Three-Dimensional Analysis and Surgical Planning in Craniomaxillofacial Surgery

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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.

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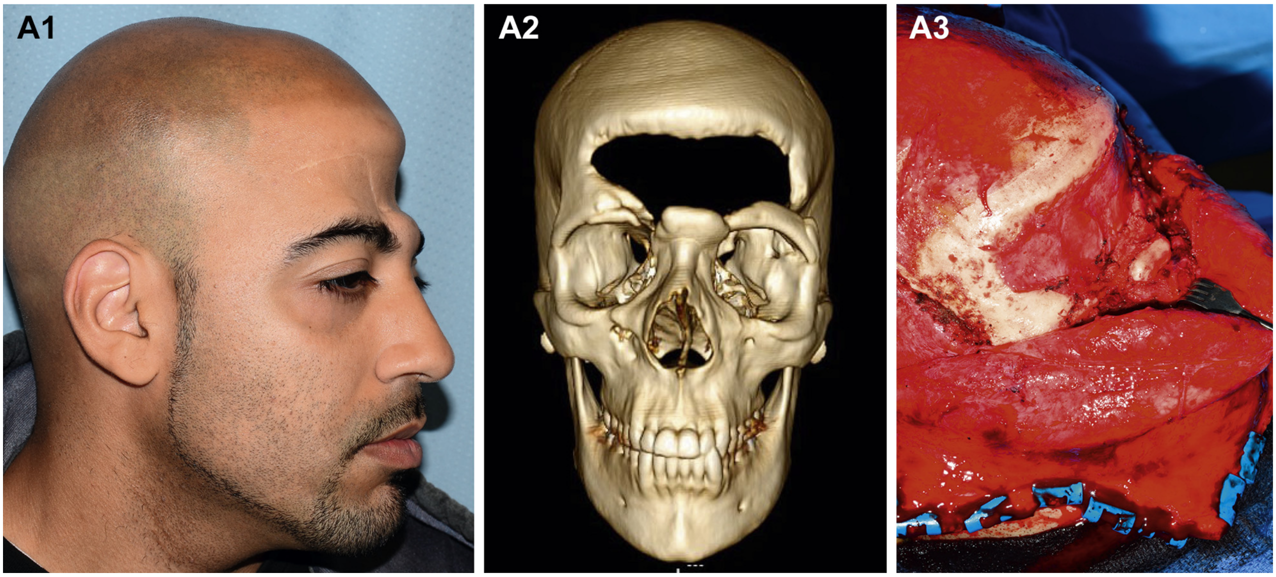

FIGURE 1A. Cranial reconstruction. *A1*, Preoperative image depicting a cranial frontal defect. *A2*, Computed tomogram displays loss of frontal bone with preserved supraorbital rims. *A3*, The frontal sinus is absent and a soft tissue dural scar is present, sealing the ethmoid and nasal cavity from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

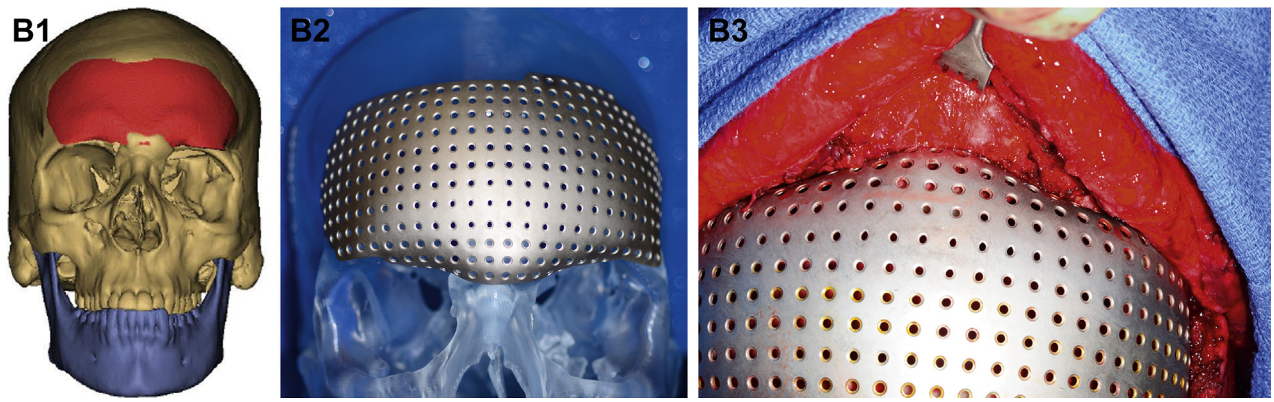

FIGURE 1B. *B1*, Three-dimensional plan is performed using digital moldable "clay." This is manipulated to fill the defect with desired size, shape, and contour. *B2*, *B3*, Custom milled titanium mesh is fabricated to offer protective and esthetic function.

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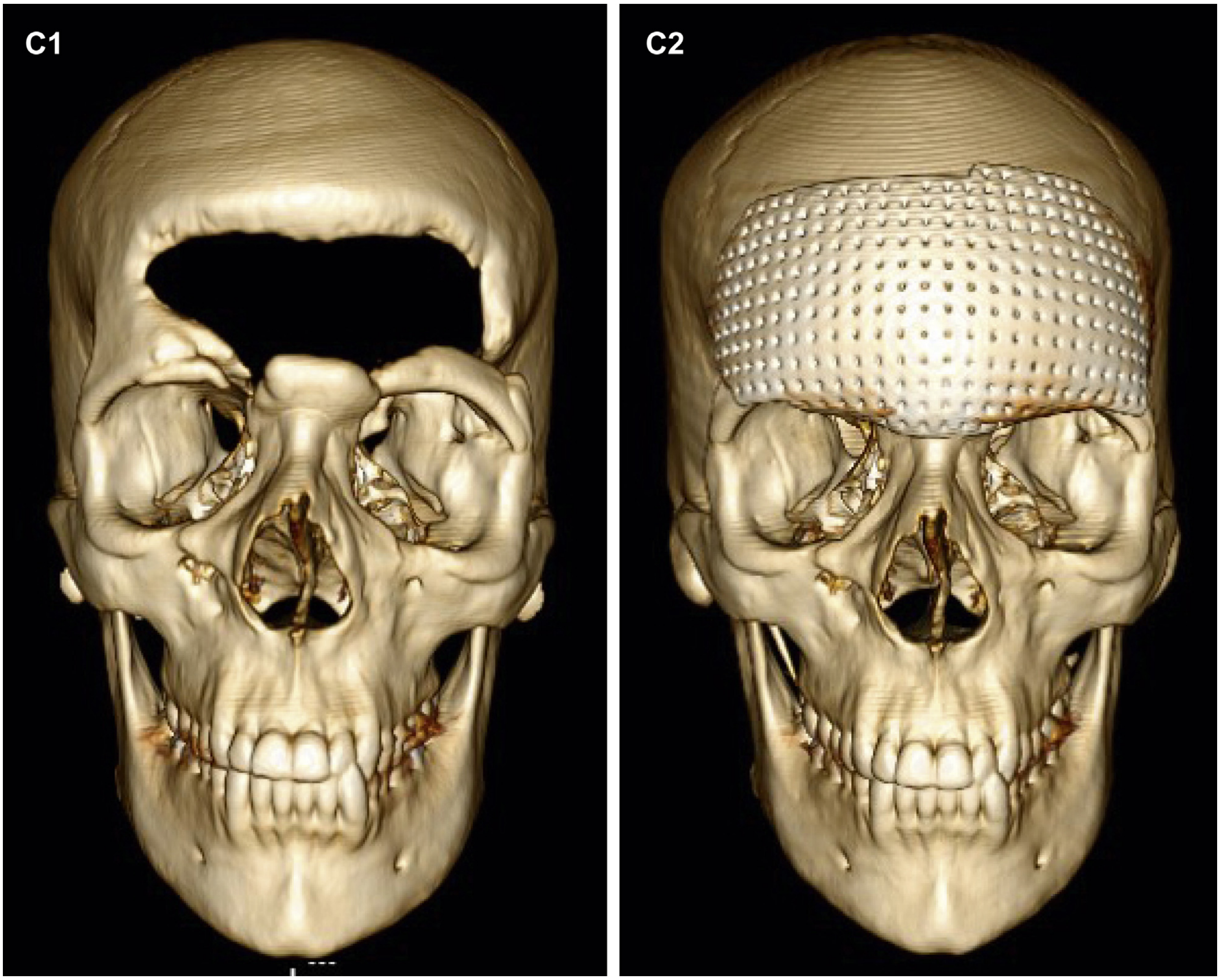

FIGURE 1C. *C1*, Preoperative and *C2*, postoperative computed tomograms.

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FIGURE 1D. *D*, *Left*, Preoperative image and *right*, postoperative clinical result.

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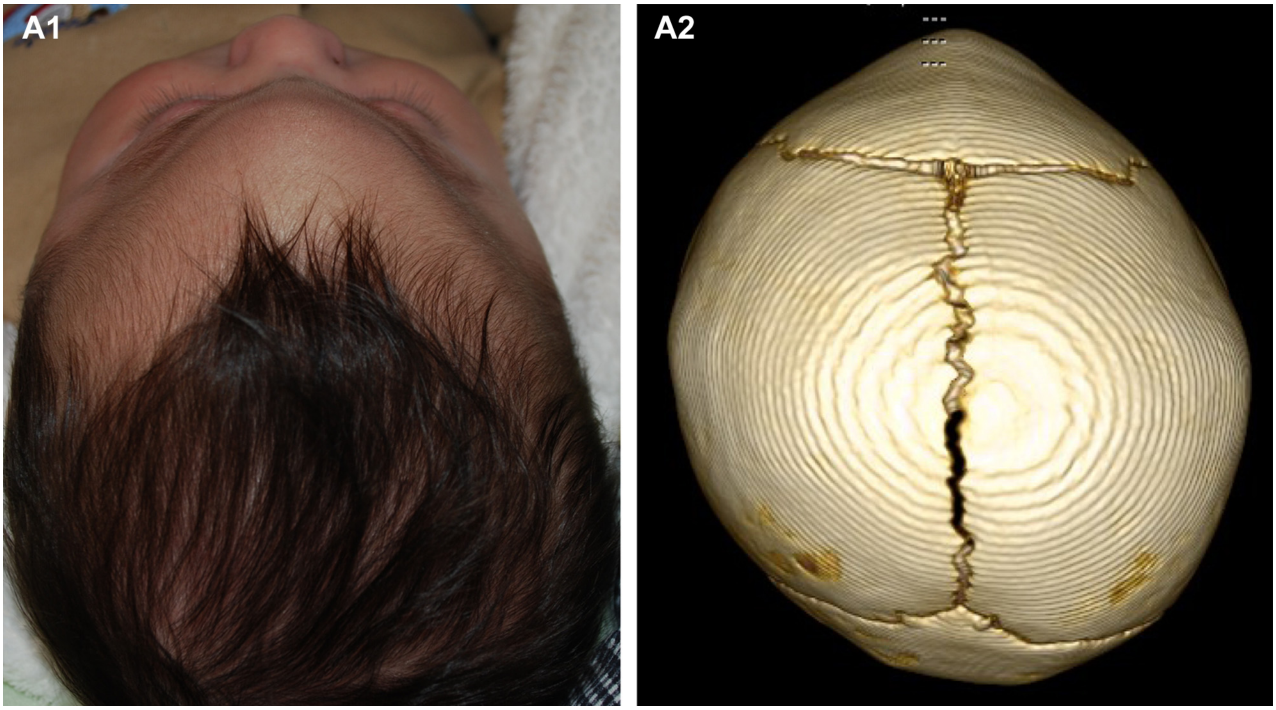

FIGURE 2A. Craniosynostosis. *A1*, Preoperative clinical and *A2*, radiographic images show metopic synostosis. Note the trigonocephaly and bitemporal narrowing. Computed tomogram shows a metopic ridge.

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problem. In broad strokes, for reconstructive craniomaxillofacial surgery, one can consider problems as follows: *1)* defect (missing tissue), *2)* deformity or dysmorphology (structures are present but are too small, large, or deformed), *3)* malrelations (the anatomy is there but in the wrong place), or *4)* some combination of these.

Planning

The planning phase is the opportunity to consider the type, extent, and magnitude of correction required and then ultimately decide on the single best option. The plan is devised to correct the problem identified during the analysis phase. Endpoint goals to address

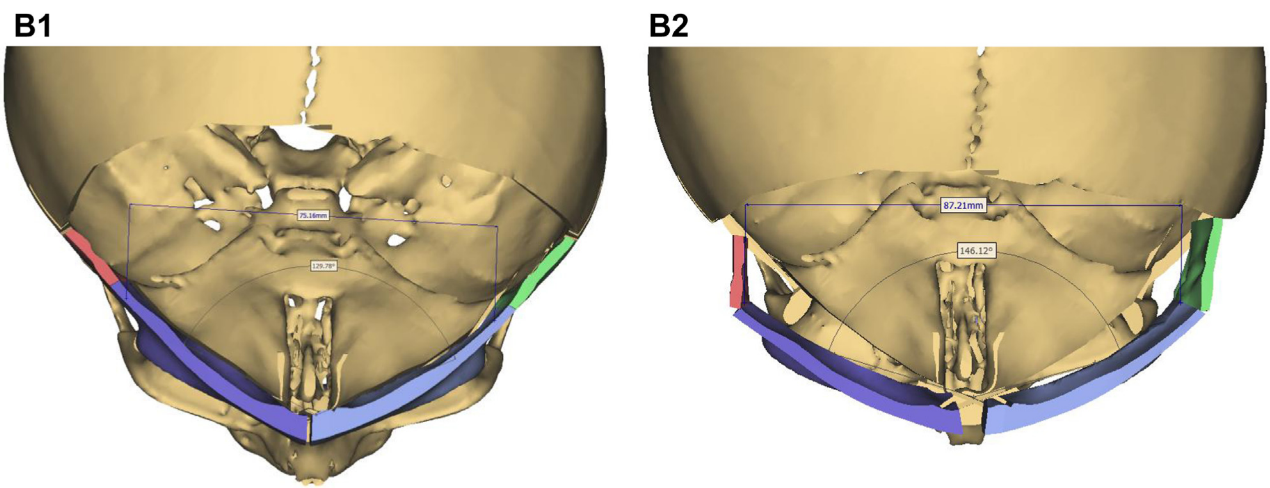

FIGURE 2B. *B1*, *B2*, The plan is performed to achieve a normal endocranial bifrontal angle, with appropriate bitemporal form and expansion at the radix.

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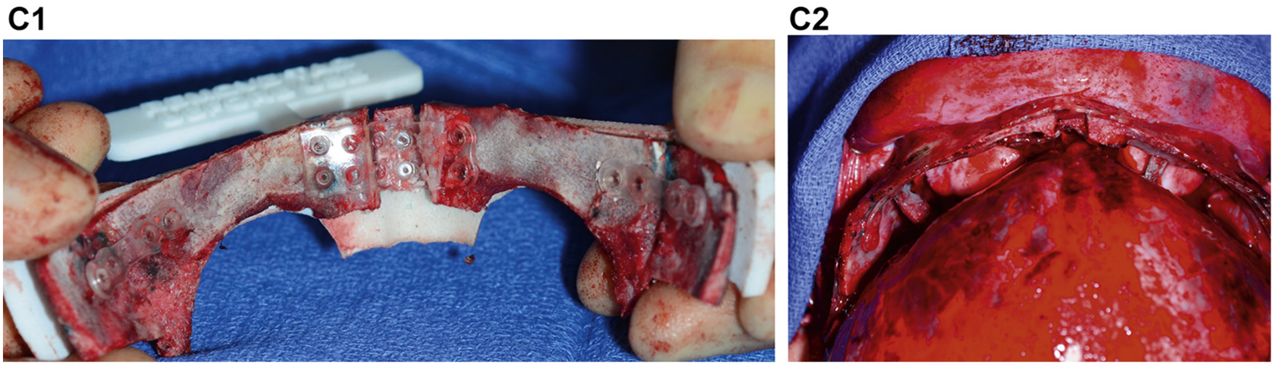

FIGURE 2C. *C1*, *C2*, An intraoperative guide or cradle is used to achieve the desired bandeau dimensions, expansion, and shape.

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the underlying defect, deformity, or dysmorphology should be incorporated into the surgical options. These could include reconstitution of missing tissue, movement or repositioning of anatomic segments, removal and reshaping of structural elements, or some combination thereof. The treatment goals can include filling a defect for protection and esthetics or expanding or moving tissue to improve function. A stable, static position is not always sufficient, because it might be necessary to estimate future growth or factor in overcorrection to minimize relapse. The proposed surgery can be based on quantitative anthropometric guides, a superimposed normal side, or a mirrored normal side. The plan can be dictated by desired esthetic goals and anatomic interrelations; examples include a "proper" forehead projection and form, nasal length, lip support, tooth show on smile, and chin position.

Virtually Performing the Surgery

The next step, after problem identification and establishing the goals of treatment, is to virtually perform the surgery. This is performed part and parcel with planning the surgery. The proposed procedure is digitally carried out by incorporating the goals of the intervention to address the clinical problem. The virtual plan permits a run through or dress rehearsal of the procedure in digital space. Benefits of this include identification of the intrinsic, manipulated anatomy, with requisite relations to nearby or subjacent structures (eg, nerves, teeth, sinus cavities). Then, the pitfalls, interferences, and unanticipated consequences of the surgery can be intimately considered and shed light on how the operative procedure could or should be modified. In addition, several scenarios, or surgical options,

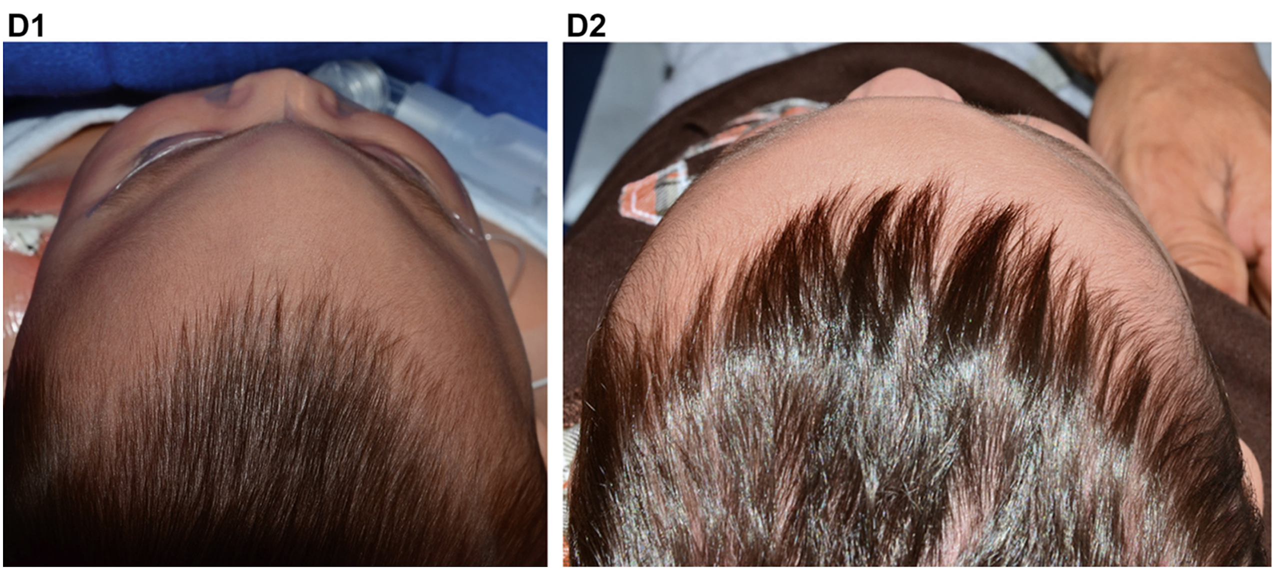

FIGURE 2D. *D1*, Preoperative image and *D2*, postoperative clinical result.

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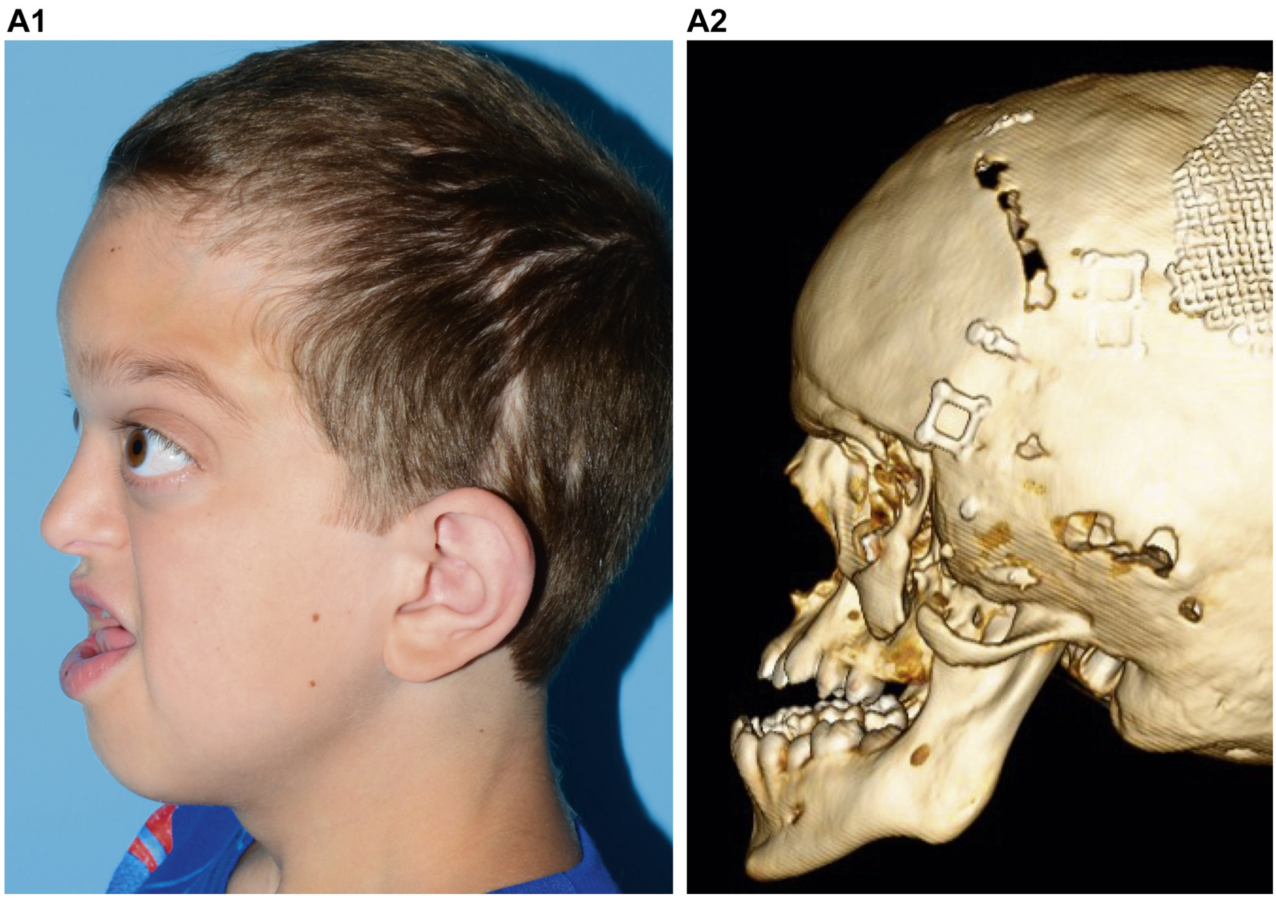

FIGURE 3A. Midface advancement. *A1*, Preoperative image of child with Crouzon syndrome. Note the exorbitism (relative exophthalmos), the shortened nasal length, midface hollowness, poor upper lip support, and lip incompetence. *A2*, Computed tomogram depicts bony deficiency and an anterior crossbite.

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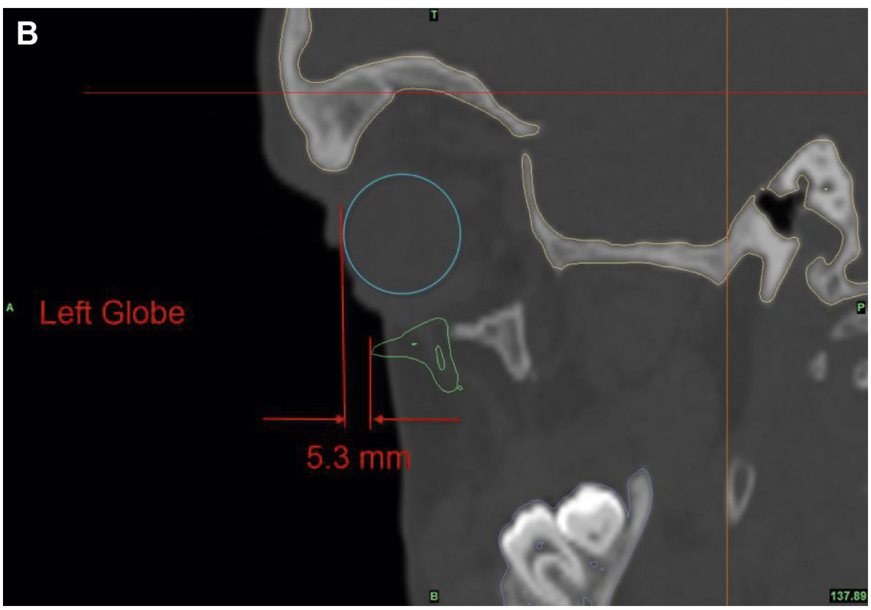

FIGURE 3B. *B*, A Le Fort III osteotomy is planned to optimize the orbital globe relation. The relation of the anterior cornea to the infraorbital rim is used to guide movement.

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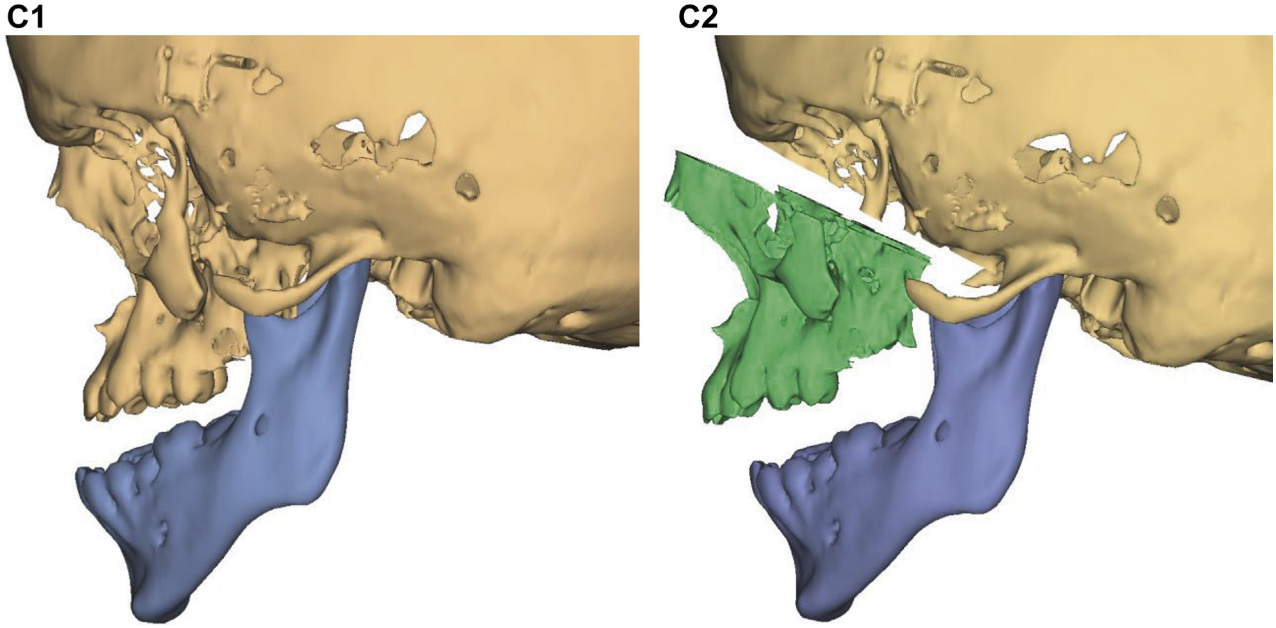

FIGURE 3C. *C1*, *C2*, The Le Fort III osteotomy is performed digitally and the orbital relation, nasal length, angle formed by the sella, nasion, and A point, and occlusion are confirmed as desired.

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can be carried out and compared. The different treatment strategies can be measured, globally inspected, or overlaid with one another to contrast and weigh their merits. Once the final plan is decided, a stepwise guide with operative sequence and treatment notes is generated and referred to intraoperatively. The a priori virtual surgery creates a visual image, and expectation, that mentally prepares the surgeon and likely improves efficiency and enhances the overall result.

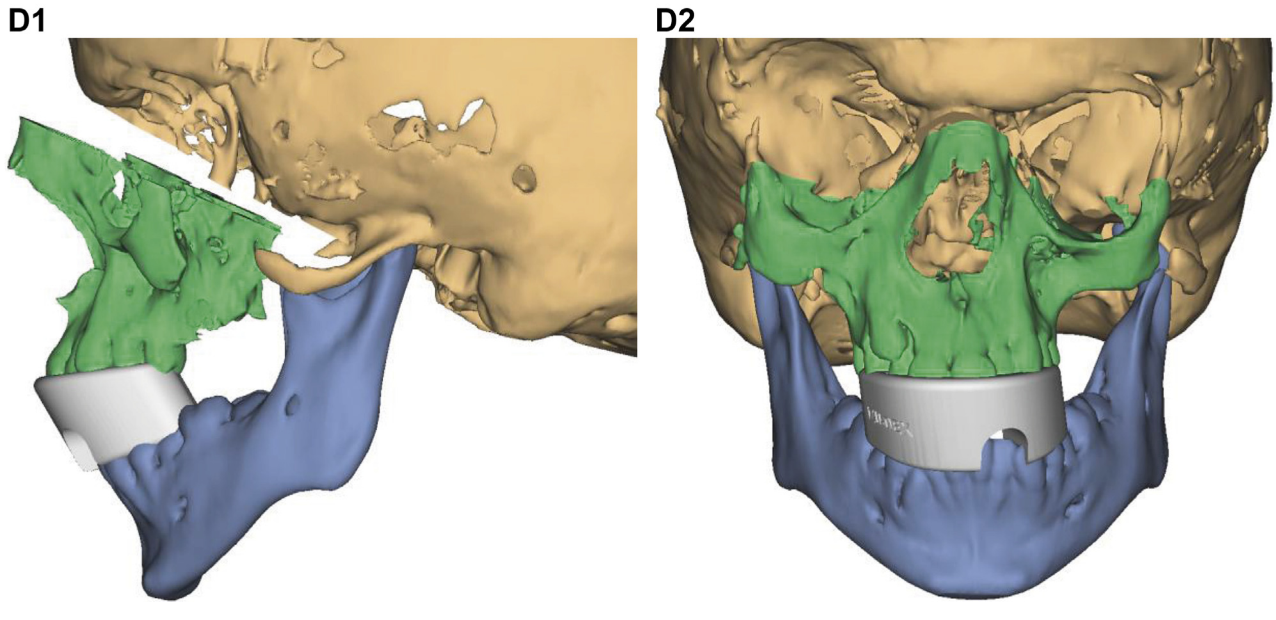

FIGURE 3D. *D1*, *D2*, In an older child with a smaller magnitude of movement, a single-stage Le Fort III osteotomy with rigid fixation can be performed. To avoid the change from oral feeding to a nasal tube, a specialty splint can be fabricated.

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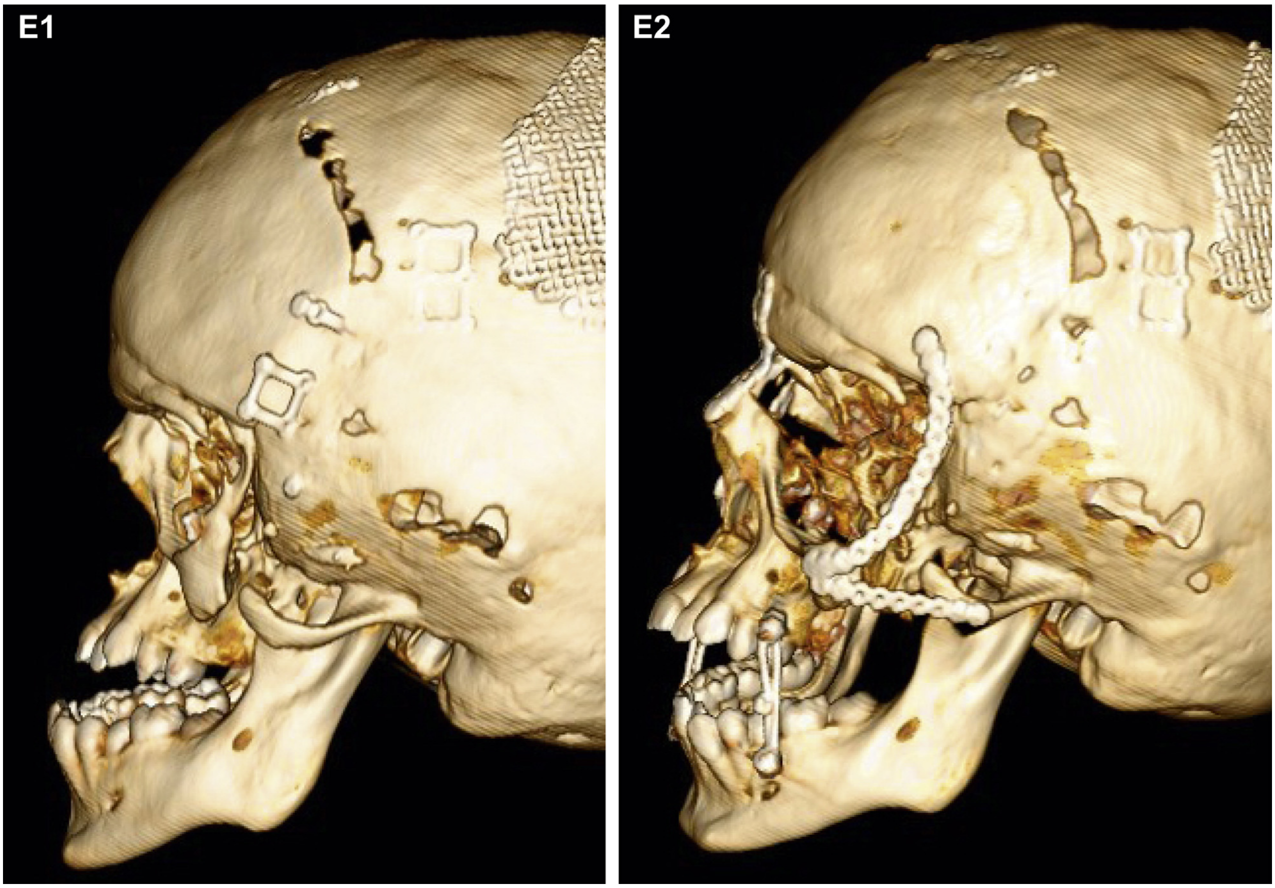

FIGURE 3E. *E1*, Preoperative and *E2*, postoperative computed tomograms.

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3D Printing of Guides, Splints, or Implantable Elements

Once the virtual surgical plan is finalized, the stereolithographic file allows for guides, splints, or implants to be printed in 3 dimensions. These prints are based on the actual rendering and 3D anatomy and therefore accurately interdigitate with the region of interest. Guides and implants can be temporary (used and then removed) or permanent (implantable as part of the reconstruction). Temporary guides are usually made of a high-grade plastic and can be sterilized. Examples include a cutting and positioning guide for mandibular distraction, a cutting guide to shape the donor fibula during mandibular reconstruction, or occlusal splints used to reposition the jaws in orthognathic surgery. These temporary guides, splints, and cutting templates are typically used and removed during surgery or occasionally left in place for a short postoperative period and then removed. The usual example of a tool that is temporary but maintained for a few weeks after surgery is an occlusal splint during a segmental orthognathic case. All other cutting and positioning guides are removed before the end of surgery.

Permanent, implantable items also can be fabricated from the 3D virtual surgical plan. Frequent examples include pre-bent plates (custom bent to printed stereolithographic models), custom milled plates (constructed based on the virtual plan), or custom implants (polyether ether ketone, porous polyethylene, or titanium) to be permanently implanted as a critical component of the reconstruction.

Comparison of Planned With Actual Results

After surgery, it is critical to analyze the result obtained. To determine whether the outcome was precise or adhered closely to the plan, a critical assessment with an overlay of the planned and actual morphologies must be performed. A postoperative CT scan is required and used for evaluation. This is a learning opportunity to consider whether or why any deviations occurred. Were the differences made necessary by some intraoperative change? For

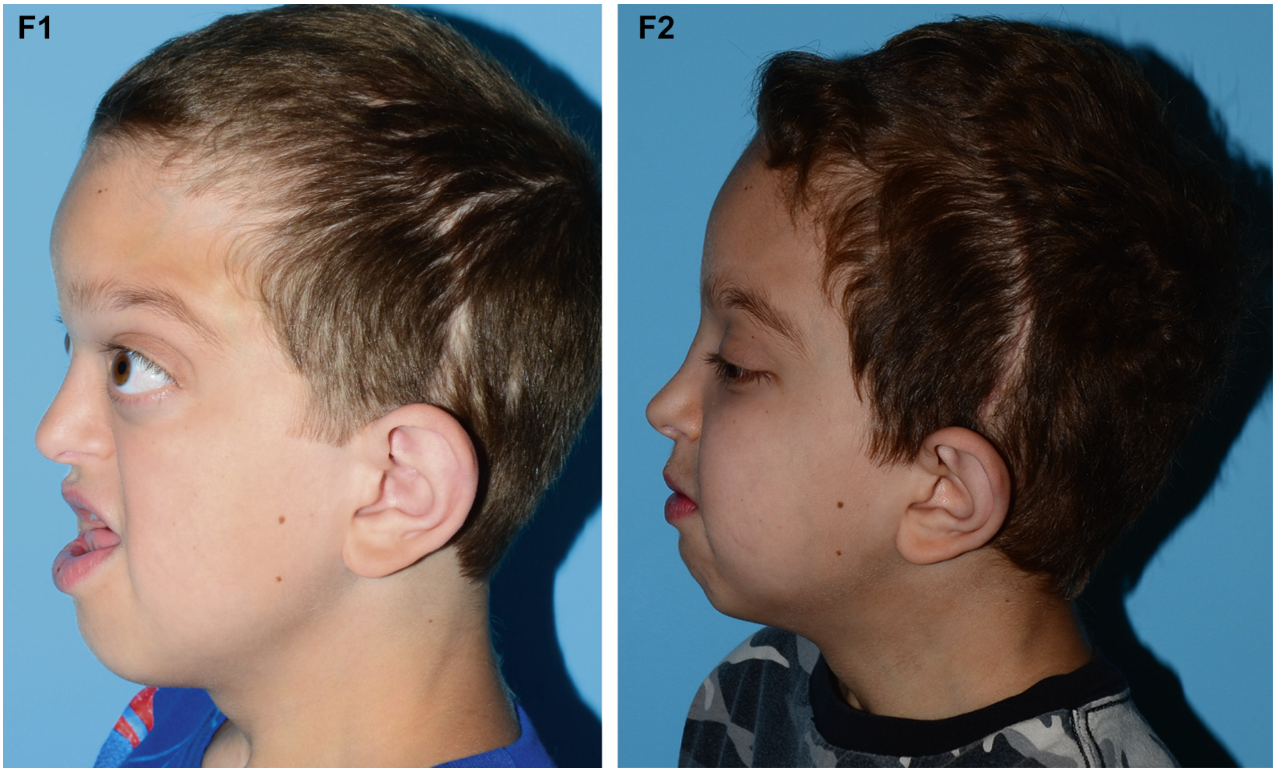

FIGURE 3F. *F1*, Preoperative image and *F2*, postoperative clinical result.

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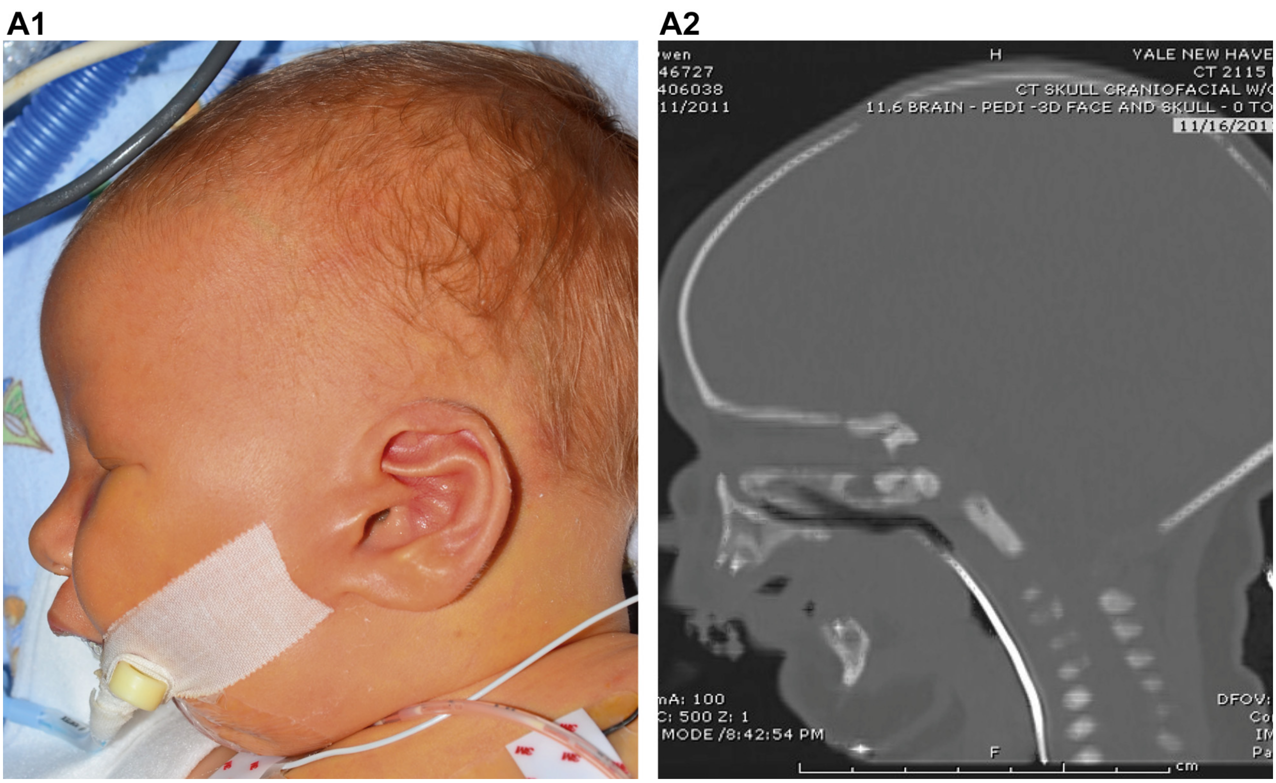

FIGURE 4A. Mandibular distraction. *A1*, *A2*, Preoperative image of neonate with mandibular micro-retrognathia, glossoptosis, and airway obstruction who cannot be extubated.

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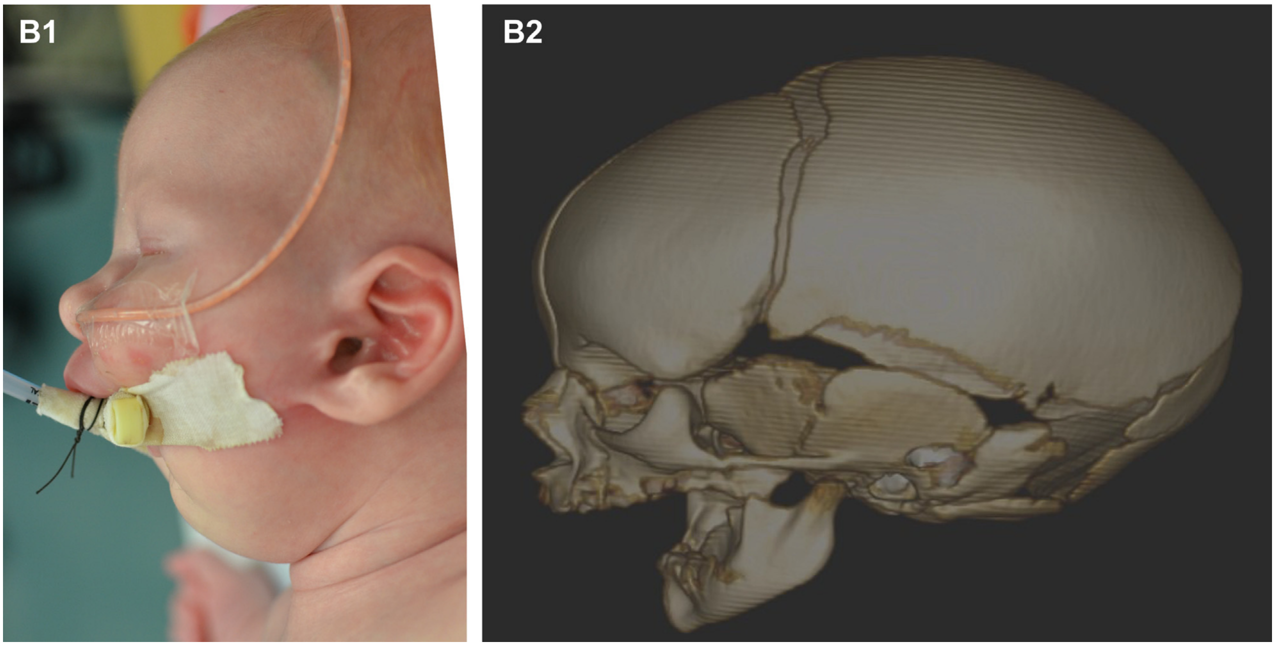

FIGURE 4B. *B1*, Clinically, the chin is retrusive. *B2*, Three-dimensional computed tomogram shows the retruded mandibular body.

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instance, in some cases, a resection is larger than planned, requiring a larger reconstruction, with the requisite change to the final result. Were the deviations from the overlay unplanned? If the attempt was to adhere closely to the plan, and no intraoperative occurrence changed the goals, but the actual result was different, then this should be investigated. Was the change minor and not clinically important? Or, was the change major (potentially requiring near or long-term revision)? Small alterations are expected, especially when moving parts are involved, such as the temporomandibular joint (TMJ), and rotation or closure of space about this structure could have occurred. Analysis and recognition of any alteration provides important feedback to consider for future cases. Attention to such deviations with continual

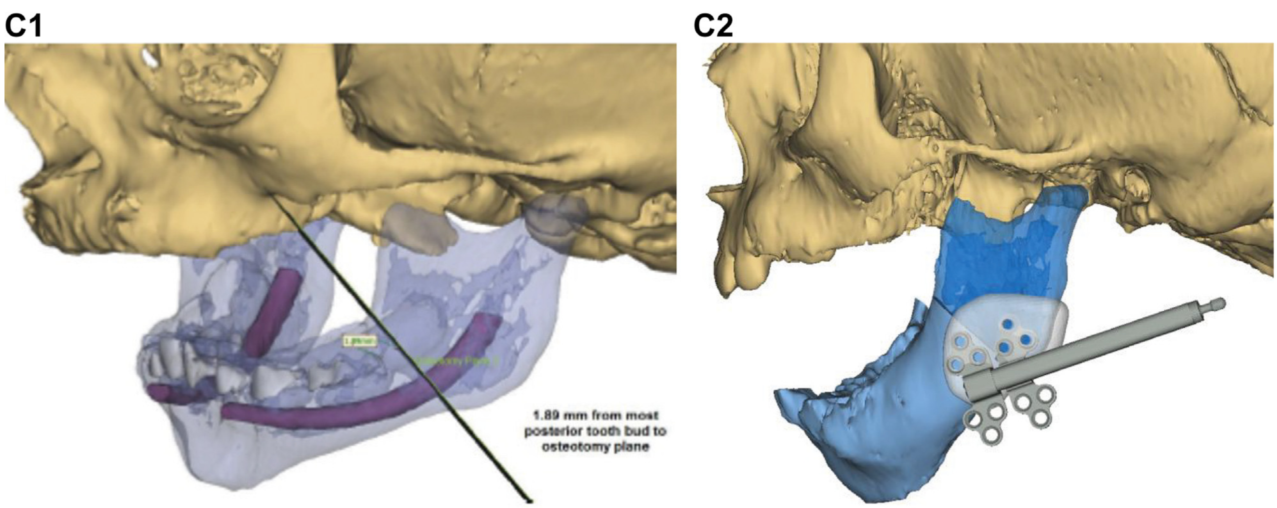

FIGURE 4C. *C1*, Three-dimensionl planning allows visualization of the inferior alveolar nerve and tooth buds. *C2*, A positioning and cutting guide is fabricated to ensure placement of the device and the corticotomies.

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FIGURE 4D. Clinical comparison of *D1*, preoperative image, *D2*, consolidation stage, and *D3*, after distraction removal.

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tweaking, trouble shooting, and modification will improve reproducibility of results. In rare cases, a major deviation might occur that was not recognized intraoperatively or was required by intraoperative events, and the surgical result must be revised or modified in the future. For example, malposition of the maxilla after Le Fort osteotomy is possible despite 3D planning owing to the subjectivity allowed with vertical positioning and the possibility of midline rotation owing to the spatial "play" in the TMJs when manipulating the maxillomandibular complex.

Depending on the case type, the precision of outcome can be more or less predicted or reproducible. For instance, the most highly re-created scenario is filling a defect or void with a custom-made 3D implant that spans stable surfaces without moving parts (eg, a frontal cranial bone defect). Less predictable are cases with moving parts within a device and the spanning

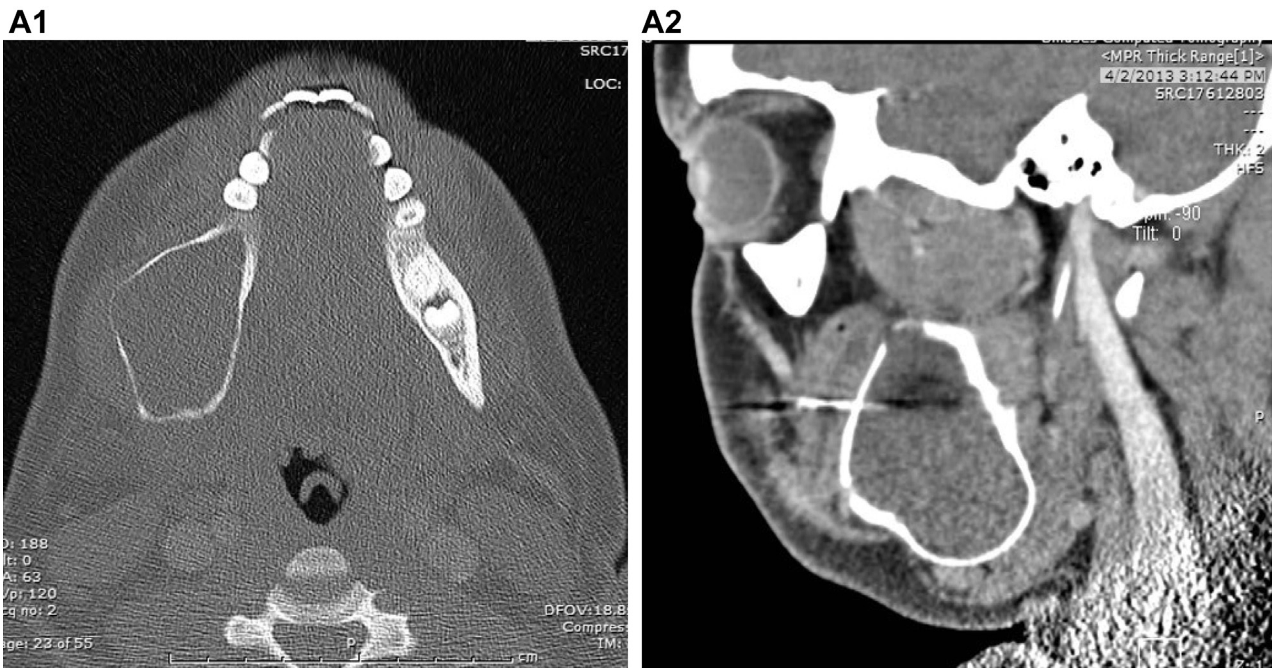

FIGURE 5A. Mandibular reconstruction. *A1*, *A2*, Computed tomograms showing an aggressive mandibular myxoma.

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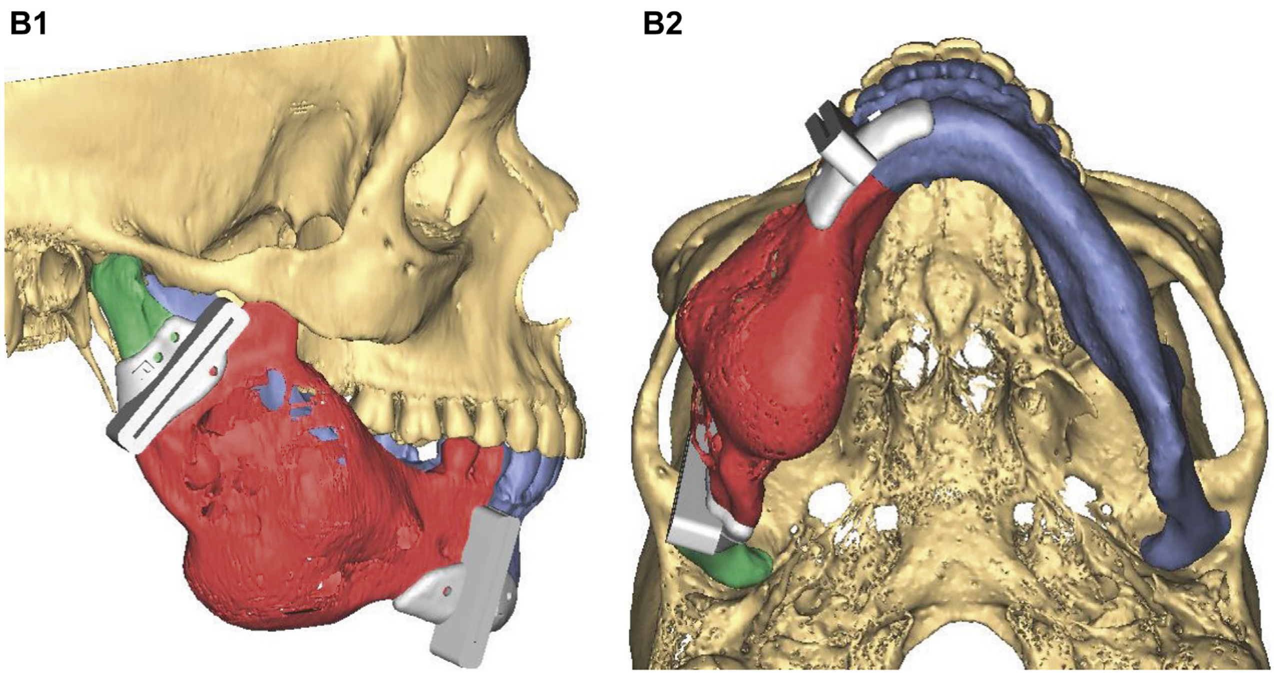

FIGURE 5B. *B1*, *B2*, Three-dimensional plan highlighting the planned resection (*red*), with resection cutting guides.

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anatomy (eg, mandibular distraction). Here, slight modifications of device placement, orientation, and opening can alter the movement of the distracted segment in space. In addition, muscle pull and the mobile TMJ make determination of the exact final position of the distal mandible difficult. This is even more important in multidirectional devices.

Remember that precise results do not necessarily mean a perfect clinical result or a result that everyone agrees is the best possible. If the diagnosis

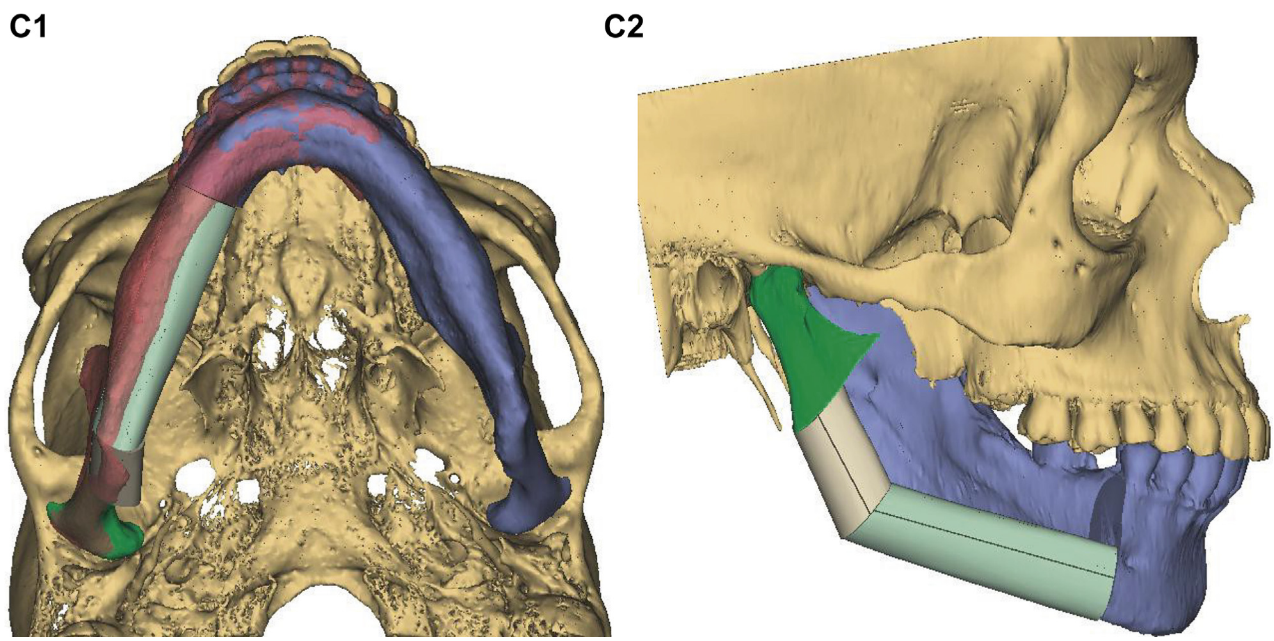

FIGURE 5C. *C1*, *C2*, Three-dimensional reconstruction plan showing the mirrored normal side mandible (*red*) to guide the placement and segments needed for fibula reconstruction.

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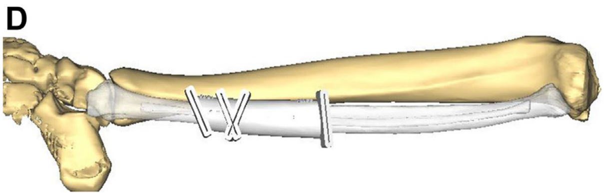

FIGURE 5D. *D*, Cutting guides are generated to help fashion the fibula to achieve the desired mandibular contour. Note the distances from the lateral malleolus to the closing wedge ostectomies factored into the guide.

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or plan is flawed, then the result is jeopardized. In addition, forces over the long term, growth, scarring, and relapse cannot always be predicted. However, overlaying the plan on the actual result will reflect how well the planned surgical and morphologic control was executed and could shed light on these factors that cannot always be controlled, such as muscle pull, scar forces, and device malfunction.

CASE EXAMPLES

Three-dimensional planning has applicability across different cases in craniomaxillofacial surgery. The following scenarios depict concepts of analysis, planning, and reconstruction using virtual surgery and 3D printing. These concepts are highlighted using common treatment examples, including case types not traditionally addressed using 3D planning: *1)* cranial reconstruction, *2)* craniosynostosis, *3)* midface advancement, *4)* mandibular distraction, *5)* mandibular reconstruction, and *6)* orthognathic surgery (Figs 1-6).

SUMMARY 3D ANALYSIS AND PLANNING

Three-dimensional analysis and planning is a powerful tool for research and clinical applications. It sets the frame of reference to establish surgical goals after assessment and analysis. The planned surgery is virtually carried out using the patient's actual anatomy and evaluating interferences and pitfalls. Comparison with anatomic structures and overlay of the planned relations before and after movement add clarity to the plan. Once the plan is finalized, guides, splints, and implants help enable a precise replication of the plan, intraoperatively, and this is verified postoperatively with comparison overlays.

The research implications of 3D analysis also are notable, as is feedback to enhance clinical results. For instance, 3D volumetric assessment of structures in dysmorphology compared with normal morphology

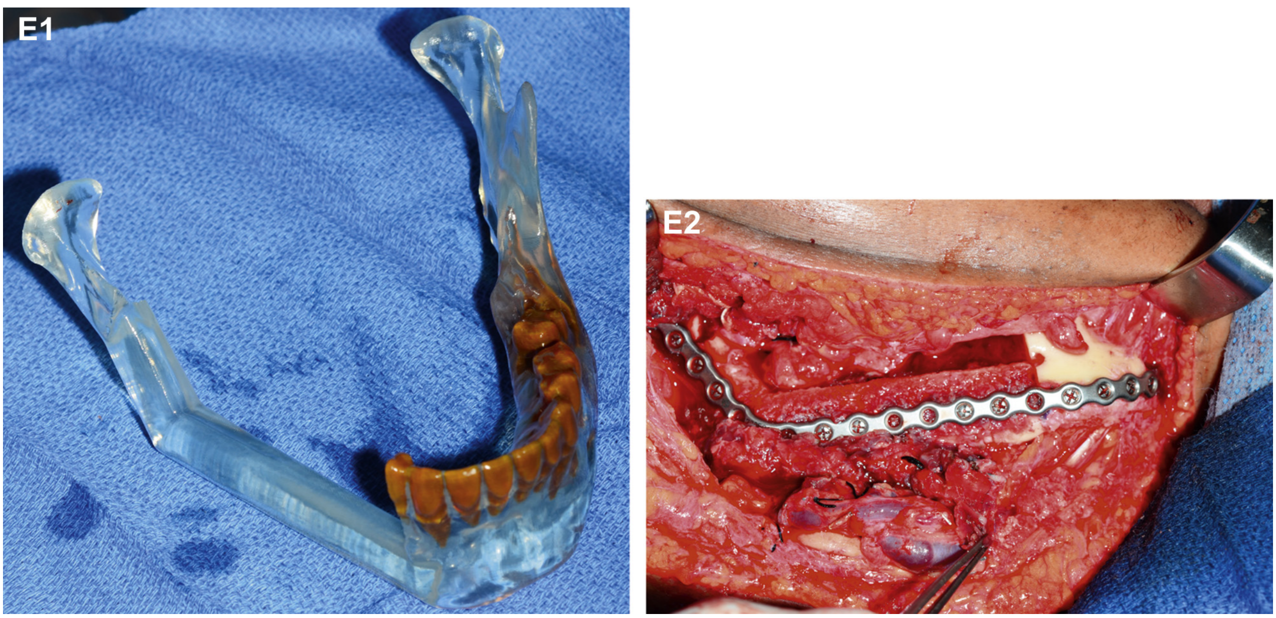

FIGURE 5E. *E1*, A stereolithographic model is printed to show the planned reconstruction. *E2*, The fibula is segmented at the leg while still attached to its vasculature and plated to the pre-bent reconstruction plate. The entire construct is transferred to the mandible, minimizing ischemia time and the manipulation required after detachment from the donor site.

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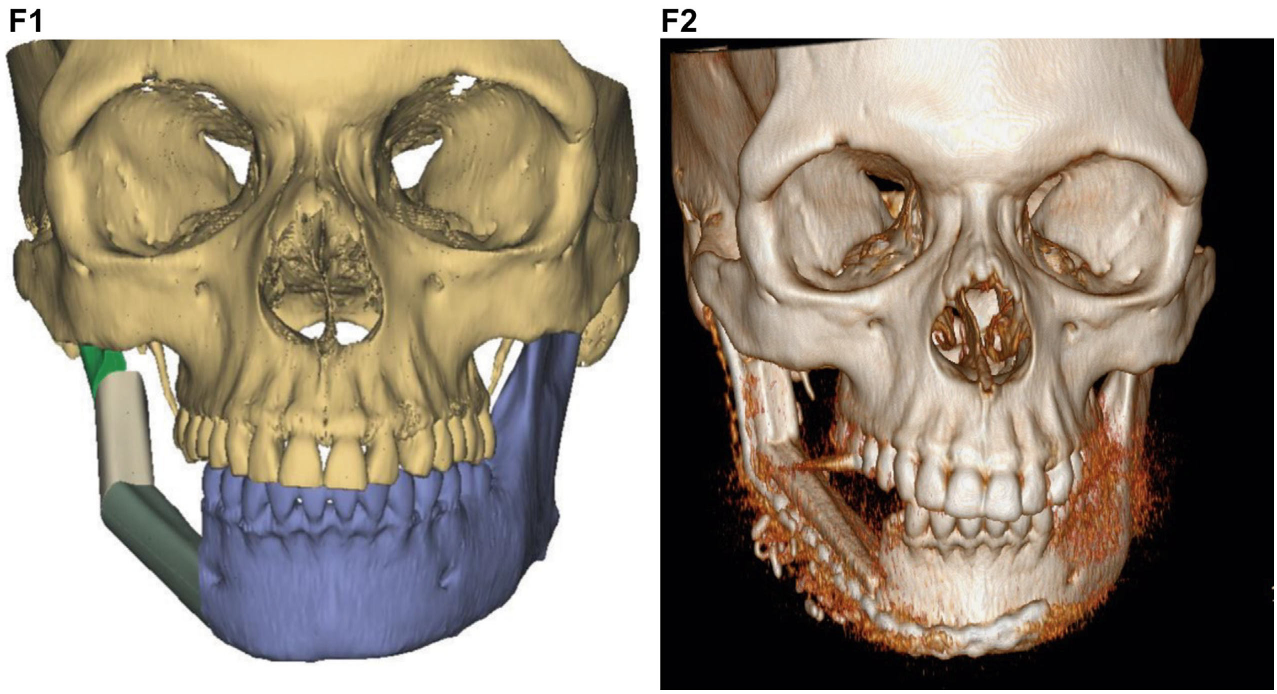

FIGURE 5F. *F1*, Planned versus *F2*, actual result to check precision and reproducibility.

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FIGURE 6A. Orthognathic surgery. *A*, Preoperative clinical view showing soft tissue and bony asymmetry.

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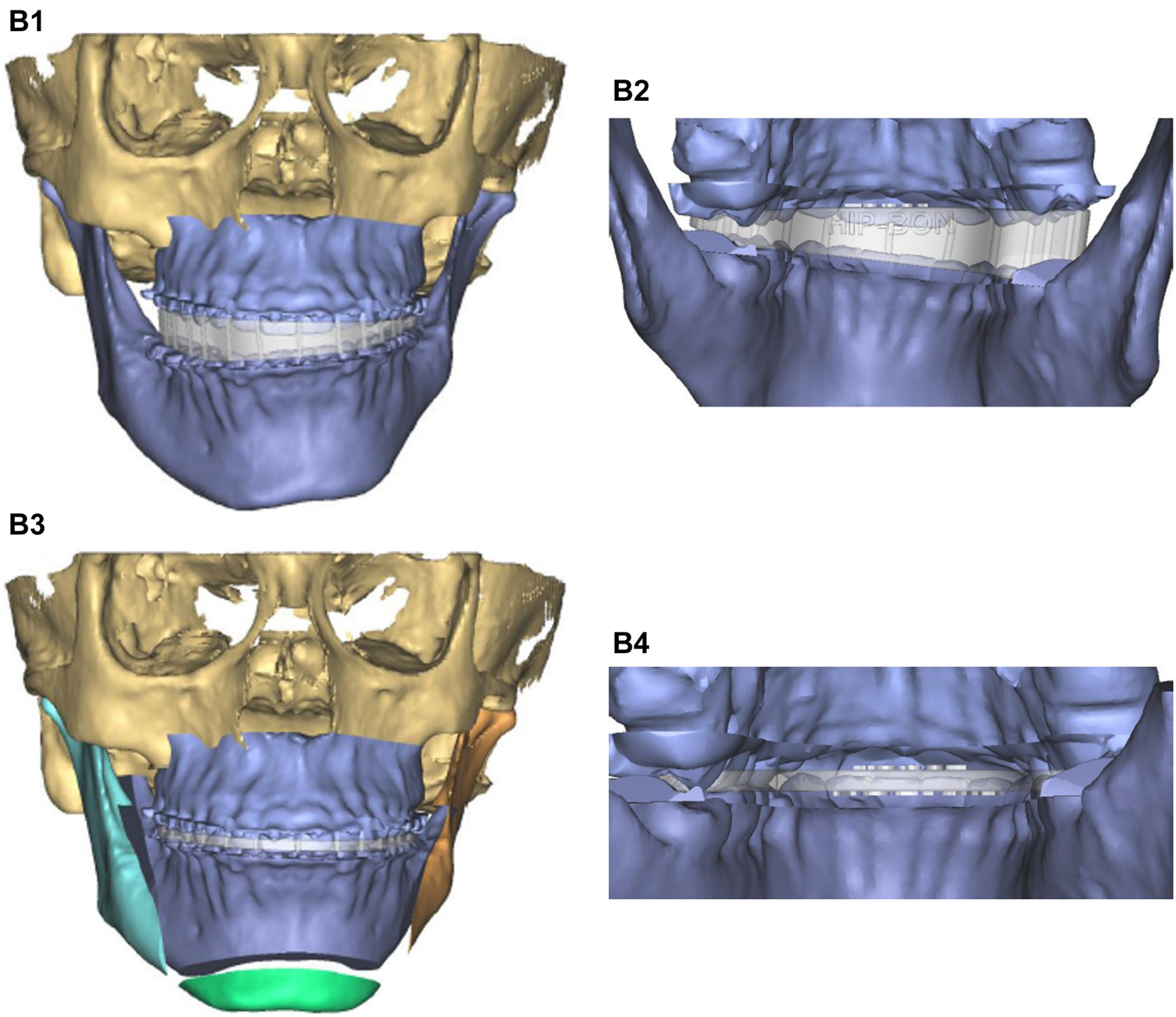

FIGURE 6B. *B1*, Three-dimensional planning with maxillary movement first, *B2*, with advancement and right side impaction for cant correction using the intermediate splint. *B3*, The final splint is used after a sagittal split and *B4*, the genioplasty is performed last.

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allows for a more granular understanding of the problem and then the solution.[9-17] The treatment outcome also is ripe for analysis by tracing it back to the virtual analysis and plan and noting the pros and cons of the procedure. Investigation of the use of guides and the ability to impart precision can be investigated.[18-20] Overlay of the actual and planned results allow study of reproducibility and establish the baseline for future research and growth comparisons.[21-23] Performing a series of cases using 3D planning and then critically analyzing the results is a valuable research pursuit that improves future surgical results. Similarly, craniometric and quantitative analyses of disease situations and normal anatomy (based on age and gender) enable improved understanding of goals and objectives.

Future directions will entail obtaining even greater granularity in the quantitative assessments and improved precision and accuracy with translation to the actual surgical procedure. The intersection of soft tissue and bone is critically important to predict functional and esthetic results.[24,25] A window into the dimensions dictated with time, growth, relapse, and scar also might be possible with continued honing of 3D virtual surgical analysis and planning.

Three-dimensional surgical analysis and planning have several advantages. The primary advantage is

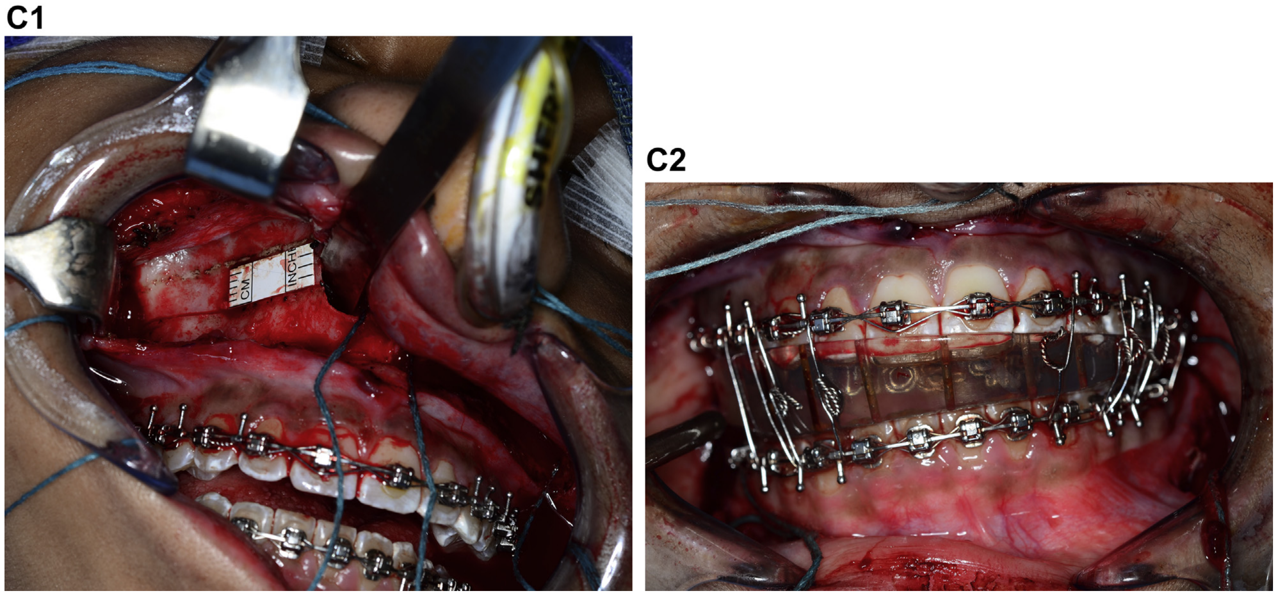

FIGURE 6C. *C1*, Intraoperative view showing maxillary impaction on the right and *C2*, the differentially thick intermediate splint for cant correction.
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the ability to comprehensively see and define the problems and understand the preoperative anatomy. This analysis sets the stage to establish a solution to meet the treatment goals, including morphologic, esthetic, and functional. Growth and relapse considerations can be factored into the plan. It allows for a virtual run through of different scenarios to arrive at the best overall treatment choice. Guides, splints, and plates can be fabricated to help reproduce the digital plan in reality. In conclusion, 3D planning enhances efficiency, accuracy, creativity, and reproducibility in craniomaxillofacial surgery.

FIGURE 6D. Comparison of images *D1*, before surgery, *D2*, after orthognathic surgery, and *D3*, after orthognathic and rhinoplasty.
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References

1. Barker GF (ed): Röntgen Rays: Memoirs by Röntgen, Stokes and JJ Thomson. New York, NY, Harper & Brothers, 1899
2. Papillault G: The international agreement for the Unification of Craniometric and Cephalometric measurements. Report of the commission appointed by the XIII International Congress Of prehistoric anthropology and archaeology at Monaco (1906). Am J Phys Anthropol 2:46, 1919
3. Steiner CC: Cephalometric for you and me. Am J Orthod 39:729, 1953
4. Obwegeser HL: Surgery as an adjunct to orthodontics in normal and cleft palate patients. Rep Congr Eur Orthod Soc 42:343, 1966
5. Vannier MW, Marsh JL: Three-dimensional imaging, surgical planning, and image-guided therapy. Radiol Clin North Am 34: 545, 1996
6. Tay F, Roy A: CyberCAD: A collaborative approach in 3D-CAD technology in a multimedia-supported environment. Comput Ind 52:127, 2003
7. Troulis MJ, Everett P, Seldin EB, et al: Development of a three-dimensional treatment planning system based on computed tomographic data. Int J Oral Maxillofac Surg 31: 349, 2003
8. Xia JJ, Gateno J, Teichgraeber JF: Three-dimensional computer-aided surgical simulation for maxillofacial surgery. Atlas Oral Maxillofac Surg Clin North Am 13:25, 2005
9. Steinbacher DM, Bartlett SP: The relationship of the mandibular body and ramus in Treacher Collins syndrome. J Craniofac Surg 22:302, 2011
10. Steinbacher DM, Gougoutas A, Bartlett SP: An analysis of mandibular volume in hemifacial microsomia. Plast Reconstr Surg 127:2407, 2011
11. Beckett JA, Persing JA, Steinbacher DM: Bilateral orbital dysmorphology in unicoronal synostosis. Plast Reconstr Surg 131:125, 2013
12. Beckett JA, Chadha P, Persing JA, et al: Classification of trigonocephaly in metopic synostosis. Plast Reconstr Surg 130:442e, 2012
13. Wong K, Pfaff MJ, Chang CC, et al: A range of malar and masseteric hypoplasia exists in Treacher Collins syndrome. J Plast Reconstr Aesthet Surg 66:43, 2013
14. Pfaff MJ, Persing JA, Steinbacher DM: Zygomatic dysmorphology in unicoronal synostosis. J Plast Reconstr Aesthet Surg 66:1096, 2013
15. Beckett JA, Pfaff MJ, Diluna ML, et al: Dolichocephaly without sagittal synostosis. J Craniofac Surg 24:1713, 2013
16. Ezaldein HH, Metzler P, Persing JA, et al: Three-dimensional orbital dysmorphology in metopic synostosis. J Plast Reconstr Aesthet Surg 67:900, 2014
17. Forte AJ, Alonso N, Persing JA, et al: Analysis of midface retrusion in Crouzon and Apert syndromes. Plast Reconstr Surg 134:285, 2014
18. Stirling Craig E, Yuhasz M, Shah A, et al: Simulated surgery and cutting guides enhance spatial positioning in free fibular mandibular reconstruction. Microsurgery 35:29, 2015
19. Shah A, Patel A, Steinbacher DM: Simulated frontoorbital advancement and intraoperative templates enhance reproducibility in craniosynostosis. Plast Reconstr Surg 129:1011e, 2012
20. Pfaff MJ, Metzler P, Kim Y, et al: Mandibular volumetric increase following distraction osteogenesis. J Plast Reconstr Aesthet Surg 67:1209, 2014
21. Diluna ML, Steinbacher DM: Simulated fronto-orbital advancement achieves reproducible results in metopic synostosis. J Craniofac Surg 23:e231, 2012
22. Metzler P, Geiger EJ, Alcon A, et al: Three-dimensional virtual surgery accuracy for free fibula mandibular reconstruction: Planned versus actual results. J Oral Maxillofac Surg 72:2601, 2014
23. Steinbacher DM, Wink J, Bartlett SP: Temporal hollowing following surgical correction of unicoronal synostosis. Plast Reconstr Surg 128:231, 2011
24. Metzler P, Geiger E, Chang C, et al: 3D nasolabial changes following Le Fort I osteotomy. Plast Reconstr Surg 133(suppl): 1002, 2014
25. Metzler P, Geiger EJ, Chang CC, et al: Assessment of three-dimensional nasolabial response to Le Fort I advancement. J Plast Reconstr Aesthet Surg 67:756, 2014