Three-Dimensional Analysis and Surgical Planning in Craniomaxillofacial Surgery

Derek M. Steinbacher, DMD, MD

Purpose: Three-dimensional (3D) analysis and planning are powerful tools in craniofacial and reconstructive surgery. The elements include *1)* analysis, *2)* planning, *3)* virtual surgery, *4)* 3D printouts of guides or implants, and *5)* verification of actual to planned results. The purpose of this article is to review different applications of 3D planning in craniomaxillofacial surgery.

Materials and Methods: Case examples involving 3D analysis and planning were reviewed. Common threads pertaining to all types of reconstruction are highlighted and contrasted with unique aspects specific to new applications in craniomaxillofacial surgery.

Results: Six examples of 3D planning are described: *1)* cranial reconstruction, *2)* craniosynostosis, *3)* midface advancement, *4)* mandibular distraction, *5)* mandibular reconstruction, and *6)* orthognathic surgery.

Conclusions: Planning in craniomaxillofacial surgery is useful and has applicability across different procedures and reconstructions. Three-dimensional planning and virtual surgery enhance efficiency, accuracy, creativity, and reproducibility in craniomaxillofacial surgery.

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Craniomaxillofacial surgery requires restitution of form and function and the correction of dysmorphology, disease, and defect. Soft tissue and osseous reconstructions are performed often in concert. The craniofacial region is complex, with topographic relations and compartments between anatomic sites. A comprehensive understanding of the problem is the first step before carrying out the definitive reconstruction. Preoperative planning, which can include geometric and quantitative factors, with virtual simulation will help to optimize the result.

Modern 3-dimensional (3D) analysis and surgical planning have their roots in 2-dimensional (2D) plain radiography[1] and craniometrics performed on 3D dried skulls by anthropologists.[2] These 2 modalities were merged with the advent of cephalometrics and implemented by orthodontists to gauge growth and assist in treatment.[3] Combined surgical and orthodontic planning advanced this approach by establishing goals for jaw movement to achieve the desired occlusal result.[4] Three-dimensional renderings of 2D computed tomographic (CT) data have allowed for more precise analysis in the craniofacial realm.[5] Design, engineering, architecture, and other industries have paved the way for the manipulation and printing of 3D objects.[6]

Virtual surgical 3D simulation and planning have gained steam during the past several decades.[7,8] It must be stressed that despite the many advantages of this technology, it cannot replace a surgeon's clinical judgment or technical skill. Three-dimensional planning can increase efficiency and accuracy, but does not guarantee an ideal or perfect result. The 5 core components of 3D analysis and planning include *1)* analysis, *2)* planning, *3)* virtual surgery, *4)* 3D printing, and *5)* comparison of planned with actual results. The purpose of this article is to provide an overview of 3D virtual planning in craniomaxillofacial surgery.

Director of Craniomaxillofacial Surgery, Associate Professor Plastic Surgery and Oral Maxillofacial Surgery, Department of Plastic and Craniomaxillofacial Surgery, Yale University, New Haven, CT.

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Address correspondence and reprint requests to Dr Steinbacher: Department of Plastic and Craniomaxillofacial Surgery, Yale University, 330 Cedar Street Boardman Building, New Haven, CT 06520; e-mail: derek.steinbacher@gmail.com

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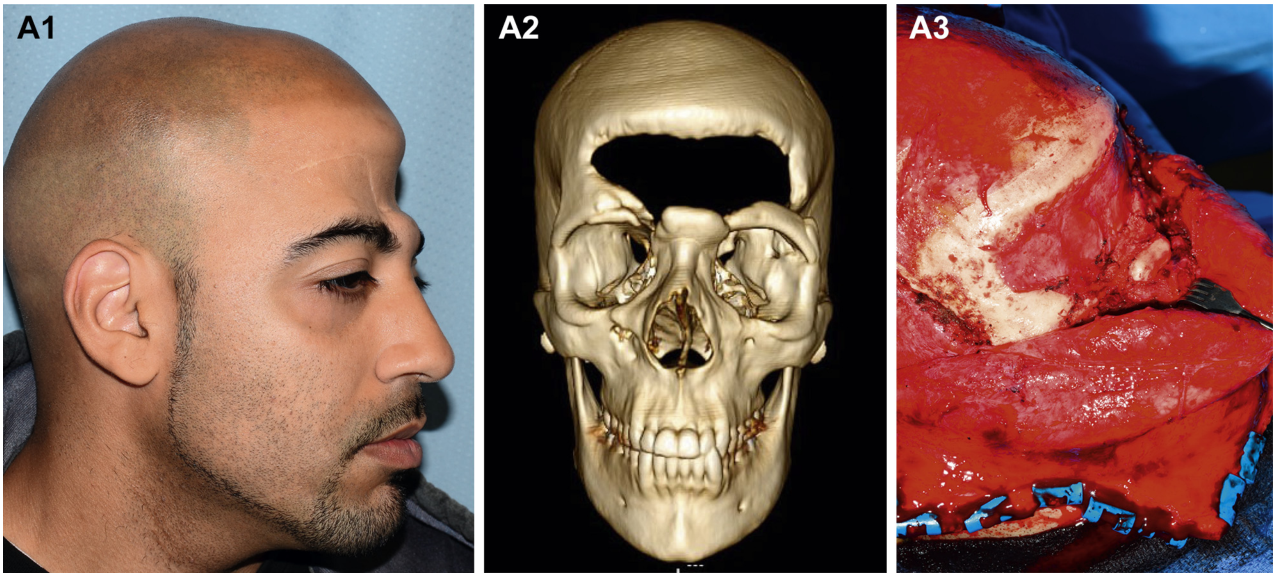

FIGURE 1A. Cranial reconstruction. *A1*, Preoperative image depicting a cranial frontal defect. *A2*, Computed tomogram displays loss of frontal bone with preserved supraorbital rims. *A3*, The frontal sinus is absent and a soft tissue dural scar is present, sealing the ethmoid and nasal cavity from the frontal lobes.

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Analysis

A 3D rendering of bone and soft tissue allows for in-depth consideration of the anatomy and problems at hand. Typically the CT data are uploaded into a virtual surgical platform and manipulated in digital space. The region of interest can be viewed at scale or magnified and rotated to visualize contours and relations. Anatomy that will not be involved in treatment can be digitally removed to enhance focus of the planned surgical site. Layers of structure can be virtually subtracted to allow for unfettered visualization from multiple vantage points. Tools allowing linear, angular, and volumetric measurements can be used. These quantitative and morphologic values can be compared with "normal" or idealized situations to better understand what needs correction and establish the groundwork to develop a plan.

The analysis is perhaps the most critical step in planning surgery. This is, in essence, the diagnostic phase—not a diagnosis such as "Crouzon syndrome" or "squamous cell cancer," but rather a descriptive morphologic understanding and capture of the

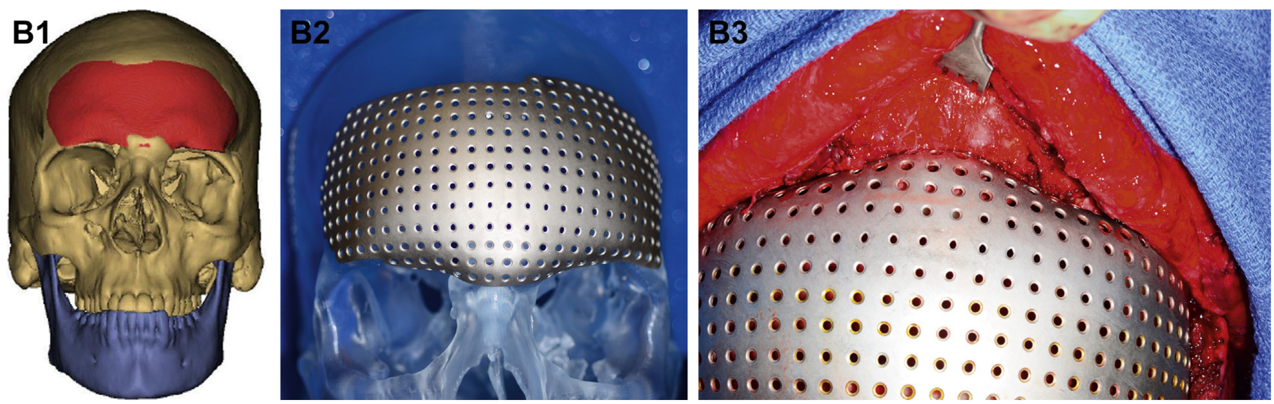

FIGURE 1B. *B1*, Three-dimensional plan is performed using digital moldable "clay." This is manipulated to fill the defect with desired size, shape, and contour. *B2, B3*, Custom milled titanium mesh is fabricated to offer protective and esthetic function.

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