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REVIEW ARTICLE

Current Concepts in Restoring Acquired Cranial Defects

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Abstract Restoring acquired cranial defects has been in vogue for long, and the reconstructive techniques continue to evolve. Over the decades various techniques and materials are employed in rehabilitating cranial defects. Advances in bioengineering, custom templates and Rapid prototyping technology has given greater impetus in restoring larger cranial defects. With the variety of options available it will be very crucial in deciding the best possible technique and material to rehabilitate patients with cranial defects.

Keywords Cranioplasty · Autograft · Allograft · Rapid prototyping · Tissue engineering

Introduction

The primary function of the skull is to house and protect the brain and various important structures of the central nervous system. It is, therefore, imperative to correct and reconstruct any loss in the continuity of this protective shield.

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Cranioplasty is the surgical intervention to repair cranial defects. The goal of cranioplasty is to achieve the accurate closure of the defect by using various biocompatible materials there by restoring the esthetics of the patient in best possible way.

Many different types of materials have been used throughout the history of cranioplasty. Among these materials are Autologous bone, Polymethy methacrylate, Ceramics, Hydroxyapatite, Polyether ether ketone (PEEK), Carbon-fiber-reinforced polymer (CFRP) and Titanium [1, 2]. With the emerging developments in biomedical technology, new materials are made available to be used by the surgeons. Although numerous materials and techniques had been described, there is still no universal consensus about the best material. On the other hand ongoing researches on both biologic and non biologic substitutions continue to strive harder with an aim to develop the ideal reconstruction materials.

Historic Background

Cranioplasty is an ancient procedure and there is evidence that Incan and Muiscan surgeons were performing cranioplasty using precious metals and gourds [3]. Early surgical authors, such as Hippocrates and Galen, do not discuss cranioplasty, and it was in the sixteenth century that cranioplasty in the form of a gold plate was mentioned by Fallopius. The first bone graft was recorded by Job Janszoon van Meekeren, who in 1668 noted that canine bone was used to repair a cranial defect in a Russian man. In 1885, Macewen and in 1888, Burrell used the remaining calvarial bone after trepanation to repair cranial defects [4]. In 1890, Muller developed the sliding flaps techniques of the external tibia, which was applied in the late postoperative period. The next advance in cranioplasty was the experimental ground work in bone grafting, performed in the late nineteenth century. The use of autografts for cranioplasty became popular in the early twentieth century. The destructive nature of casuality defects in twentieth century warfare provided an impetus to search for alternative metals and plastics to cover large cranial defects. The metallic bone substitutes have largely been replaced by modern plastics. Methyl methacrylate was introduced in 1940 s and used in fabrication of various prosthesis in maxillofacial region. Research in cranioplasty is now directed at improving the ability of the host to regenerate bone.

Materials and Techniques in Cranioplasty

Reconstruction of the cranial defect can be undertaken as a primary or secondary procedure depending upon the duration, severity of injury, location of the defect and condition of the overlying soft tissues. Only autografts and alloplastic materials have been employed in the repair of cranial defects. With the evolving new biomedical technology, new materials are now available to be used by the surgeons.

Autologous bone grafts remain the best option for adult and pediatric patients with small to medium defects and viable donor sites. Large defects in the adult population can be reconstructed with titanium mesh in conjunction with polymethylmethacrylate overlay and also with or without the use of computer-assisted design and manufacturing customization. In pediatric patients, exchange cranioplasty offers a viable technique for using an autologous bone graft, w simultaneously filling the donor site with particulate bone graft. Advances in alloplastic materials and custom manufacturing of implants will have an important influence on cranioplasty techniques in the years to come.

An ideal cranioplasty material should be, [5]

- Radiolucency
- Resistance to infections
- Dimentionally stable
- Should be resistant to heat and cold
- Easy to shape
- Inexpensive
- Ready to use
- And finally it should accurately fit with the cranial defect to achieve complete closure.

Autografts

The use of autografts from iliac crest, rib, tibia and calvarium either as a free graft or transferred on a vascularized pedicle is a preferred mode to repair defects less than 5 cm in diameter. Although source of membranous bone is limited, they are preferred graft materials for cranial reconstruction since they exhibit less resorption compared to endochondral bone.

Split thickness skull cranioplasty are currently used by the surgeons in correcting small to medium cranial defects. They are bio-compatible, can be easily harvested and has less risk of infection [6]. Main advantages of osteoplastic reconstruction are easy harvesting, less risk of infection, the use of local own tissue, provides natural radiodensities, allows growth and they are bio compatible. But the drawbacks include possible resorption and loss of contour, availability of sufficient graft material for large defects and donor site morbidity.

Allografts and Xenografts can also be used, but success with these grafts has not been encouraging. These grafts have not found favour because of high rate of rejection and their proximity to vital structures.

Alloplastic Materials

Various alloplastic materials have been evaluated and virtually computerized virtually designed implants are found increasingly wider use. Among these materials PolymethylMethacrylate (PMMA), Ceramics, Hydroxyapatite, PEEK, CFRP and Titanium are popular.

A very common and economically viable material is PMMA, but often the cosmetic outcome is poor, especially when the cranioplasty involves two plane rehabilitation like parts of the forehead and viscerocranium [7, 8]. Rejection of PMMA grafts has been reported in literature.

Materials like Ceramics, HA, PEEK, CFRP and Titanium are available for computerized remodeling. The osteo-inductive potency of hydroxyapatite makes it as a material interesting for the clinical use in cranial reconstruction. However, the high infection rate of up to 22.4 %, especially when utilized to cover large defects, has made some clinicians to reject this material. Ceramic materials often have too much volume and are difficult to attach to the adjacent bone and also require more extensive dissection. Whereas for custom made Titanium cranioplasties, a small volume of implant material is needed and plate is simply laid over the defect and fixed with mini-screws. Thus, it is not necessary to dissect the dura and the osseous rims.

Future in Cranioplasty

Because of the limitations of autologous bone grafts and alloplastic materials, new methods towards performing cranioplasties are needed to achieve perfection in cranioplasty. With the help of modern technology ongoing researches on both biologic and non-biologic substitutes continue to evolve on a faster pace. Current concepts are focusing more on newer materials and techniques in cranial defect rehabilitation. Among the advances, Rapid prototyping and Tissue engineering with or without CAD-CAM has shown promising outcomes.

Prototyping is a widely used method reported in the worldwide literature since 1980 s. This technique has been used in medical and dental areas for surgical planning and prosthesis fabrication [9–17]. After obtaining an image of the cranium in helical computerized tomography (CT) with thin slices (1 mm) and three-dimensional reconstruction techniques of mirroring and interpolation of images are used to project the model in real dimensions. There are several types of prototyping for creation of biomodels (replication of the morphology of a biologic structure in solid substance). Methods of RP were developed based on the acquisition of reconstructed images and using laser that solidifies a liquid polymer or photo-sensitive resin to obtain the object. Then, an accurate replica of the cranium is produced.

The fabrication of the prosthesis can result from models determined by graphic software or using CAD-CAM or manual techniques based on a prototyped cranium [15–17]. The advantages of rapid prototyping technology as reported in the literature are reduced surgical period, planning and review of the surgical procedure before the surgery, accurate fabrication of prostheses and didactical method for anatomy teaching. Besides, this technique allows better patient education towards understanding about the patient about its pathology and the procedure to be conducted [15, 18, 19].

Tissue engineering has become a promising approach for bone regeneration. The successful repair of bone defects utilizing this technique has been demonstrated in immune-deficient animals, such as Athymic mice [20, 21, 22] as well in immune competent animals like canine and sheep [23, 24]. Thesleff et al. [25] reported stem cells derived from abdominal fat-used along with a synthetic bone grafting material-as a potentially valuable new approach to repairing skull defects after brain surgery. The researchers have also used the adipose tissue derived stem cell (ADSC) technique to restore skull defects in four patients, average age 64 years. All patients had persistent skull defects-averaging about 3 by 2½ inches in size-resulting from complications after surgery. Stem cells were prepared from a small sample of fat obtained from the patient's abdomen. These fat-derived stem cells consists of an intriguing new source of stem cells for research and treatment purposes. Unlike bone marrow-derived stem cells, ADSCs can be obtained in large numbers and easily expanded. Similar to bone marrow stem cells, ADSCs can be induced to develop (differentiate) into many different kinds of cells-including bone-forming (osteogenic) cells.

After developing the stem cells, Dr. Thesleff and colleagues combined them with a synthetic bone grafting material (called betaTCP) to fill the skull defects in the four patients. The results were assessed by computed tomography (CT) scans performed 1 week after surgery and at 3 months' and 1 year's follow-up, which showed the new bone filled in gradually, reaching the density of the neighboring bone within several months. This new study suggests that ADSCs are a promising alternative for repair of these persistent skull defects. These cells in combination with synthetic bone-graft material, they can be used to create a "custom-made" implant for the patient..

Conclusion

Recent research has provided promising evidences in the reconstruction of large cranial defects. However, these novel ideas require long term studies, refinement and development to turn these materials and methods into a reproducible and reliable treatment regimen in cranial bone reconstruction.

Conflict of interest None.

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