Abstract
Titanium cranioplasty is one of the well-established and widely used techniques in restoring skull defects for optimal protection to skull internal structures and re-establishing skull conformity. Nowadays, most centres utilise computer-assisted reconstruction for manufacture of titanium plates. In this paper we presented a method for making titanium cranioplasty plates using the 3D innovation through making a 3D model.

It can be stated that computer assisted production titanium plate for repairing skull defects is hassle free to patient and prosthetists, efficient and reliable, accurate and reproducible method. Furthermore, the resultant prosthesis constructed is accurately fitting.

Keywords: Titanium, Cranioplasty, Skull defects, Three-Dimensional Model.

Introduction
Maxillofacial prosthetics are defined as “the art and science of anatomical, functional or cosmetic reconstruction by means of artificial substitutes of those regions in the maxilla, mandible, and face that are missing or defective because of surgical intervention, trauma, pathology, or developmental or congenital malformation”.1 Facial defects often result in devastating cosmetic, functional and psychological consequences and continue to require difficult and challenging management procedures from maxillofacial surgeons and prosthodontics alike.

Complete rehabilitation of patients with disfigurements (i.e. facial, skull) is achieved using a multidisciplinary team approach, involving both surgical and prosthetic personnel.

The role of technology in facial prosthetics is vital in transforming the fabrication process of facial prosthetics. It spans wide uses including computerized shade selection, three-dimensional digital photography, virtual surgical planning, surface scanning, and three-dimensional imaging to obtain the wax pattern.1

Three-dimensional photography and surface scanning have been achieved using Phase measuring profilometry (PMP), CAD/CAM technology and laser scanning.1-4 A cranioplasty is the term that relates to the procedure of repairing skull bone defect,5 to provide neural protection to the internal skull structures (including the brain) in an aesthetically desirable and functional way. Ideally, bone flap is removed during the operation and is stored for later insertion. However, in most cases a bone flap may not be available to repair, especially trauma defects caused by congenital abnormalities, comminuted or compound fractures, skull tumours, osteomyelitis or bone flap resorption.6,7 Thus, many substitute materials proven to have high biocompatibility and clinical reliability, such as Poly Methyl Metha crylate (PMMA), titanium, and ceramics6 and it is still unclear of the optimum material. However, titanium plates offer an excellent choice for cranioplasty based on their strength, low infection rate, biocompatibility, handling characteristics and being suitable for postoperative imaging techniques.6 There have been different methods documented in the literature to manufacture titanium plates including conventional impression techniques or computer assisted technique.8-10
Techniques of plate fabrication have often been difficult and inexact. Additionally, producing a cosmetic deformity, poorly shaped prostheses may be problematic to insert which subsequently cause scalp necrosis, perforation and infection. Modern computer technology enables three-dimensional (3D) reconstruction of computer tomography (CT) images. Usually these 3D reconstructions are viewed as two dimensional (2D) images. Models produced by these CT scans are of high accuracy, details and reproducible. Furthermore, these models enable the operator for better visualisation of the defect in 3D orientation and thus better results are achieved when compared to conventional casts produced by traditional impression techniques. This paper aims to present a method of making titanium cranioplasty plate utilizing 3D innovations.

**Case History and Presentation**

**Diagnosis:** A 26 year old female teacher was originally admitted to Kings Mill Mansfield A&E department (Nottingham, UK) following a sudden onset occipital headache. A CT scan showed subarachnoid blood and was transferred to the neurosurgical unit at Queens Medical Centre (QMC, Nottingham, UK). She was found to have a large left deep cerebral Venous Malformation (VM) on CT angiogram. She underwent a partial embolisation of this VM complicated by intra-ventricular re-bleed. Her GCS (Glasgow Coma Score) were initially well being at 14-15 however, 7 days post procedure she developed dense right hemiparesis and became aphasic secondary to vasospasm. Her GCS dropped to 4. A CT showed large left-sided maturing infarct with global left hemispheric swelling and mild sub-falcine herniation. The same day she underwent a left decompressive craniecotomy. Later, she underwent tracheostomy and her GCS improved to 11.

Her management plan included physiotherapy, speech and language therapy and occupational therapy prior to transfer to a rehabilitation unit. Follow up showed that she improved. On examination her face is moving symmetrically and she still has good sensation in her right arm and leg. Her left craniotomy wound has healed nicely.

Next steps of treatment are titanium cranioplasty manufacture and fitting and further treatment of her residual deep VM.

**Cranioplasty Manufacture**

1. **Production of 3D model:** A three dimensional (3D) CT of the defect has been conducted in order to produce a 3D model of the defect following these steps:

   1. CT scans are produced as DICOM digital format. These are then converted using MIMICS (Materialize, Belgium) into MCS extension files. These files were converted to STL (Standard Triangulation Language). This is an open format that is possible to be opened by most 3D manufacture machines world wide.

   2. MCS extension files were converted to files with PR extension that makes them compatible (readable) with the Z print software (Z Corp 310 plus print system, Burlington, MA, USA). A 3D virtual model was produced giving us the potential for rotating and slicing. The CT scan files enabled us to customize the area of interest for printing as only the defect was sent for printing rather than printing the entire skull (Figure 1).

3. The printer formed the 3D model by binding gypsum powder (ZB 140, Z Corp, USA) particles using clear binder solution (ZB 60, Z Corp, USA) and water in layering technique. Then the mould was sealed and made ready for waxing up.

2. **Titanium plate production:** Steps are illustrated in figure 2. The defect was restored by waxing up to normal conformity, and then it was duplicated in crystal cal (Stone Type IV, British Gypsum, UK). An impression of the wax and surrounding area is taken using alginate (Hydrogum, Coltene, UK) which is backed with plaster (Sugical plaster, British Gypsum, UK). Then the impression was cast with vacuum mixed crystal cal gypsum. Using an indelible pencil a line outlining the defect margin was drawn, and another line was drawn...
5mm outside the defect line. These lines determine the periphery of the final titanium implant.

The model is then invested in a large flask to produce the die, which was then separated with mould seal (Vertex, Bracon, UK) and topped with another crystal ca mix to produce the counter-die. Then a piece of titanium plate (0.5mm, Titanium International, UK) is cut, larger than the defect and placed between the two halves of the flask, and the flask was closed slowly using hydro press to swage the plate to the desired shape. Then the flask was opened after couple of hours and the excess was cut. It was closed, and tightened and placed under bench press, and the opening/closing process was repeated couple of times (over 5 days period) till the implant has been swaged to the desired contour. The periphery rounded using rubber wheels, and holes (for screws fixing) were drilled. The implant was cleaned and sterilized (10w Steam at 132°C) prior to sending it to theatre.

Discussion
The need for precision-fitting titanium plates has prompted the development of several computer-aided methods of cranioplasty plate manufacture. Defects have been modelled from CT scan data using SLA (Stereolithography), LOM (Laminated Object Manufacture), ThermaJet Wax Printer, SLM (Selective Laser Melting), and FDM (Fused Deposition Modelling).

On one hand, titanium cranioplasty plates manufactured using most of these methods have been reported to fit even more complex defects, are easy to insert, and produce excellent cosmetic results. Furthermore, 3D modelling and scanning technique have been related to storage saving in addition to reproducibility (meaning ability to cast as much models as needed without the need to take another impression) and being patient friendly.

On the other hand, the main disadvantage of these computer-assisted techniques is capital. It is necessary to have access to a computer work station with a large memory capacity and running appropriate software that will render the CT data. The final cost of the titanium plate would be about £695 which is the sum of the cost of running the work station, royalties for using the software, maintenance contract annual, production of the model by a computer modelling technique and scanning technique have been related to reproducibility (meaning ability to cast as much models as needed without the need to take another impression) and being patient friendly.

A side form the technological aspect, titanium sheet is a commonly used material for cranioplasty. While it is a safe and highly biocompatible material, it can modify the presentation of post-operative complications, thus we are currently in the process of investigating the possible use of net shaped glass fibres that have been used in crown and bridge restoration in what is known as all-polymer fixed prostheses. They have shown similar or increased mechanical properties in comparison to conventional metal ceramic prostheses, indicating fibres as suitable substitutes for metal FPDs. They are highly aesthetic and easy to manipulate and work with. We expect that this new technique in comparison to the conventional titanium-plate technique will save time, effort, materials and subsequently cost.

Recommendations for future use of CT scans and measurements are to create an analogue without the cost and time required for an SLA model.

Summary
Computer assisted production of titanium plate for repairing skull defects is hassle free to patient and prosthetists, efficient and reliable, accurate and reproducible method. Furthermore, the resultant prosthesis constructed is accurately fitting.

References