REVIEW OF MATERIALS USED IN CRANIOPLASTY

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ABSTRACT

Cranioplasty is the surgical intervention to repair cranial defects. The aim of this procedure is not only a comestic issue, also the repair of cranial defects gives relief to psychological drawbacks and increase the social performances. Although many different materials had been described, there is still no consensus about the best material, and ongoing researchs on both biological and nonbiologic substitutions continue aiming to develop the ideal reconstruction material in cranioplasty. In this article, we review the materials used in cranioplasty.

***Keyword**: Cranioplasty, autologous bone, titanium, polyetheretherketon*

Various materials have been utilized in cranioplasty. An ideal cranioplasty material should possess the following characteristics: it must fit the cranial defect to achieve complete closure, be radiolucent, resist infection, and be conducive to biomechanical processes (1).

Cranioplasty materials can be classified into two main categories: biological and synthetic (2),(3).

I. BIOLOGICAL MATERIALS (4),(5)

Biological materials include allografts (bony materials and cartilage from cadavers) and xenografts (bony material from animals). The most common complications associated with allografts and xenografts are high infection rates, resorption, and rejection. Tissues such as cartilage and bone have been employed as xenografts and allografts. While cartilage has been found to have a lower infection rate, it lacks the strength necessary to protect neural tissue.

Xenografts were first introduced in cranioplasty, with canines being the initial subjects used. Although allografts of cartilage and bone were also utilized, cadaver bone allografts demonstrated comparable strength to bone autografts but resulted in a higher infection rate.

Autografts are widely regarded as the gold standard due to their ability to reduce infection rates and enhance the host immune response. Various bone harvest sites have been explored for performing cranioplasty, starting with the tibial bone, followed by the ribs, iliac crest, scapula, sternum, and fascia. Bone flap substitution using an autograft is generally considered the first and best option for cranioplasty after decompressive craniectomy. One significant advantage of an autologous bone flap is its cost-effectiveness and favorable cosmetic outcomes. However, autografts risk necessitating reoperation and replacement with other materials due to the possibility of bone resorption, particularly in the pediatric population. Autologous bone can be preserved either through cryopreservation or by placement in a subcutaneous abdominal pocket, with both methods demonstrating comparable efficacy for storage in non-traumatic brain injury contexts.

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II. SYNTHETIC MATERIALS

While autologous bone grafts are preferred for their cosmetic results, lower costs, and patient integration, synthetic materials are considered viable alternatives to address the disadvantages of bone grafts.

Metals (4)

Metals have primarily been explored due to their strength, stabilizability, and malleability. Aluminum was the first metal used in the late 1800s, but was prone to infection. Gold, while demonstrating no adverse tissue reaction, is unfavorable due to its high cost and softness.

Methyl Methacrylate (4), (6)

Methyl methacrylate, discovered in 1939 and extensively studied in the 1940s, is a polymerized acrylic acid ester with strength comparable to bone. It offers better compression and stress resistance than hydroxyapatite. The radiolucency of methyl methacrylate presents both advantages and disadvantages: it allows visualization of cerebral vasculature during angiography yet complicates the detection of plate fractures. Key disadvantages of this material include the risk of implant rupture in more significant defects and a high long-term failure rate due to a lack of integration with bone, attributed to its inert nature.

Titanium Mesh (2), (5)

Titanium mesh can be combined with other synthetic materials, such as methyl methacrylate or hydroxyapatite, to enhance cosmetic outcomes or used independently. As a metallic alloy, titanium exhibits high strength and malleability, is non-corrosive and non-inflammatory, and has a low risk of infection, contributing to excellent cosmetic results. Titanium demonstrates good biocompatibility, no risk of allergic reactions, good mechanical strength, and low infection rates. Additionally, it is more radiolucent and less expensive than many other metals, making it suitable for use alone in reconstructing cranial defects. Despite its hardness, titanium can still be shaped intraoperatively. Recent technological advancements have enabled the customization of prostheses through computer-aided design and modeling based on imaging. Titanium is frequently used as a secondary repair mechanism after unsuccessful autologous bone repairs. Moreover, titanium meshes have recently been utilized to support cement materials, combining titanium's strong resistance to mechanical stress with the ability to remodel cement.

Polyetheretherketon – PEEK (3), (6)

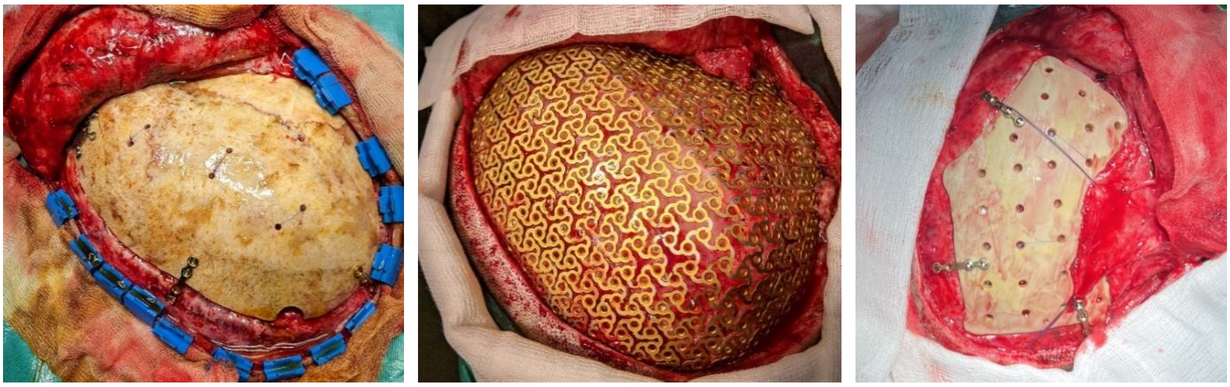
PEEK implants can be customized with high accuracy according to the craniectomy defect. They are light and nonconductive and do not interfere with imaging modalities. However, they are subject to extrusion, show limited osteointegration, and are expensive. Custom-made PEEK implants show the best cosmetic outcome. They are designed to fit cranial defects accurately using 3D printers. However, they are the most costly implants among all types and lack osteogenic properties. This factor increases the risk of dislodgment and infection because of the lack of integration into the surrounding bone. Furthermore, foreign body reaction was previously reported. PEEK implants are a good choice for more significant defects or defects in the fronto-frontotemporal area, especially since using autologous bone flaps is impossible.

Poly(methylmethacrylate) – PMMA (1), (2)

It was used in medicine due to its comparable bone strength, good results in compression and torsion testing, low cost, and readily available. Its radiolucency characteristic is positive for detecting cerebral vasculature by angiography, but plate fracture became challenging to detect. To overcome this problem, barium was infused within the plate, detectable by radiographic means. When associated with titanium, used as support wire mesh for the placement of large cranioplasties, a reduction in fracture was detected, and a more cosmetic resolution.

III. CONCLUSION

The ideal material for cranioplasty has to be strong, easy to shape, not expensive, with a low rate of infection, and radiolucent, biocompatible, porous, firm, and stable to provide the most significant advantages to the patients. Between the synthetic materials, PMMA, alone or in combination with other materials like titanium, shows excellent tensile strength. Despite its fracture susceptibility and infection rates, it is one of the most extensively used materials. PEEK and titanium are perfectly modeled by 3D printing technology, designing specific implants for patients' craniotomy defects.



Autologous bone 3D - titanium 3D - PEEK

Figure 1: ***Materials used in cranioplasty at Department of Neurosurgery, Saint Paul General Hospital (Hanoi)***

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