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CASE REPORT
Pediatric/Craniofacial

The Use of Virtual Surgical Planning for Reduction Cranioplasty

Eli Saleh, MD*
Alexander Govshievich, MD*
Julian Justino, MD*
Alexander G. Weil, MD, FRCSC, FACS†
Daniel E. Borsuk, MD, FRCSC, FACS‡

Summary: Hydrocephalic macrocephaly may occur as a result of untreated hydrocephalus. Reduction cranioplasty is the treatment of choice for these patients when the weight of their head interferes with normal development and negatively impacts quality of life. However, this procedure has several associated risks, including prolonged anesthesia, significant blood loss, and death. Virtual surgical planning (VSP) has been shown to be a useful adjunct for orthognathic and craniofacial surgery. The following report details the application and advantages of this technology in the setting of a reduction cranioplasty. We report the case of a 2-year-old girl with severe hydrocephalic macrocephaly who underwent a reduction cranioplasty guided by VSP with computer-aided design and manufacturing (CAD/CAM). Prefabricated cutting guides and a concave assembly bowl were used for precise fixation of bony segments. Our patient underwent a successful reduction cranioplasty using VSP and CAD/CAM. This technology allowed precise remodeling of the cranial vault with minimal bony gaps in the final construct. Head circumference and intracranial volume were reduced from 70 cm and 4,575 cm^3 to 62 cm and 2,645 cm^3, respectively. VSP with CAD/CAM can serve as a useful adjunct in complex cases of cranioplasty allowing for an increase in the precision, the efficacy, and the esthetic result. *(Plast Reconstr Surg Glob Open 2020;8:e2565; doi: 10.1097/GOX.0000000000002565; Published online 20 January 2020.)*

Macrocephaly is a condition defined by a head circumference greater than 2 SDs above the mean.[1] Reduction cranioplasty is a surgical technique that aims to reduce calvarial volumes. It has the potential to improve quality of life and may decrease difficulties in the long-term care for patients with severe macrocephaly.[2–4] However, it remains a high-risk procedure.[5]

During a reduction cranioplasty, a large amount of intraoperative time may be spent cutting and rearranging bone segments to obtain proper coverage of the brain. Precise alignment of these segments with minimal gaps is of utmost importance.[6]

Virtual surgical planning (VSP) has recently emerged as a useful adjunct to craniofacial surgery.[7] Despite its extensive use in orthognathic surgery, the application of this technology in a reduction cranioplasty is limited.[8] The following report provides further evidence for the use of VSP for a reduction cranioplasty.

*From the *Division of Plastic and Reconstructive Surgery, University of Montreal; †Division of Neurosurgery, Sainte-Justine Hospital, University of Montreal; and ‡Division of Plastic and Reconstructive Surgery, Sainte-Justine Hospital, University of Montreal, Montreal, Quebec, Canada.*

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CLINICAL REPORT

We present a 2-year-old girl with severe hydrocephalic macrocephaly. At initial presentation, her head circumference was 74 cm. At the age of 23 months, she had significant neurocognitive delays. Functionally, the patient was unable to hold her head up.

VIRTUAL SURGICAL PLANNING

Precise imaging of the craniofacial skeleton was acquired. VSP allowed the surgeon to create digital osteotomies and manipulate bone segments. Cutting and positioning guides and pre- and postoperative stereolithographic models were created.

INTRAOPERATIVE TECHNIQUE

Bicoronal flaps were raised anteriorly and posteriorly. The cutting guides were then placed onto the exposed calvaria, and the planned osteotomies were

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marked with green dye. Each segment was marked by an alphabetical letter to ensure proper orientation. Osteotomies were then carried out by the neurosurgery team. The occipital H and F segments were kept in place to provide support for the heavy brain and dura while the neurosurgery team decreased the intracranial volume. Cerebrospinal fluid (CSF) was gradually drained, although progressive dural plication and excision was being performed. Total planned fluid reduction was 2,210 cm^3.

Concomitantly, the Plastic Surgery team performed osteotomies of the small lettered segments from the 2 large calvarial pieces. A novel bowl-shaped positioning guide was then used to reorient the bone segments and to allow for accurate fixation on intracranial surface (Fig. 1).

During reduction duraplasty and dural plication, venous oozing from the anterior superior sagittal sinus was encountered. This stemmed from anterior venous congestion caused by excessive dural plication and potential kinking of the mid-portion of the sagittal sinus. Toward the end of the procedure, the patient became coagulopathic with platelet values at 87,000. The procedure stopped prematurely after reduction of 1,930 cm^3 of CSF.

When placed over the dura and the modified cranial base, the reconstructed calvaria provided adequate brain coverage with exception of small segments which were easily filled with remaining autologous bone. The construct was fixed to the cranial base with resorbable plate and screws. Total operative time was 9 hours (**See Video [online],** which displays a demonstration of the intraoperative technique).

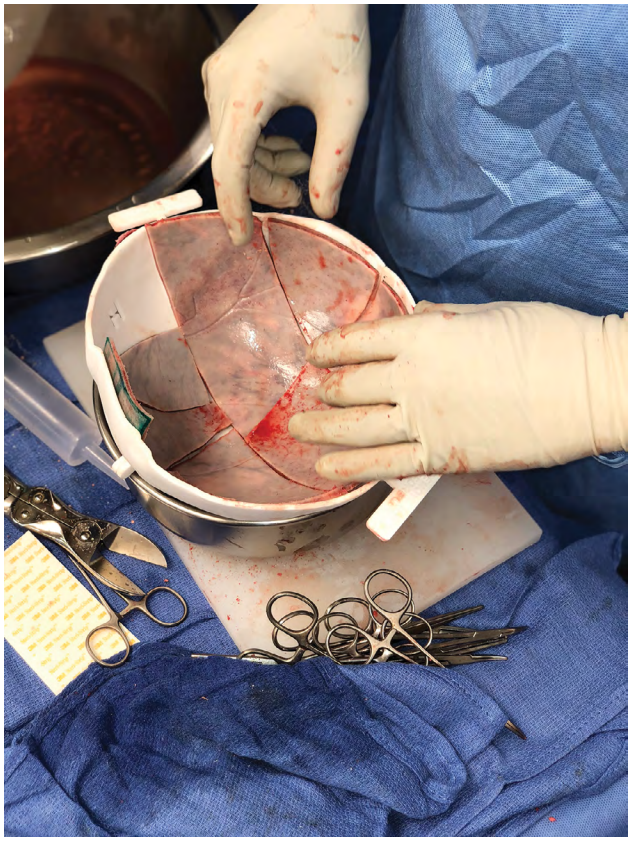


Fig. 1. Positioning guides were manufactured to ensure proper alignment of the segments. Each segment was marked by an alphabetical letter to ensure proper orientation.

RESULTS

An analysis was performed comparing the pre- and postoperative dimensions and volumes using the CT scans (Fig. 2). Head circumference went from 70 to 62 cm (Fig. 3).

No significant alterations in cognition were noted in the immediate postoperative period. At 6- and 9-month follow-up, the patient was significantly improved neurologically and functionally including better socialization and interaction with her environment, improved language, and better control of her head.

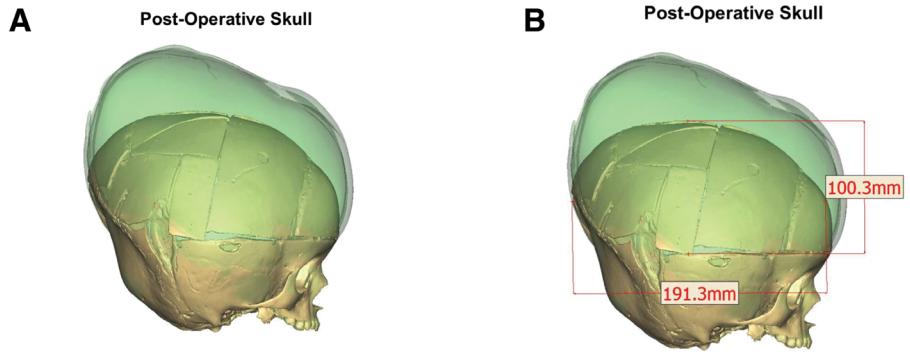
DISCUSSION

Untreated hydrocephalus resulting in macrocephaly is a serious condition which may cause defects in neurological function and physical development.[9] The indications for a reduction cranioplasty must be outweighed against the risks of the procedure, which include CSF shunt complications, neurological injury, or death.[2,10]

The main goals of VSP include the production of pre- and postoperative stereolithographic models, as well as cutting and positioning guides that can be used by the surgeon.[7] Computer-aided design–planned osteotomies can help minimize irregularities seen in free-hand osteotomies and can help provide the patient with the best possible esthetic result.[8] The application of VSP allowed for accurate and rapid assembly of the resected segments with high precision in an assembly bowl. This resulted in a final construct that had a smooth shape, good bony contact, and minimal gaps.

Our biparietal distance (BPD) did not significantly decrease in the postoperative period. A 7 percent reduction was achieved in comparison with the planned 13 percent reduction. Although it is possible to in-fracture the cranial base[8] or perform barrel stave osteotomies[11] to further decreased circumference and BPD, this was not planned in our surgery. The goal was to minimize potential complications in a procedure that was already set to be long and complex.

There are several limitations associated to the use of VSP. There is a learning curve involved and it requires an understanding of the procedure and of the anatomy by the surgeon and the engineer.[7] Although it remains a useful tool, the surgeon should be ready to adapt if any intraoperative changes occur. During the large intracranial volume reduction, plication and excision of dura may lead to venous congestion and bleeding from sagittal sinus, as it did in our case.[5] Because of this, full adherence to preoperative plan was not possible. Intraoperative modifications of the design were done to accommodate a larger than anticipated volume. This was accomplished by leaving more bone posteriorly which changed the plane



Volumetric Measurements	(cm^3)
Intracranial (Pre-Op)	4575
Brain Volume	1450
Fluid Volume (Pre-Op)	3125
Intracranial (Post-Op)	2645
Fluid Remaining (Post-Op)	1195
Fluid Reduction (Post-Op)	1930

Dimensional Measurements	(mm)
Skull Height (Pre-Op)	152
Skull Height (Post-Op)	100
Height Reduction	35%
Skull AP Width (Pre-Op)	206
Skull AP Width (Post-Op)	191
AP Width Reduction	7%

Fig. 2. Three-dimensional CT scan reconstructions demonstrating the pre- and postoperative volumetric measurements (A) and dimensional measurements (B). Pre-Op, preoperative; Post-Op, postoperative.

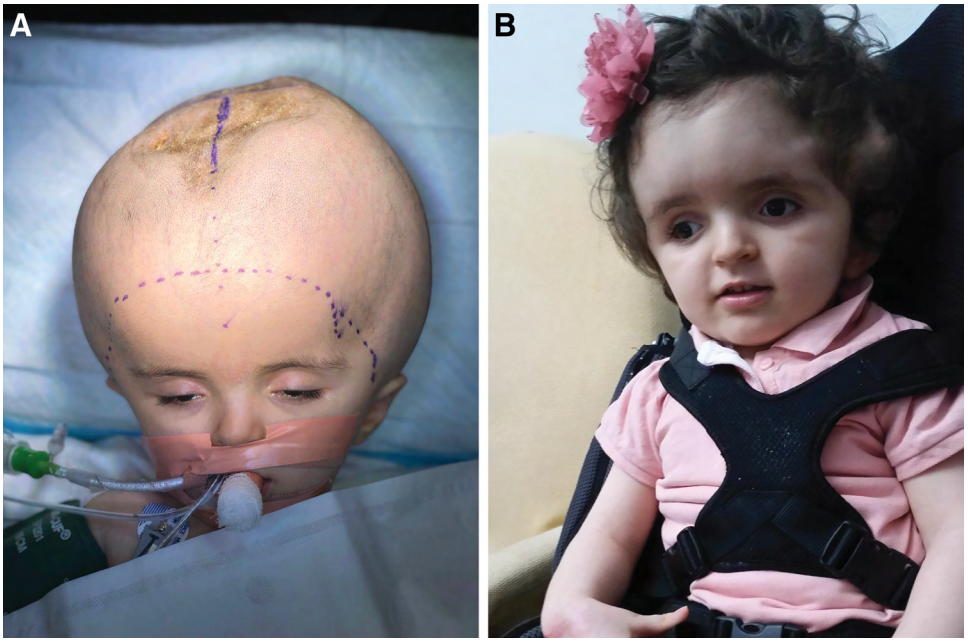


Fig. 3. A, Preoperative photograph of a 2-year-old child with severe macrocephaly. Head circumference was 70 cm. B, The patient at 6 months postoperative. Head circumference was 62 cm.

of the overall osteotomy and increased posterior pitch of the new construct.

SUMMARY

Reduction cranioplasty remains the exclusive treatment modality for advanced hydrocephalic macrocephaly. It is a complex procedure with many important risks. The use of VSP with computer-aided design and manufacturing can assist the surgeon by planning some of the intraoperative steps to the preoperative period.

VSP allowed for the creation of a smooth construct, with good apposition and minimal gaps. In our case, this was further facilitated by the novel application of a 3-dimensional printed bowl-shaped positioning guide.

Although VSP can serve as a useful adjunct in complex reduction cranioplasties, further experience is required to minimize complications, identify pitfalls, and analyze the relationship between costs and benefits.

Daniel E. Borsuk, MD, FRCSC, FACS
Division of Plastic and Reconstructive Surgery
University of Montreal
CHU Sainte-Justine
3175 Ch. de la Côte-Ste-Catherine
Montréal, QC H3T 1C4, Canada
E-mail: info@drborsuk.com

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