Journal of Plastic, Reconstructive & Aesthetic Surgery (2014) 67, 336–343

ELSEVIER

JPRAS
An International Journal of Surgical Reconstruction
www.JPRASurg.com

Three-dimensional preoperative virtual planning and template use for surgical correction of craniosynostosis

Samir Mardini [a,*], Saad Alsubaie [a], Cenk Cayci [a], Harvey Chim [a], Nicholas Wetjen [b]

[a] Department of Plastic Surgery, Mayo Clinic, Rochester, MN, USA
[b] Department of Neurological Surgery, Mayo Clinic, Rochester, MN, USA

Received 26 August 2013; accepted 10 November 2013

KEYWORDS
Craniosynostosis;
Computer-aided design;
Virtual surgical planning;
CAD/CAM;
Cranial vault remodelling

Summary *Background:* Surgical correction of craniosynostosis aims to remodel the cranial vault to achieve a morphology approaching that of age-matched norms. However, current surgical technique is highly subjective and based largely on the surgeon's artistic vision in creating a normal head shape. Here, we present our technique and report our experience with the use of virtual surgery using computer-assisted design (CAD)/computer-assisted manufacturing (CAM) techniques to create a prefabricated template for the planning of osteotomies and the placement of bone segments, to achieve standardised, objective and precise correction of craniosynostosis.
Methods: Four patients who underwent cranial vault remodelling (CVR; three metopic synostosis and one sagittal synostosis) underwent virtual surgical planning (VSP) preoperatively using CAD/CAM techniques. VSP allows pre-planning of osteotomies to achieve the desired cranial vault shape. Surgical osteotomies and placement of bone segments were performed intraoperatively based on prefabricated templates.
Results: All patients demonstrated markedly improved head shape postoperatively. One patient developed a subdural haematoma 6 weeks postoperatively subsequent to a fall where he hit his head. The haematoma was drained and a soft spot was present in that location 3 months postoperatively.
Conclusion: The use of virtual surgery and prefabricated cutting guides allows for a more precise and rapid reconstruction. Surgical osteotomies are pre-planned and rapidly performed using a template, and precise placement of calvarial bone segments is achieved without the need for subjective assessment of the desired calvarial shape. In addition, patients and families have a significantly better understanding of the disease process and anticipated surgery

* Corresponding author. Department of Plastic Surgery, Mayo Clinic, 200 1st Street SW, Rochester, MN 55905, USA.
E-mail address: mardini.samir@mayo.edu (S. Mardini).

http://dx.doi.org/10.1016/j.bjps.2013.11.004

preoperatively with the visualisation achieved through virtual surgery. This results in better alignment of hopes and expectations between the parents and surgeons.

Craniosynostosis is a congenital disorder that occurs when the sutures between the bones of a child's skull prematurely fuse leading to the development of an abnormal head shape and occasionally increased intracranial pressure.[1–3] The disorder is relatively common and affects approximately 1 in every 2500 live births and can contribute to calvarial deformity, increased intracranial pressure and neurodevelopmental impairment.[7] A number of surgical procedures have been developed to correct deformities associated with craniosynostosis.[2,11] There is varied opinion regarding which surgical procedure is optimal and leads to the best cosmetic outcomes with least risk to the patient and lowest overall cost of care.[4,5,6] Regardless of the surgical technique used, cranial vault remodelling (CVR) still requires a significant degree of subjective assessment by the surgeon, both preoperatively and intra-operatively, to determine how to remodel the calvarium to best restore normal head shape.

Computer-assisted procedures are gaining more credibility in the field of head and neck surgery[16–18]. Combined with three-dimensional (3D) data (e.g., computed tomography (CT), cone-beam CT and optical surface scanning), these methods have been used previously for other complex reconstructive procedures such as cranioplasty and craniofacial reconstruction. Applications range from surgical planning, computer-assisted design (CAD), computed-assisted manufacturing (CAM) of implants to creation of surgical templates for bone resection or bone reconstruction, to assist in craniosynostosis surgery, osseous genioplasty or dental splints in orthognathic surgery.[8–10,13,14,19]

Burge and colleagues recently[12] developed a system that relies less on subjective assessment and more on a standardised normal for age shape of the child being operated on by using age-matched templates and CAD/CAM techniques for preoperative planning in surgical correction of craniosynostosis. Here, we report our surgical technique and experience in the use of preoperative virtual surgery to better achieve precise intra-operative goals using a CAD/CAM technique for surgical correction of craniosynostosis.

Preoperative planning and surgical technique

The patient undergoes a CT scan of the cranial structures with 3D reconstruction. Helical CT scans are obtained and 0.755-mm-thick slices are used to generate a 3D model in the form of uncompressed Digital Imaging and Communications in Medicine (DICOM) data, which is used by the company. The radiation dose per scan ranges between 1 and 2 mSv. This is much lower than a comparable infantile abdominal CT scan (20 mSv). Once these data are available, the plastic surgeon and the neurological surgeon meet along with a biomedical engineer to perform virtual surgery and plan the surgical osteotomies on a computer workstation. Normative age-appropriate data were used to generate ideal 3D models to aid the surgical plan based on radiological measurements of normal children.[20] In this normative study involving measurements of 1464 radiographs from 732 children, fronto-occipital diameter, biparietal diameter and cranial length were measured and used to provide mean age- and gender-appropriate measurements. These data were used to create precise age-appropriate normative models of calvarial morphology based on techniques described by Saber et al.,[15] with the aid of a company experienced in virtual surgical planning (VSP; Medical Modeling Inc., Golden, CO, USA).

VSP allows planning of surgical osteotomies and repositioning of bone segments based on age-appropriate normative models to achieve the desired calvarial morphology. Virtual surgery is performed during Web-based team meetings consisting of the paediatric plastic surgeon, neurosurgeon and engineer from the company. Typically, there are two meetings lasting 1.5–2 h. In the first meeting, two models are presented by the engineer – the first based on the patient's CT scan data and the second constructed from an age-appropriate normative model. The two models are then overlapped, and virtual osteotomies are performed to reshape the patient's skull to match its normative model. The software allows virtual repositioning of bone segments to best reshape the patient's skull. Following virtual surgery, planned surgical osteotomies are uploaded into the computer to create templates to be used in surgery. In the second meeting, details are reviewed before generation of customised templates using stereolithography. Two templates are created – the first to guide the location of osteotomies to be made and the second to guide placement and fixation of bone segments. The plan is discussed with the patient and the family, with visualisation aided by the CAD/CAM workstation.

The patient is then taken to the operating room, and is prepared and draped in the usual fashion with the 3D model templates within view of the operating field. A coronal incision is made and flaps elevated in a subperiosteal plane to allow exposure of the entire calvarium. Templates are shown for a patient with sagittal synostosis. The first cutting template (Figure 1) guides placement of osteotomies on the calvarium. Individual bone segments are labelled with different alphabets to aid orientation and placement of bone segments in the second template. The cutting template allows both marking of osteotomies on the calvarium and labelling of individual bone segments. Craniectomy with osteotomy of individual segments is then performed. The second shaping template, fabricated based on age- and gender-appropriate normative measurements, guides placement of individual bone pieces to best achieve a normal calvarial morphology. The bone segments are