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3-D titanium mesh reconstruction of defective skull after frontal craniectomy in traumatic brain injury

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ABSTRACT

Introduction: Decompressive craniectomy (DC) is a treatment strategy used to reduce intracranial pressure in patients with traumatic brain injuries. However, this procedure has a number of shortcomings, such as excessive sinking of the skin flap, which can lead to cerebral compromise and negatively affect the appearance of the patient. The reconstruction of skull defects has been proposed as a means to overcome these disadvantages. Few previous studies have reported the reconstruction of frontal skull defects using titanium mesh. The aim of this study was to provide a comprehensive review of aesthetic and surgical outcomes associated with this procedure and to list the complications encountered during the repair of frontal skull defects using three-dimensional (3-D) titanium mesh.
Methods: A retrospective review was conducted using records from seven adult patients (32–60 years of age) who received titanium mesh implants at a university hospital in Taiwan between January 2011 and June 2012. Aesthetic outcomes, the function of cranial nerves V and VII, and complications (hardware extrusions, meningitis, osteomyelitis, brain abscess, and pneumocephalus) were evaluated.
Results: An algorithm capable of accounting for bifrontal skull defects and median bone ridges was developed to improve computer-assisted design/manufacturing (CAD/CAM) of one-piece 3-D titanium mesh implants, thereby making it possible to repair bifrontal skull defects in a single operation. Following this procedure, aesthetic and functional outcomes were excellent and the implants in all patients appeared stable. However, extended healing times in two of the patients resulted in subclinical infections, which were resolved by administering antibiotics over a period of 2 weeks. No patients suffered trigeminal or facial dysfunction.
Conclusions: Our findings support the use of 3-D titanium mesh in frontal skull reconstruction. Few complications were encountered, the contours of the forehead were faithfully rendered, and the cosmetic appearance of patients was excellent. For patients with bifrontal skull defects, the use of one-piece implants in a single operation provides numerous advantages over conventional staged surgeries. This application helps to reduce operating time, which is particularly beneficial for elderly patients and those requiring bifrontal cranioplasties.

Introduction

Following decompressive craniectomy (DC), some patients with skull bone defects develop a sunken or flattened skin flap (i.e., trephined syndrome). This complication is particularly prevalent among the elderly [1]. Excessive sinking of the skin flap can result in local compression, which can in turn disturb brain autoregulation and compromise cerebral haemodynamic status [2,3]. However, this dire situation can be avoided by reconstructing skull defects. Cranioplasty plays a critical role in protecting intracranial content from exposure and compression (from atmospheric pressure) and also helps to correct disfigurement [4]. Following cranioplasty, many patients with "syndrome of the

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trephined" present a deterioration in neurological status [5]. It appears that clinical improvements following cranioplasty may be due to the restoration of normal brain anatomy, cerebral re-expansion, and recovery of normal scalp flap curvature [5].

Various techniques and materials have been used in the repair of skull defects following DC, such as autogenous bone grafts and xenogenetic or alloplastic implants [1,6–10]. Considerable advances have been made in computer-assisted design/manufacturing (CAD/CAM) to improve the quality of implants. A number of studies have reported the effectiveness of three-dimensional (3-D) CAD/CAM implants in craniofacial skeletal reconstruction with regard to improved cosmesis and fewer complications, compared to conventional autogenous or alloplastic bone, particularly in patients with large skull defects [4,11–13].

Most previous studies on the use of CAD/CAM-fabricated implants have focused on the repair of skull defects following fronto-temporo-parietal (F-T-P) DC (standard trauma craniectomy) [4,11,14]. For example, we previously presented a quantitative analysis of craniofacial symmetry based on the cranial index of symmetry (CIS) following craniofacial skeletal reconstructions using polymethyl methacrylate (PMMA) [1] and titanium cranioplasty [15]. However, little is currently known about the use of CAD/CAM-fabricated implants in the repair of skull defects following frontal DC. This study reviewed the results of seven patients who underwent frontal craniectomy (three unilateral and four bifrontal) using 3-D titanium mesh implants in our institution. Specifically, a one-piece titanium mesh was used to cover bifrontal skull defects and the frontal median bone ridge as an alternative to conventional methods applied bilaterally using multiple implants.

Materials and methods

Patients

Between January 2011 and June 2012, seven consecutive patients aged 32–60 years with severe head injuries and frontal intracranial hematomas were treated in our institution. All patients presented pronounced neurological deficits and underwent cranial decompressive surgery. Operative methods included a bicoronal scalp flap and frontal DC to remove a haematoma on one side ($n = 3$) or both sides ($n = 4$). In patients with unifrontal DCs, a bicoronal skin flap was implemented and frontal bones on the lesioned side were removed. In cases of bifrontal DC, we bilaterally removed the frontal bones and preserved a frontal median bone ridge (single arrow in Fig. 3E) over the superior sagittal sinus to prevent bleeding [16].

All seven patients appeared physically and neurologically stable at an average of 1.8 months postcraniectomy, whereupon they underwent cranioplasty using seven 3-D titanium mesh implants. Three patients with a unifrontal skull defect underwent unilateral cranioplasty on the lesioned side. Four patients with bifrontal skull defects underwent a bilateral cranioplasty using a one-piece 3-D titanium mesh that provided bilateral coverage over both sides (Fig. 1).

3-D titanium mesh design

Brain computed tomographic (CT) scans and CAD/CAM of 3-D titanium mesh for F-T-P skull defects were as described in our previous study [15]. Briefly, each patient received a CT scan on the area of the brain representing a slice (1.25 mm thick) from the base of the skull to convexity (including the region of the skull defect). These high-resolution CT images were then transferred to Medtronic (Golenta, CA, USA) for use in the 3-D CAD design of skull segments.

Image-editing software was used to extract digital information from the CT scans, which in turn guided the reconstruction of the contours of area(s) containing skull defects. Contour reconstruction had to account for bilateral frontal skull defects and frontal median bone ridges in patients who had undergone bifrontal DCs (arrow in Fig. 2E and F). The symmetry of the reconstructed contours and their relationship with existing skull bone were simultaneously investigated from axial, coronal, and sagittal views (Fig. 2A, B, E and F). We observed the 3-D CAD reconstruction of artificial flaps and cranial segments using an image-editing software in order to evaluate implants in terms of external appearance and symmetry (Fig. 2C, D, G and H).

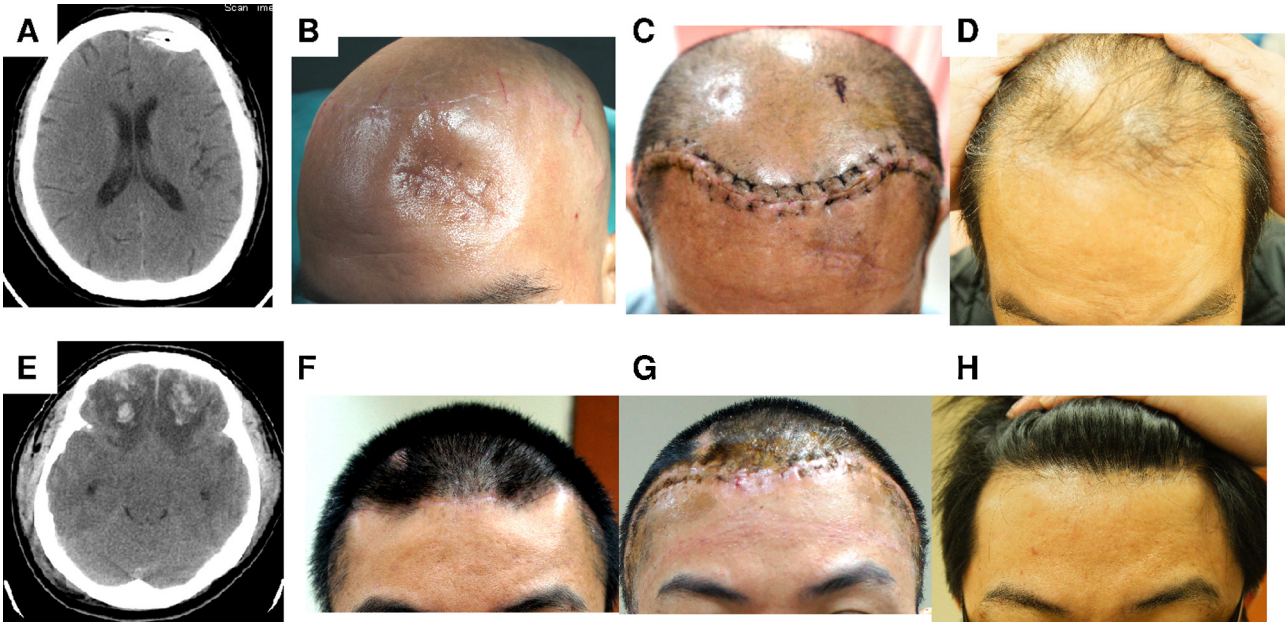

Fig. 1. Representative photographs of TBI patients before and after titanium mesh reconstruction. (A–D) Case 1, unifrontal DC; (E–H) Case 2, bifrontal DC. (A) Preoperative CT scan revealing a fracture in which bone fragments separated intraparenchymally at the left frontal lobe. (E) Preoperative CT scan revealing acute bifrontal intracerebral haemorrhage with significant mass effects. (B and F) Depression appearing on the patient's forehead following DC. The appearance of a patient's forehead after cranioplasty using 3-D CAD/CAM-fabricated titanium mesh at 30 days (C, G) and 2 years (D, H) postoperatively.