Chapter 1
Computer Assisted Cranioplasty

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1.1 Introduction to Cranioplasty and Materials for Repair

1.1.1 Introduction to Chapter

The purpose of this chapter is to provide the engineer, medical imaging specialist, and surgeon an introduction and insight into the practicalities of creating custom made implants for the skull. This field of research has grown steadily over the past decade. However, we still do not have a definitive solution to the problem—“How do we create a bio-compatible, easy to fit, durable and cost effective implant for repairing holes in the skull?” We have a number of solutions to the problem, although it is not clear from the literature which brings the most benefit to the patient, to the surgeon and which is most cost-effective.

The term cranioplasty describes the correction of a bone defect or deformity in the cranium using a bio-compatible material. Historically, many substances have been used to fill holes in the skull which were caused either by injury, primitive operations or disease. For example, defects have been filled with precious metals (gold or silver), animal bone, autologous bone graft (the patient’s own bone) and more recently methyl methacrylate (Sanan and Haines 1997). Skull remnants from ancient graveyards in Peru showed evidence of trephination, the creation of a hole in the skull, and repair. Nowadays, the two most common methods of creating a repair are autologous bone (harvested from the patient’s skull or the body) (Sheikh 2006) or acrylic resin, commonly known as bone cement, in the form of polymethylmethacrylate (PMMA) (Park et al. 2001; Chiarini et al. 2004; Raja and Linskey 2005). Other materials have also been used to varying degrees of success. Thin titanium sheet, with a thickness of between 0.5 and 1.0 mm can be formed under pressure to fit the contour of the skull. The plate is fitted with lugs to take fixation screws used to attach the plate to the outer surface of the skull (Joffe et al. 1999a). Hydroxyapatite cement on its own or used with titanium mesh has also been employed to repair small holes in the skull (Arriaga and Chen 2002). Titanium mesh has also been moulded into shape on polyurethane skull replica (Brandt and Haug 2002) and also compared to thin titanium sheet in a limited number of cases (Schipper et al. 2004). Schipper noted that titanium mesh on its own was useful
for defects smaller than 100 cm$^2$ as it had reduced stability and shock resistance compared to the sheet.

The following sections detail methods of cranioplasty, computer assisted cranioplasty and implant design and current research in the field.

### 1.1.2 Clinical Indication for Cranioplasty

Holes in the skull may be caused by trauma, the result of decompressive surgery or a re-implanted bone flap becoming infected after a neurosurgical procedure (Artico et al. 2003). In each of these cases the patient’s own bone has been damaged or become unusable due to infection and has to be replaced with another biocompatible material. An autologous implant is one which has been derived from the same patient whereas an alloplast implant is one that has been constructed from an inert biocompatible material. There is evidence in the literature that not only does repairing a cranial defect provide protection to the brain and a good cosmetic outcome for the patient but may also relieve neurological symptoms like headache, dizziness, depression and anxiety (Rotaru et al. 2006). It has also been demonstrated that a patient will recover neurocognitive function after cranioplasty (Anger et al. 2002). Normally, if the patient has had recent trauma or surgery, the surgeon will wait around 6 months for healing to occur before embarking on the repair.

### 1.1.3 Materials and Methods of Repair

As mentioned earlier a range of materials may be used for repairing a cranial defect. Acrylic resin, titanium sheet/mesh and hydroxyapatite have all been employed. Each of these materials have different physical and biological properties. They may be used alone or in combination with calvarial bone, bone dust or other alloplast materials. Cranial implants are normally preformed following moulage of the defect (the creating of a plaster impression through the overlying skin) (Gronet 2003). The patient’s scalp is shaved and the palpated margins of the defect are outlined with an indelible marker. This margin is transposed onto the plaster impression. Swelling, haemorrhage, oedema and overlying muscle all contribute to the imprecise definition of the defect margin. Implants created using this method often require further manipulation during theatre to accurately fit the skull defect contour and are flat in appearance (Joffe et al. 1992).

Acrylic resin is provided to surgeons in kit form and is also known as bone cement. Its principal use has traditionally been in securing hip and knee implants in orthopaedic surgery. There is extensive research on a range of resins in these applications and many reviews in the field (Gousain 2004). The acrylic resin kit requires the surgeon to mix a polymer powder with a liquid monomer component (methyl methacrylate) to create a malleable paste. The powder may also contain a colour agent and a radio-opaque substance to make it visible after implantation by X-ray