Cranioplasty materials

Across the centuries, many materials have been used for covering bony defects, including coconut shells, bones from both human and non-human donors, metals including gold, silver, tantalum, and titanium and more recently, biosynthetic materials such as resins and ceramics.

A review provides an overview of biomaterial implants and bone flap manufacturing methods for cranioplasty surgery. In addition, tissue engineering and regenerative medicine-based approaches to reduce clinical complications are also highlighted. The potential use of data-driven computer applications and data-driven artificial intelligence-based approaches is emphasized to accelerate the clinical protocols of cranioplasty treatment with less manual intervention and shorter intraoperative time [1).

Autologous bone flap

see Autologous bone flap cranioplasty.

Gold cranioplasty

Synthetic implants

Several materials are available. Each has its advantages and disadvantages. Search is on for an ideal material.

Polymethylmethacrylate cranioplasty and polyetheretherketone (PEEK) are the most commonly applied today.

Mesh cranioplasty

Custom made cranioplasty.

Celluloid cranioplasty

Hydroxyapatite Cranioplasty.

PEEK cranioplasty

Fiberglass cranioplasty

Polypropylene polyester knitwear

Tantalum cranioplasty

Titanium cranioplasty

Acrylic bone cement

Split-thickness calvaria

When synthetic material is used, the flap should be perforated with a dozen or so drill holes to prevent the accumulation of fluid (either underneath the flap or between the flap and the skull).

The choice of heterologous materials for cranioplasty after decompressive craniectomy is still difficult. The aim of a study of Morselli et al. was to examine the association between material of choice and related complications to suggest the best treatment option.

A systematic review was performed for articles reporting cranioplasty comparing the following heterologous implants: Titanium, poli-methyl-methacrylate (PMMA), Polyetheretherketone (PEEK) and Hydroxyapatite (HA). Extracted data included implant materials and the incidence of the most frequent complications.

The final selection resulted in 106 papers but according to our rules only 27 studies were included in the final analysis. Among a total of 1688 custom-made prosthesis implanted, 649 were Titanium (38.49%), 298 PMMA (17.56%), 233 PEEK (13.82%), and 508 were HA (30.13%). A total of 348 complications were recorded out of 1688 reported patients (20.64%). In the Titanium group,139 complications were recorded (21.42%); in the PMMA group 57 (19.26%), in the PEEK group 49 (21.03%) and in the HA group 103 (20.3%). If we examine a summary of the reported complications clearly related to cranioplasty (postoperative infections, fractures and prosthesis displacement) versus type of material in multicentric and prospective studies we can see how HA group patients have less reported infections and cranioplasty explantation after infections than PMMA, PEEK and Titanium. On the contrary HA patients seem to have a higher number of prosthesis displacement again if compared with the other materials. Since these data are not derived from a statistically correct analysis they should be used only to help to differentiate the properties of the various heterologous cranioplasties.

The ideal material for all heterologous cranioplasty has not yet been identified. The choice of material should be based on the clinical data of patients, such as the craniectomy size, presence of seizures, possibility of recovery, good long-term outcome associated with a cost analysis [2)].

Based on the available evidence till 219, fresh bone grafts and titanium mesh demonstrated the lowest surgical-site infection, surgical-site occurrence, and graft failure rates. Banked bone flaps had the highest overall surgical-site complications and graft failures. Pediatric cranioplasty outcomes studies are needed to evaluate current and novel cranioplasty materials [3).

Available evidence on the safety of cranioplasty materials is limited due to a large diversity in study conduct, patients included and outcomes reported. Autologous bone grafts appear to carry a higher failure risk than allografts. Future publications concerning cranioplasties will benefit by a standardized reporting of surgical procedures, outcomes and graft materials used [4).

A literature review in 2016 emphasizes the benefits and weaknesses of each considered material commonly used for cranioplasty, especially in terms of infectious complications, fractures, and morphological outcomes.As regards the latter, this appears to be very similar among the different materials when custom three-dimensional modeling is used for implant development, suggesting that this criterion is strongly influenced by implant design. However, the overall infection rate can vary from 0% to 30%, apparently dependent on the type of material used, likely in virtue of the wide variation in their chemico-physical composition. Among the different materials used for cranioplasty implants, synthetics such as polyetheretherketone, polymethylmethacrylate, and titanium show a higher primary tear resistance, whereas hydroxyapatite and autologous bone display good biomimetic properties, although the latter has been ascribed a variable reabsorption rate of between 3% and 50%. In short, all cranioplasty procedures and materials have their advantages and disadvantages, and none of the currently available materials meet the criteria required for an ideal implant. Hence, the choice of cranioplasty materials is still essentially reliant on the surgeon's preference [5).

In 19th century, the use of bone from different donor sites, such as ribs or tibia, gained wide population.

Many different types of materials were used throughout the history of cranioplasty. With the evolving biomedical technology, new materials are available to be used by the surgeons. Although many different materials and techniques had been described, there is still no consensus about the best material, and ongoing researches on both biologic and nonbiologic substitutions continue aiming to develop the ideal reconstruction materials.

Cranioplasty can be performed either with gold-standard, autologous bone flaps and osteotomies or alloplastic materials in skeletally mature patients. Recently, custom computer-generated implants (CCGIs) have gained popularity with surgeons because of potential advantages, which include preoperatively planned contour, obviated donor-site morbidity, and operative time savings. A remaining concern is the cost of CCGI production.

An experimental model was developed in an indoor gun range. CAD cranioplasties with a material thickness of 2-6 mm, made of titanium or PEEK-OPTIMA(®) were fixed in a watermelon and shot at with a .222 Remington rifle at a distance of 30 m distance, a .30-06 Springfield rifle at a distance of 30 m, a Luger 9 mm pistol at a distance of 8 m, or a .375 Magnum revolver at a distance of 8 m. The CAD cranioplasties were subsequently inspected for ballistic effects by a neurosurgeon.

Titanium CAD cranioplasty implants resisted shots from the 9 mm Luger pistol and were penetrated by both the .222 Remington and the .30-06 Springfield rifle. Shooting with the .357 Magnum revolver resulted in the titanium implant bursting. PEEK-OPTIMA(®) implants did not resist bullets shot from any weapon. The implants burst on shooting with the 9 mm Luger pistol, the .222 Remington, the .30-06 Springfield rifle, and the .357 Magnum revolver.

Titanium CAD cranioplasty implants may offer protection from ballistic injuries caused by small caliber weapons fired at short distances. This could provide a life-saving advantage in civilian as well as military combat situations [6].

Methylmethacrylate and porous polyethylene (PP) were resistant to fracture and disruption. MMA provided the greatest neuroprotection, followed by PP. Autologous bone provided the least protection with cranioplasty disruption and severe brain injury occurring in every patient. Brain injury patterns correlated with the degree of cranioplasty disruption regardless of the cranioplasty material. Regardless of the energy of impact, lack of dislodgement generally resulted in no obvious brain injury [7].

Sonolucent cranioplasty

see Sonolucent cranioplasty.

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