruction of mandibular, maxillary, and other craniofacial defects.

Concurrent with advances in software, the development of 3-dimensional printing allows the creation of physical models from CAD computer data that are not only helpful in allowing the surgeon to visualize the patient's actual anatomy but, more practically, can serve as a template for bending and shaping the hardware used for bone flap, graft, and implant fixation (Fig. 4.2).[1–3] Additionally, computer-generated slotted cutting guides can also be manufactured using the same 3-dimensional printing process to assist with making osteotomies at the precise angles and lengths needed to replicate the planned reconstruction. Three-dimensional printing typically involves laying down successive thin layers of material that are bound or hardened by glue, light, or heat until the desired object has been manufactured. Three-dimensional printing processes are available for polymers, ceramics, glass, and metals. Because the process does not involve molds or dyes, 3-dimensional printing is substantially faster and less expensive than conventional manufacturing processes. Three-dimensional printing is also known as additive manufacturing, to distinguish it from subtractive processes, such as milling items from a block of material.

The term "stereolithography" specifically refers to the manufacture of 3-dimensional models using UV-light cured acrylic polymer resins. Stereolithography was the first additive manufacturing technique developed (in the 1980s) and has since spawned a multi-billion dollar industry for 3-dimensional printing. The process utilizes an ultraviolet laser to cure a photosensitive resin in sequential, thin, horizontally-oriented layers. The laser traces an area on the surface of a vat of liquid resin, curing only where it traces. The single layer, ranging of about 0.05–0.2 mm in thickness, is then hardened and "dipped" into the liquid vat to coat it with a new liquid layer. Subsequent scanning of the laser on the new layer both solidifies the new layer and adheres it to the layer below. Over the course of several hours, a 3-dimensional model is created. Post-processing is performed to remove excess liquid resin and fully cure the resultant parts. Stereolithographic models can be gas sterilized for use during surgery.

MANDIBULAR AND MAXILLARY RECONSTRUCTION

In a typical scenario, a fine cut (1–1.25 mm) axial head and neck CT scan with 0° of gantry tilt is obtained. The data is saved to a computer disk in a generic format (Digital Imaging and Communications in Medicine, DICOM), which can be utilized by CAD software to create a virtual 3-dimensional model of the facial skeleton that can be rotated in any direction. A CT scan of the bony free flap donor site is obtained, so that it can be manipulated using the software to create an idealized reconstruction. The fibula is usually used for bony free flap reconstruction in most practices, but virtually any site (e.g., scapula or iliac crest) can be imaged and imported into the CAD platform. If a donor site CT scan is not obtained, outcomes from using generic donor site data are usually acceptable.

The author, as well as others, have had success collaborating with computer engineers in third-party manufacturers

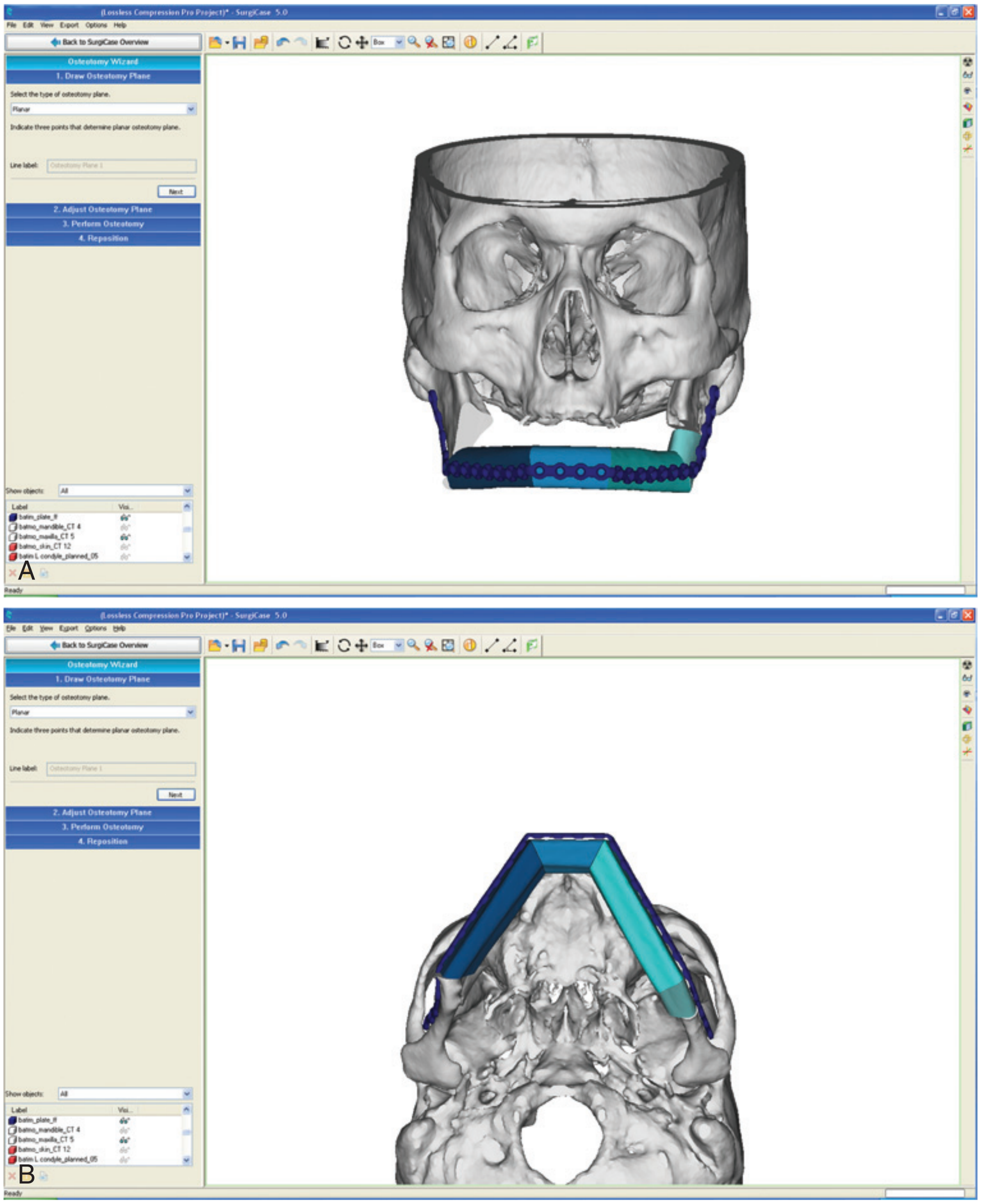

Figure 4.1 Computer-assisted design virtual reconstruction of the mandible with a fibula free flap in (A) anterior-posterior and (B) submental views. The head can be rotated in any direction to confirm that the planned reconstruction is ideal in terms of restoring the patient's mandibular shape and occlusion.

rather than designing and printing our own models as we initially did.[1–3] Virtual resection osteotomies of the mandible or maxilla in consultation with the resecting surgeon, if different from the reconstructive surgeon, are then planned. Next, the desired fibula, left or right, is selected and virtual osteotomies are performed as needed to reconstruct the missing mandible or maxilla. The original mandible or maxilla can be visualized as a partial transparency or "ghost" to help guide the shaping of the fibula reconstruction. When the existing mandible is misaligned due to displaced fracture or prior resection, the mandibular remnants can be repositioned. Occlusion is checked in multiple planes prior to finalizing the plan. If desired, a "double-barrel" fibula can be configured to correct for the height discrepancy between the fibula (mean of 17.9 mm in width on its lateral border in males) and the anterior mandible (mean of 33.5 mm in height at the symphysis in males).[4]

Once the virtual plan is finalized, a model of the reconstructed mandible or maxilla is constructed using 3-dimensional printing technology. Slotted cutting guides are made for the maxilla or mandible that fit along the existing bony contours, as well as for the fibula or other free flap donor site (Fig. 4.3). During surgery, the cutting guides are temporarily fixated to the mandible or maxilla and to the fibula with monocortical screws, and a reciprocating saw blade is inserted into the slots. Newer generation cutting guides feature metal inserts that snap into the slots, to minimize saw blade play and increase the accuracy of osteotomies. The models are sterilized and made available for use