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CRANIOPLASTY: REVIEW OF MATERIALS AND METHODS

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Reconstructive plastic surgeries, in particular cranioplasty, are becoming increasingly common in modern neurosurgical practice. The presence of a skull bone defect not only leads to cosmetic imperfections and related psychological problems, but can also cause neurological disorders. Reconstruction of skull defects is considered an important neurosurgical stage in the recovery of victims after a traumatic brain injury. Currently, there are no clear algorithms for performing and timing of cranioplasty. The paper presents information on the history of development and stages of formation of reconstructive neurosurgery. The effectiveness of treating trepanned skull syndrome by cranioplasty is proven. The main materials used to close skull bone defects are covered, and the requirements for the material for closing skull defects are described. The disadvantages and advantages of modern materials are presented in detail: autobone, allobone, reperen, polyethertecon, polymethyl methacrylate , titanium, hydroxyapatite. A separate section of the article is devoted to transplant modeling methods - 3D printing and stereolithography. The basic principles of cranioplasty are then formulated. The modern arsenal of materials and methods for performing cranioplasty allows for the closure of cranial bone defects of virtually any size, location and shape, achieving excellent functional and cosmetic results in the postoperative period.

Key words: cranioplasty, skull fractures, neurosurgery, reconstructive surgeries, transplant modeling, 3D printing, autotransplantation, allotransplantation

Introduction

One of the first mentions of cranioplasty dates back to the 16th century, when F. Gabriele (1523-1562) described a case of reconstruction of a bone defect of the skull with a gold plate [1-3]. In 1668, Van Meekeren described an incident of reconstruction of a skull defect of a Russian nobleman after a sabre injury (a dog's skull bone was used for cranioplasty) [4-6]. Despite the continuous development of new methods and materials for reconstruction of cranial vault defects, the problem of cranioplasty is still relevant [7-9]. Currently, there are no specific algorithms for the selection of materials and timing of cranioplasty [10].

Selecting Material for Cranioplasty

Existing materials for replacing cranial vault defects are divided into:

1) autoplasty (patient's tissue);

2) alloplasty (tissues from another person);

3) heteroplasty (animal tissue);

4) implants (medical devices implanted into the human body as prostheses).

A number of requirements are imposed on modern materials [13]:

- biocompatibility;
- absence of carcinogenic effect;
- plasticity;
- possibility of sterilization and combination with additive technologies;
- compatibility with neuroimaging methods;

Figure 1. Postop CT scan, 3D reconstruction of the patient

Cranioplasty performed with autogenous bone. Autogenous bone was stored in a freezer. 280

- resistance to physical and mechanical stress;
- low thermal and electrical conductivity;
- optimal cost;
- low risk of infectious and inflammatory complications.

At present, there is no graft that meets current requirements other than autogenous bone (Fig. 1) [11-13].

According to Finnish researchers (JM Piitulainen, T. Kauko), after reconstruction of the skull bones with auto-bone in the postoperative period there is a need to remove the bone flap in 40.0% of cases. The leading causes of complications and removal of the autograft were infections and bone resorption (20.0-50.0 and 15.0-25.9%, respectively) [14-17]. CL Rosinski et al. compared the results of cranioplasty with auto-bone: in group 1, the autoimplant was stored subcutaneously, in the 2nd - in freezers. The duration of the surgical intervention was shorter in group 2, but there were no differences in the number of postoperative complications, re-hospitalizations and reoperations [18]. The researchers concluded that subcutaneous and frozen storage of autogenous bone resulted in similar outcomes, and cryopreservation may be preferable due to shorter operative time and avoidance of abdominal wall complications, while subcutaneous storage remains favorable for patients undergoing cranioplasty at another institution.

MC Fan et al. identified risk factors associated with infection and bone flap resorption after cranioplasty with cryopreserved bone flaps [19]. Autobone resorption was higher in patients <18 years than in patients >18 years (9.38% vs. 3.61%, $p < 0.05$) and with cryopreservation longer than 365 days (6.88% vs. 2.92%, $p < 0.01$). The incidence of autobone infection was higher in emergency craniectomy (8.81% vs. 2.59%, $p < 0.01$) and in patients with diabetes mellitus (10.53% vs. 3.07%, $p < 0.01$). Therefore, cranioplasty with cryopreserved autobone should be performed within 12 months after craniectomy [10].

Xenoimplants (materials of non-biological origin) have become the most widely used for reconstructive neurosurgery [13, 14]. Popimetometacripates (PMMA). This group has a number of advantages that are well known and widely used by most neurosurgeons: ease of modeling an implant of any configuration and size, relatively low cost [20]. Despite their widespread use, they are associated with a relatively high risk of complications in the postoperative period. Local inflammatory reactions are associated with the toxic and allergenic effect of PMMA [21, 22]. A plate obtained from a mold is fraught with errors in restoring the cosmetic appearance, due to

which is why PMMA has become less used [23]. A PMMA plate impregnated with antibiotics, vancomycin for methicillin-resistant Staphylococcus aureus (MRSA), shows a low level of evidence [24].

Polyethertecones (PEEK). Due to their high melting point, materials from this group are produced only in press molds [25]. Positive properties of PEEK include chemical inertness, strength, elasticity, heat resistance, and good compatibility with modern neuroimaging methods. However, PEEK, like any xenoimplant, has its drawbacks: high cost of powder for plate preparation, high incidence of infectious and inflammatory processes (compared to other synthetic and titanium transplants), difficulty in combining it with other substances [26].

Reperen. In 1996, the synthetic material reperen was introduced into practice [13]. Initially, it was used in ophthalmology as an artificial lens, iris, etc. [27]. Then it began to be used in surgery for hernioplasty. Since 2006, reperen plates have also begun to be used in reconstructive neurosurgery. It is a spatially cross-linked polymer made of oligomers of the methacrylic series. Using programmed parameters and photopolymerization, a plate ready for use is manufactured. Its main positive quality is that during surgery, the plate can change its configuration; for this, a sterile saline solution heated to 80 °C is used. Under the influence of high temperature, the reperen plate becomes soft and elastic, which makes it possible to model it for a skull defect and change its size and configuration using general surgical instruments [13]. Its disadvantage is that when used on complex skull defects, the modeling time at the time of surgery can take from several minutes to several hours.

Titanium. The following materials are currently used: titanium alloys, pure titanium, stainless steel, cobalt-chromium alloys [28, 29]. This material has low weight and thermal conductivity, high strength and biological inertness, corrosion resistance, average cost, and is non-toxic [30]. Titanium meshes are easily modeled during surgery. With the advancement of 3D printing in medicine, titanium plates are used in reconstructive neurosurgery as individual products [31]. An individual transplant is made from titanium powder using a 3D printer (Fig. 2).

Titanium is currently the material of choice for secondary cranioplasties [32]. The main disadvantage is the presence of artifacts in the images during neuroimaging, the presence of a proprietary screwdriver during surgery [33]. In

Currently, there are a large number of companies on the medical market that produce titanium plates for cranioplasty: "CONMET", 81gukeg, "Medbiotech", including those using 3D printing. Hydroxyapatite. In its pure form, hydroxyapatite cement is used for defect sizes up to 30 cm2. For extensive defects, in order to impart high strength and acquire better cosmetic effects, it is necessary to reinforce it with a titanium mesh. The main positive quality of this material is its almost complete biocompatibility. With small defects, hydroxyapatite is completely resorbed and replaced by bone tissue within 18 months. The disadvantages of this material include the high cost of a number of compositions, the need for additional reinforcement with a titanium mesh for extensive defects, and the impossibility of use in areas of the skull that bear a functional load [1].

Transplant shape modeling. To solve the problem of functional and aesthetic restoration of lost skull bones, it is necessary to create an individual implant that accurately replicates not only the shape of the defect, but also the normal bone architecture of the skull of a specific patient [33]. For the precise production of a three-dimensional model of the transplant, methods based on stereolithographic modeling and frameless navigation are used [34, 35]. There are indications in the literature of the possibility

, 3D reconstruction. Cranioplasty with titanium plate. 3D - printed individual implant

the use of frameless navigation in cranioplasty, and the implant is manufactured under the control of neuronavigation during surgery [1, 6]. The number of scientific publications on this topic has increased more than 10-fold since 2013, which is due to the popularization of 3D printing technology and a decrease in cost [36]. Currently, 3D printing seems to be a working and promising technology for the manufacture of various prostheses, implants, and fragments of some organs [37]. In principle, there are two main 3D printing technologies: laser and inkjet. With laser technology, polymerization occurs under the influence of a laser or melting under the influence of a laser (electron beam melting technology). With inkjet technology, molten plastic is fed from a nozzle, and upon cooling it hardens, forming a 3D model [38, 39]. Metal printing technology has been divided into two branches: direct laser growth technology and selective laser sintering (SLS) and melting (SLM) technology [6, 39]. Many researchers have proven that the use of implants created according to a three-dimensional model of the patient's skull at the preoperative stage reduces the duration of the surgical intervention, allows for the use of fewer screws to fix the implant, reduces the number of postoperative complications, and allows for better aesthetic and cosmetic results [1].

Basic principles of cranioplasty. Depending on the time of surgery, there are primary, primary-delayed (5-7 weeks after TBI) and late (more than 3 months) cranioplasty [10]. Cranioplasty should be performed earlier (up to 60 days after the primary surgery), which is necessary to reduce the time it takes for the wound to heal and prevent subsequent complications [13]. In Korea, if the patient’s condition allows, the cranioplasty period can be reduced to 6 weeks; this is considered optimal in terms of complications and regression of neurological deficit [1]. Early cranioplasty reduces the risk of infectious complications, bone flap resorption and epileptic seizures. During intraoperative modeling of the transplant, it is necessary to strive for the most accurate reproduction of the configuration of the resected bone tissue. This transplant must not have protruding sharp edges. When placed in place of the defect, it must be “flush” with the adjacent bones of the skull. It should be remembered that with defects of temporal localization, gradual atrophy of m. temporalis occurs, therefore, even with complete identity of the transplant of the resected temporal bone in the postoperative period, a cosmetic defect is possible due to the lack of soft tissues above the plate. This problem is solved by contour plastic surgery of soft tissues with a bone implant. In the area of the atrophied m. temporalis, the implant must be made

thicker and protruding above the surface of the cranial vault, creating a smooth transition (without a step) between the plate and the cranial bone [1, 25]. The absence of fixation, including in the form of simple suturing of soft tissues over the transplant, seems unacceptable, since this does not provide the necessary fixation and its absence seems to be a reliable risk factor for the development of implant dislocation [25, 33]. Personal experience. In the clinical practice of the neurosurgical departments of the Volga District Medical Center of the Federal Medical and Biological Agency of Russia, City Clinical Hospital No. 39 (Nizhny Novgorod Interregional Neurosurgical Center named after A.P. Fraerman) and City Clinical Hospital No. 40 of Nizhny Novgorod, the following materials are used for cranioplasty: autobone, titanium, reperen, RMMA. Autologous bone is stored in freezers in combination with thermal and chemical treatment. In case of skull defects of complex localization (frontal-orbital, etc.), individual implants are used using 3D printing.

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