during surgery. Utilizing models to prebend titanium hardware prior to surgery can save operative time.

In our experience, use of virtual computer planning and 3-dimensional medical models with cutting guides saves operative time and increases reconstructive accuracy.[2] Prebending hardware, as well as using the cutting guides to simplify osteotomies, saves operative time, particularly when multiple osteotomies are needed. The preoperative planning that occurs may also increase operative efficiency by improving surgical decision-making and reducing trial and error during fibular harvest and shaping, since the surgeon is forced to mentally rehearse the surgery ahead of time. We have shown increased accuracy compared with traditional methods of template bending along the native contours of the maxilla or mandible, and “eyeballing” the reconstruction when necessary, as well as a close correlation between the final reconstruction and the computer-assisted virtual plan.[2] It has also been suggested that virtual planning and medical modeling makes bony head and neck reconstruction more accessible to less experienced and occasional osteocutaneous free flap surgeons.[5] Even in experienced hands, however, computer planning and 3-dimensional models are beneficial for those cases in which the original architecture of the mandible or maxilla is not easily identifiable, including patients with exophytic tumors, displaced or comminuted pathologic fractures, and prior resections with and without prior reconstructions. In these patients, creating a template for shaping the reconstruction along the native contours of the mandible or maxilla is often difficult or impossible.

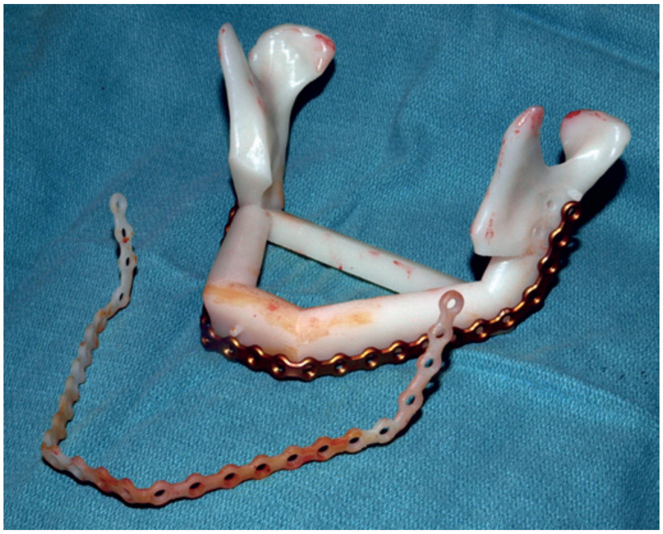

Figure 4.2 A 3-dimensional rapid prototype model made of acrylic polymer that can be used to guide surgery as well as act as a template for bending titanium hardware, which can be done preoperatively to save time, then sterilized in preparation for surgery.

A negative of utilizing these technologies includes costs for engineering and manufacturing the models, which are arguably offset by operative time savings and increased accuracy. Virtual planning requires anywhere from 30 to 60 min, usually performed between the surgeon and a software engineer via web conference. Time is also needed to print and ship the models. While this usually only takes 1–2 days with express shipping, it makes the technique unfeasible when the initial consultation is performed just prior to surgery. Perhaps the greatest limitation is that the benefits of virtual planning and medical modeling are reduced when the operative plan changes, for example, due to tumor growth. To limit the potential for change in the resection and needed reconstruction, recent imaging is recommended, as is close communication between the resecting and reconstructive surgeons.

Rapid prototyping and computer-assisted design software continues to evolve. Such technologies are already commonly used by oral surgeons to guide endosteal implant placement in the native mandible and maxilla.[6] Some have

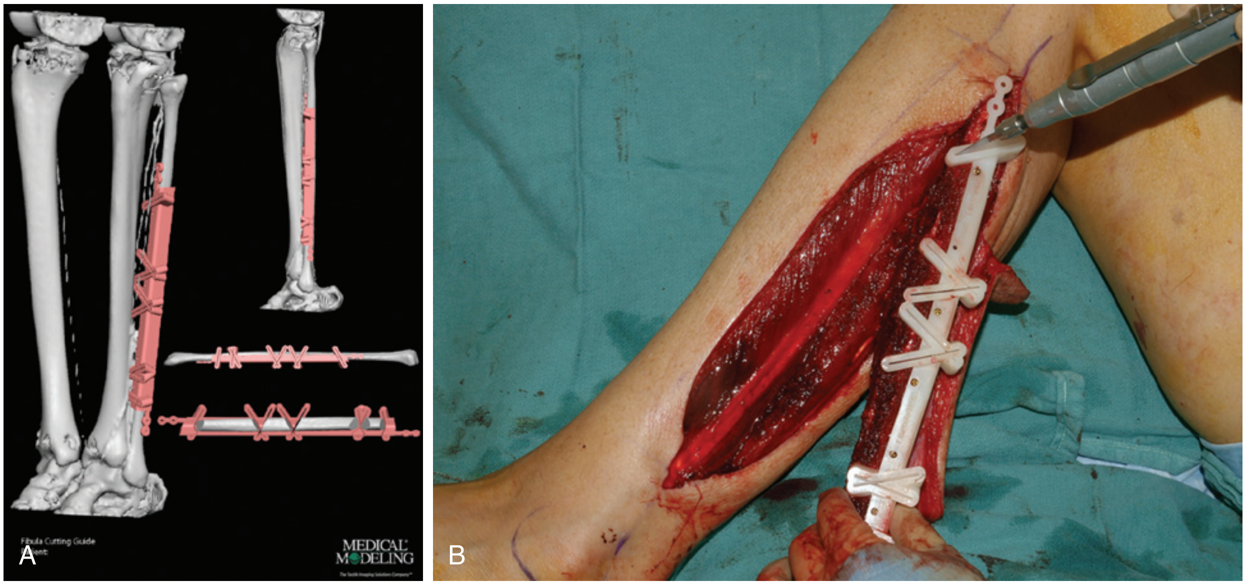

Figure 4.3 Computer-generated cutting guides can also be manufactured to simple osteotomies, making it easier to cut the fibula at the precise lengths and angles needed to duplicate the virtual plan. (A) Virtual representation and (B) actual intraoperative photograph, demonstrating the use of the cutting guide.

Figure 4.4 A custom-made titanium plate based on the preoperative virtual plan next to a 3-dimensional mandible model. The plate is created using a computer-guided milling process rather than by printing for increased strength. The screw hole placement and angulation is defined by the surgeon during computer planning. (Photograph courtesy of Patrick Garvey, MD.)

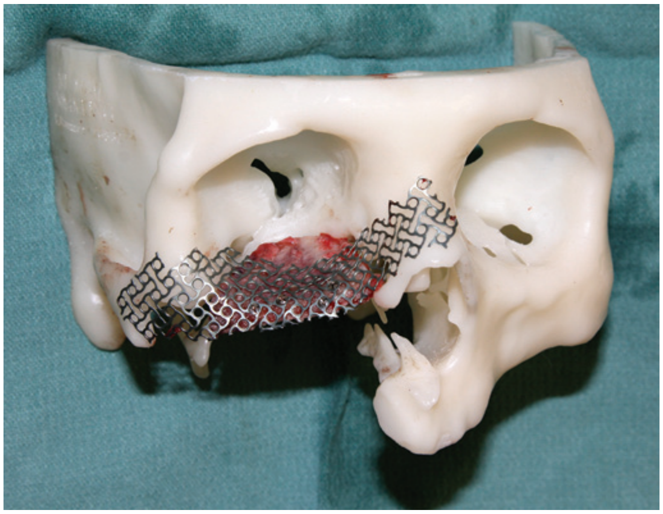

Figure 4.5 A 3-dimensional model used to guide orbital reconstruction with titanium mesh and bone graft for accurate restoration of the orbital floor, which is critical to prevent enophthalmos, exophthalmos, and/or orbital dystopia.

explored performing immediate implant placement at the time of free flap reconstruction, utilizing computer planning and custom drill guides to precisely place implants between hardware screws.[7] Immediate implant placement takes advantage of the increased accuracy of bony reconstruction, since implants are rendered unusable if placed inaccurately at the wrong angulation. Another step that may substantially contribute to increased accuracy is the creation of patient-specific titanium hardware, which is not prebent, but rather milled from a solid block of titanium for maximal strength. Such patient-specific hardware allows the surgeon to select individual screw hole placement in the number, location, and angulation that is most optimal for a specific defect (Fig. 4.4).

ORBITAL RECONSTRUCTION

In addition to mandibular and maxillary reconstruction, virtual surgical planning and medical models has also been useful for orbital reconstruction.[8,9] Very precise restoration of the orbital cavity is necessary to avoid enophthalmos, exophthalmos, or vertical dystopia (eyes at different heights). Bony free flaps can be designed for orbital reconstruction virtually, just as for the mandible and maxilla. More commonly in our practice, titanium mesh or bone grafts are used for orbital reconstruction and supported by soft tissue flaps. In these cases, we find that using a 3-dimensional model as a template for shaping bone grafts and mesh implants is easier than using the patient's actual orbit because surgical exposure is often limited, and retraction of the eye can result in injury to the globe, traction on the optic nerve, or bradycardia due to the oculocardiac reflex. Hardware or mesh is bent along the contours of a rapid prototype model (Fig. 4.5), so that accurate restoration of the orbit is achieved. In cases where the original anatomy is distorted or absent, such as by tumor or trauma, a virtual template for reconstructing the bony contours of the orbit can be created by mirroring the unaffected side onto the affected side. Another more costly alternative is to create a patient-specific implant or plate that is produced by a third company that either mirrors the normal side or is created based on an orbit of an age matched control.

INTRAOPERATIVE STEREOTACTIC NAVIGATION

While use of bony free flap models combined with computer-generated cutting guides increases the accuracy of osteotomies and fixation of the flap segments to each other, accurate fixation to the remaining craniofacial skeleton is also necessary to restore facial shape and symmetry. Flap or graft insetting is particularly challenging in the midface and orbit when limited access incisions are used and surgical exposure is compromised. Inaccurate insetting, even by several millimeters, can result in malocclusion and inappropriate mid-facial projection or height in maxillary reconstruction, even when bony free flap osteotomies are perfectly executed. In orbital reconstruction, the tolerance for inaccuracy is even lower, with errors in fixation having not only aesthetic consequences but also potentially impaired vision or even blindness. In such cases, we, as well as others, have utilized intraoperative stereotactic navigation to confirm positioning of flaps and grafts in three dimensions.[8,9]

Intraoperative navigation systems were initially developed for neurosurgical applications and were then adopted for use also in endoscopic sinus surgery. When utilizing navigation for virtually planned reconstructions, the virtual reconstruction images are back-converted to DICOM files and loaded into the central processing unit (CPU) of the navigation system along with the original CT data, so that both sets of images can be referenced during surgery. The most common computer navigation systems include InstaTrak (General Electric Healthcare, Buckinghamshire, UK); StealthStation (Medtronic-Xomed, Jacksonville, FL); Stryker Navigation System (Stryker-Leibinger, Kalamazoo, MI), and