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Titanium cranioplasty in children and adolescents

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ABSTRACT

Full thickness calvarial defects present considerable challenges to reconstructive surgeons. In paediatric cases, the use of biomaterials as a substrate for cranioplasty rather than autologous bone is controversial. Alloplastic cranioplasty in adults is supported by several large case series however long term outcome of biomaterial use in paediatric cases is limited. Retrospective seven year analysis of departmental database and clinical records identified 22 patients aged under 18 who had undergone 23 custom made titanium cranioplasties by a single surgeon using the same technique. Data including patient demographics, reason for craniectomy and complications experienced following surgery was obtained. The mean age at operation was 12 years 9 months. The mean defect size was 44.3 cm^2. No significant complications related to the cranioplasty were recorded in the early post operative period or during long term review (average follow up 4 years 6 months). No cranioplasty implant required removal. This retrospective case series shows that custom made patient specific titanium cranioplasty is a viable alternative to autologous bone as a reconstructive material in paediatric patients under specific circumstances.

1. Introduction

The use of biomaterials rather than autologous bone grafts in paediatric cranioplasty is controversial (Gosain et al., 2009). Despite several decades of technique refinement no single method has proved superior and gained widespread acceptance. Full thickness calvarial defects arise from numerous pathologies including congenital defects, osteomyelitis, trauma, tumour resection, decompressive procedures and infected or resorbed bone flaps replaced following conventional neurosurgery. Calvarial defects expose brain to trauma and can create significant cosmetic morbidity, especially if the defect is large, and can have significant negative impact on active, school age children. The most common donor sites for full thickness calvarial defects are split calvarial grafts and split ribs (Tessier et al., 2005; Jackson et al., 1986). Autogenous bone provides a biological reconstruction that has the potential to grow with the patient and once revascularised has minimal long term infection risk, however limitations include donor site morbidity, limited availability of sufficient bone, difficulty in contouring grafts adequately (Frodel et al., 1993) and high incidence of resorption compared to adults (Grant et al., 2004). Biomaterials in current use include acrylics, ceramics, polyethene, polyetheretherketone (PEEK) and titanium (Cho and Gosain, 2004; Hanasono et al., 2009). Each material has relative merits and disadvantages, however the principle concerns in using biomaterials in paediatric cranioplasty relate to the possible deleterious effects of a rigid material on normal cranial growth, intracranial migration of reconstruction components and high incidences of failure through infection, adverse tissue reactions and material breakage (Resnick et al., 1990; Wong et al., 2011; Yaremchuk et al., 1994; Beck et al., 2002; Papay et al., 1995; Kosaka et al., 2003; Josan et al., 2004; Moreira-Gonzalez et al., 2003).

Several large case series exist of cranioplasty using biomaterials in adult populations (Wehmöller et al., 2004; Joffe et al., 1999; Shoakazemi et al., 2009; Marchac and Greensmith, 2008), however the data concerning cranioplasty using an alloplastic material as a substrate in children is limited. A retrospective analysis was carried out to determine outcome of all custom made patient specific titanium cranioplasties performed by the senior author (RPB) in paediatric patients. A literature search was carried out in addition to identify case series of cranioplasty in the paediatric population to assess current methods of calvarial reconstruction and limitations associated with these techniques in this age group.

2. Materials and methods

Ethical approval was not required for this study. Custom made titanium cranioplasty plates were used in this series of patients. A

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fine cut spiral CT of the head is obtained (0.5 mm slice, 0° gantry angle) and the DICOM data from this used to generate an STL format file which is then used to produce a model of the patient's skull using additive manufacturing. This biomodel is then used to reconstruct the defect in plaster before using the reconstructed biomodel in a hydraulic press to cold form 0.8 mm thick titanium sheet. This results in an accurately fitting, low profile onlay implant that precisely reconstructs normal cranial volume and projection of the skull. Several holes are drilled in the plate to prevent extradural accumulation of fluid and to allow for titanium screw fixation. The plate is anodised, etched with nitrofluric acid and autoclaved prior to insertion.

In all cases incisions utilise previous scars or are planned to allow best access without compromising vascularity of the overlying scalp and to avoid closing scalp wound margin directly over the cranioplasty plate. The defect is exposed in sub-periosteal plane and the cranioplasty plate is secured using titanium screws ensuring rigid fixation. The scalp is closed in layers over suction drains that are generally removed at 48 h post procedure. Antibiotic prophylaxis is given for the procedure and continued for a total of one week.

Departmental database and laboratory records were used to identify paediatric patients who underwent titanium cranioplasty using the described method by a single surgeon. The clinical records were then analysed and data collected using a proforma. Data collected included pathology leading to calvarial defect, site of defect, patient age at which the calvarial defect was acquired, age at cranioplasty, length of inpatient stay, length of follow up and complications recorded. Accurate surface area calculations of defect size using CT scan DICOM data was possible in 12 of the 22 cases due to some patients having planning scans done at external institutions.

2.1. Literature search

A search of Pubmed, ScienceDirect and Scopus was undertaken to assess the current methods in use for reconstruction of full thickness cranial defects in paediatric patients and to compare the published data with this series of patients. The search terms used were: “pediatric” and “cranioplasty”, “pediatric” and “calvarial reconstruction”, and “cranioplasty”. Full articles were included in the comparative data if the authors stated that the series related to paediatric cranioplasty. Published abstracts only were excluded. Data relating to patients less than 18 years of age was abstracted from larger series where possible. Inclusion criteria included publication since 1997, cases reporting $\geq$3 patients and full thickness defects. Data abstracted included modality of reconstruction and, where stated, mean age and range, size of defect mean and range, mean length of follow up and range, effect on cranial growth and modality of assessment, and complications requiring second cranioplasty procedure.

3. Results

The characteristics of the patients in this series are tabulated in Table 1 and summarised in Table 2.

Between 2002 and 2009, 22 consecutive patients under the age of 18 underwent 23 custom made titanium cranioplasties. One patient had bilateral frontal defects and required two cranioplasty plates inserting during a single operation. The average age at cranioplasty was 12 years and 9 months (range: 6 years 2 months–17 years 9 months). Four patients were female. The indications for cranial defect were as a result of decompressive craniectomy in 8 cases (36%), infected bone flap following conventional neurosurgery in 4 cases (18%), osteomyelitis in 3 cases (14%), traumatic loss in 3 cases (14%), congenital defects in 2 cases (9%) and growing fractures in 2 cases (9%).

Fig. 1 illustrates the site of the defects. It was possible using CT scan data to accurately measure 12 defect sizes. Of the 12 defects the average surface area was 44.3 cm^2 (range 5.3 cm^2–116.5 cm^2). Seven known defect sizes were less than 40 cm^2 however several very large reconstructions were undertaken.

Seven patients had previous infection at the surgical site. The minimum interval between cranial defect and reconstruction for this group of seven patients was 10 months (average 2 years 6 months). No particular precautions were taken in these patients other than standard peri-operative antibiotic prophylaxis and a one week post-operative course. The average inpatient episode was four days. One patient had five previous interventions at the cranioplasty site, the remainder had two or less interventions. None of the patients previously had radiation therapy to the cranium and none required tissue expansion prior to cranioplasty insertion.

No complications were recorded intra-operatively or during admission. One seroma was noted on early review which settled without intervention. One patient died five months following cranioplasty from causes unrelated to the reconstruction. The remaining patients had an average follow up of 4 years 7 months (range: 1 year 3 months–8 years 9 months). No long term complications have been observed over this time and no cranioplasty has required removal.

Review of the literature identified 22 studies reporting outcomes of paediatric cranioplasty since 1997. These studies are summarised in Table 3(Barone and Jimenez, 1997; Blum et al., 1997; Choi et al., 1998; Durham et al., 2003; Cohen et al., 2004; Grant et al., 2004; Josan et al., 2004; David et al., 2005; Pang et al., 2005; Gosain et al., 2009; Biskup et al., 2010; Singh et al., 2010; Rogers et al., 2011; Wong et al., 2011; Frassanito et al., 2012; Lin et al., 2012; Piedra et al., 2012; Bowers et al., 2013; Stefini et al., 2013; Martin et al., 2014; Piitulainen et al., 2015; Greene et al., 2008).

4. Discussion

Currently there are two sources of material for calvarial reconstruction; autologous bone or a biomaterial. Autologous cranioplasty substrates are either the preserved craniectomy bone flap or a bone graft, most commonly split calvarium or split rib. Biomaterials in adults, particularly titanium, are supported by several large case series (Joffe et al., 1999; Eufinger et al., 2005) however due to concerns regarding intracranial migration of implants and on disturbance of skull growth the use of biomaterials in paediatric cases is controversial and autogenous bone is generally advocated.

Autogenous bone is considered the gold standard reconstruction as there is the potential for revascularisation and growth with the patient. Literature review identified six studies reporting the use of preserved, either frozen or autoclaved, bone flaps in paediatric cranioplasty. Graft resorption and infection are the most frequently cited reasons for failure of replaced bone flaps with second cranioplasties being required in 18–100% of patients (Grant et al., 2004; Josan et al., 2004; Frassanito et al., 2012; Piedra et al., 2012; Bowers et al., 2013; Martin et al., 2014). In a series of 23 cases reported by Martin et al., bone flap resorption or infection requiring bone flap removal was seen in 43% of cases with decreasing age associated with increased risk of resorption (Martin et al., 2014). Grant et al. reported 50% of paediatric patients undergoing cranioplasty with a fresh frozen bone flap following decompressive craniectomy had sufficient graft resorption to warrant a second reconstruction (Grant et al., 2004). In contrast, in adult cranioplasty bone flap resorption is less frequent, but still significant, with second cranioplasty seen in up to 25.9% of adults