

# THE EVOLUTION OF CRANIOPLASTY: A REVIEW OF GRAFT TYPES, STORAGE OPTIONS AND OPERATIVE TECHNIQUE

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## ABSTRACT

Cranioplasty is a neurosurgical procedure to repair cranial defects to restore functional anatomy preventing any neurological drawbacks and taking into account the cosmetic issues. This procedure has evolved over a period of many years, with advancements regarding the knowledge of materials to be used and storage techniques. In the present age, although many materials are being used to serve as bone flaps in cranioplasty, no direct consensus considering the outcomes has been reported. Data suggests that while non-autologous flaps are also used widely for their serving purposes, autologous flaps are reported to have better outcomes, with lesser cases resulting in infections or any other complications. In peds patients specifically, autologous bone flaps allow bone remodeling and bone growth which is restricted in non-autologous flaps. Several storage techniques have also been reported, with some most widely used as preservation of bone under subcutaneous abdominal tissue, preservation of the bone in the subgaleal space on the edges of the craniotomy and freezing the bone flap. Although no direct data is present on to which one has better outcomes, the freezing technique is most widely used. Different temperatures are used in different hospital settings to freeze the flaps.

**Key Words:** Cranioplasty, bone flaps, skull defects, allografts, autografts, storage techniques.

## INTRODUCTION

Cranioplasty is the surgical reconstruction of cranial defects that were acquired as a result of trauma or intervention. It is important not only for cosmesis and protection of underlying brain, but also to restore the dynamics of a closed cranial cavity which are disturbed when in the absence of overlying bone the atmospheric pressure is allowed to exert an influence. The procedure has recently attracted widespread attention due to the increasing literature supporting decompressive craniectomies for various indications. This has resulted in a larger number of patients requiring staged cranioplasty. However, the procedure is not a new one and has seen considerable evolution over the years.

## EVOLUTION OF GRAFTS

The procedure of cranioplasty dates back to ancient times. Initially it was carried out by simple interposition of metal sheets under the scalp and was mostly seen with skepticism, until 1668, when Van Meekeren succeeded in performing heterologous cranioplasty using bone flap from dog to man. Almost a century later, the discovery of osteogenic role of periosteum by Duhamel in 1742 provided a new dimension to the

procedure and another century later, the first cranial reconstructions by heterologous, homologous and autologous bone transfers by Ollier in 1859 laid the foundations of modern day cranioplasty. Since then majority of reconstructions have been carried out by homologous and autologous bones although infections remained a frequent complication. There was also the odd case with no available homologous or autologous graft available for use which once again stimulated interest in finding other materials which would work. Today, the graft for performing a cranioplasty can be autologous, heterologous or synthetic. The ideal graft should fit the defect completely, should be inert, light-weight, radiolucent, resistant to infections, temperature resistant, strong enough for biomechanical processes, easily shaped, inexpensive and readily usable. So far, there hasn't been a single allograft to fit these criteria completely<sup>1</sup>.

The synthetic bone grafts could be metallic or non-metallic. Metals that have been tried include aluminum, silver, gold<sup>4</sup>, tantalum, titanium, lead, platinum<sup>4</sup>, vitallium<sup>4</sup> and ticonium<sup>5</sup>. All of these can cause complications, such as aluminum is prone to infectious complications, causing epilepsy in many patients after the cranioplasty, due to which its use has been

discontinued<sup>3</sup>. Gold is expensive, while silver is soft and cannot provide mechanical protection. Furthermore, silver also gets oxidized, changing the color of overlying skin<sup>4</sup>. Tantalum is expensive, not easily available and has a frequently reported adverse effect of severe headaches due to excessive heat conduction.<sup>5</sup> Titanium is hard to shape, but relatively cheaper, bio-acceptable, and radiolucent after mixing with other metals<sup>6</sup>, however it is not recommended in cases of suspect skin viability. It is still the most commonly used metal for cranioplasty. The use of lead has also fallen out of favor due to high toxicity, while platinum is still used but is highly costly<sup>4</sup>. Vitallium composes cobalt, molybdenum, and chrome, its use is popular in cranioplasty because this combination of metals gives less tissue reactions as compared to pure metals<sup>4</sup>. Ticonium is similar to vitallium but it also contains nickel. Its ease to give shape and lightness are advantages over vitallium<sup>7</sup> although both these materials are not in frequent commercial usage.

Non-metal allografts that have been used in cranioplasty are celluloids<sup>2</sup>, methyl-methacrylate<sup>6</sup>, hydroxyapatite, polyethylene<sup>7</sup>, silicon, chorale<sup>8</sup> and ceramic. These allografts, just like metallic ones, have some disadvantages that limit their use, such as use of celluloids cause post-operative fluid accumulation and aspiration<sup>2</sup>. Methyl-methacrylate is the most extensively used material in cranioplasty and has better outcomes than many other allografts<sup>9</sup>. It is easily available, inexpensive, reasonably hard and light weight. Hydroxyapatite, which is already present in bone causes increased bone repair, has minimal tissue reaction with good osteointegration. However, it is not resistant to mechanical stress and can break<sup>10</sup>. Polyethylene is very easy to shape, has great biocompatibility, early vascularization followed by ingrowth of soft tissue and collagen deposition, hence is a favorable material for allografts.<sup>11</sup> Silicon is comparatively soft and not widely used.<sup>12</sup> Chorale has great osteogenic potential but has limited durability and Ceramic has insufficient durability<sup>13, 14</sup>.

Apart from allografts, autografts are also widely used in cranioplasty. The most widely used bones are cranium, tibia, rib, scapula, fascia, sternum and ilium<sup>19</sup>. Just as allografts, each type of autograft has its own advantages and disadvantages. When cranium is used, there are techniques to use either the outer table of skull or the inner table, of which inner table is preferred due to better cosmetic outcomes at donor site. The bone flaps taken from cranium are biocompatible, easily harvested and have less infection and reaction risks. For this reason, it is considered a favorable option in

cases prone to infections<sup>3</sup>. In pediatric patients where further skull growth is expected, cranial bone grafts allow remodeling of bone and continuous growth, in contrast to fixed non biological materials causing restricted skull growth and deformities in adult ages<sup>14</sup>. The use of tibia has discontinued mostly due to the difficulty in harvesting, traumatic reactions and loss of contour in the treated patients<sup>16</sup>. Ribs are also seldom used anymore, due to complications such as deformities of the thorax and respiratory problems<sup>17</sup>. Scapula also poses complications and hence is discontinued to be used in cranioplasty. When it comes to soft tissues like fascia, only small pieces of defects can be treated. They have high healing ability and effective defect closure<sup>18</sup>. These grafts are considered highly vascularized grafts, providing good chances of swift cerebral revascularization. However non-pedicled fascia is not highly protective against infections and also not suitable after repeated craniotomies when risk of meningitis is high<sup>18</sup>. Fascial autografts are among the best known grafts used for duraplasty<sup>18</sup>. The use of sternum has also been majorly discontinued due to the lack of sufficient volume to cover the cranial defect, difficulty to harvest, and ability to rapidly resorb<sup>19</sup>. Initially Ilium was a preferred choice for cranioplasty, due to similarity in its contour to the skull, however, due to some major complications such as hemorrhage, bowel perforation and nerve damage, it has become one of the least preferred choices. It is also very rapidly resorbed<sup>19</sup>.

### **AUTOLOGOUS GRAFTS: STORAGE TECHNIQUES**

The autologous bone grafts are stored by three widely used methods with distinct advantages and disadvantages. These include preservation of bone under subcutaneous abdominal tissue<sup>15</sup>, preservation of the bone in the subgaleal space on the edges of the craniotomy<sup>16</sup> and freezing the bone flap<sup>17</sup>. There are abundant reports of storage of autologous bone graft within sub-cutaneous tissue of anterior abdominal wall. In one report, the efficacy of this method was evaluated in 53 patients, amongst whom 49 were successfully completed, 8 required complementary synthetic material for cosmetic reasons while three cases were complicated by infections<sup>18</sup>. Similarly, another report involved 43 patients also reported excellent outcomes, with only 3 unfavorable cases, one of which contracted bone infection while the other two had local absorption<sup>19</sup>. Other reports also showed similar results<sup>26,27</sup>. The subgaleal storage technique requires wide exposure of potential subgaleal space adjacent to the site of

operation using blunt dissection, and the bone flap is placed in this plane, taking care that the curvature of the bone flap does not excessively elevate the scalp or cause tension over the scalp edges. In cases where larger bone flaps are placed, the curvature may necessitate fracturing of the bone flap in two or more pieces. The relative avascularity of the subgaleal plane helps in limiting the rate of reabsorption of the bone. As no additional incision is necessary, the procedure is quick to perform both at the time of placement and replacement<sup>19</sup>. The reported complication rate with this procedure is less than 5% as one study reported only two complications among 55 cases, (one case of cutaneous perforation by sharp bone edges and other by skin necrosis due to a small subgaleal space<sup>20</sup>. Similarly, a study reported no complications after analyzing 37 cases with this technique<sup>27</sup>.

In the freezing method, the flap is preserved in subnormal temperature, ranging from anywhere between -4 to -85 degree centigrade. An obvious advantage is no requirement of another incision. The procedure is not used in certain European countries such as UK, where the Human Tissues Act makes any kind of freezer storage of bone complicated and uneconomic. In favor of this technique, a study revealed only two complications among 49 patients with a median time of 50.6 days, one case of absorption and other of flap infection. In some cases, the bone shrunk without any compromise on cosmetic problems<sup>23</sup>. However, another study showed significant bone loss in 60% of the patients undergoing cranioplasty after storage by this technique, suggesting that the storage in the abdominal subcutaneous tissue to be superior to this method<sup>25</sup>. Various temperature ranges have been tried. Too low temperatures are costlier to maintain and pose the risk of osteocyte loss and protein degradation, although at very low temperatures, infections become almost impossible. Higher temperatures on the other hand may keep the osteocytes viable, but run the risk of infections. Since no guidelines exist, various temperatures are being used in different hospital settings.

#### **AUTHORS' TECHNIQUE AND INSTITUTIONAL RESULTS OF AUTOLOGOUS CRANIOPLASTY AFTER FREEZING AT -260C**

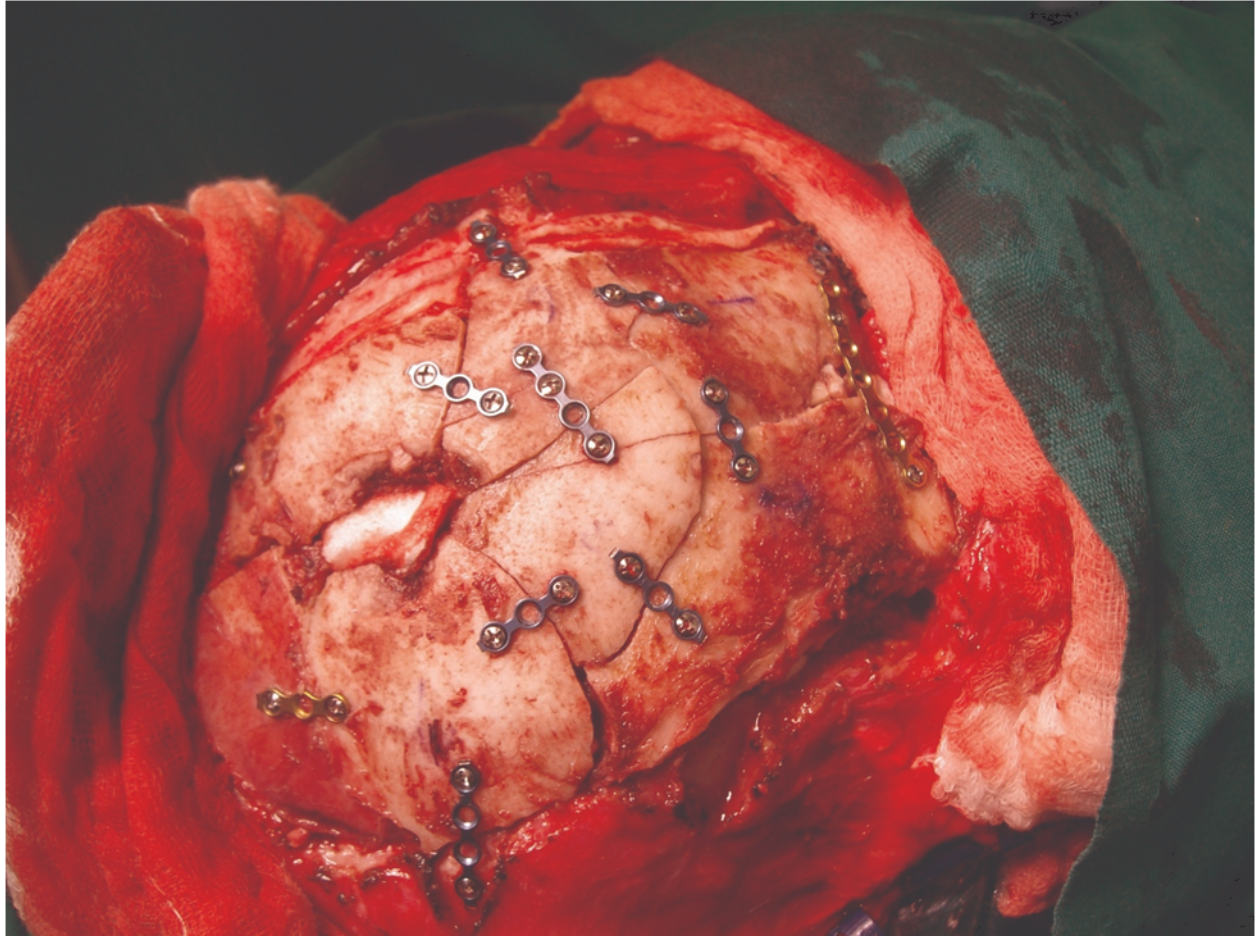
At the time of decompressive craniectomy, the bone flaps are preserved as soon as the decision to leave the bone flap out is made by the operating surgeon, thus minimizing exposure time. For non-penetrating injuries, no efforts are made to clean the bone prior to storage. The bone flaps are wrapped in two layers of

sterile waterproof paper, followed by placement in a close fitting sterile air tight plastic bag. This package is in turn placed in a bigger sterile plastic bag, and sealed in an air tight manner. The flaps are then labeled, logged and subsequently placed in an operating room based freezer maintaining a constant temperature of -260 C. at the time of cranioplasty, the plastic bags are retrieved and thawed within its packing, at operating room temperature. Flaps are removed from their packing only after the galeal flap had been raised and craniectomy edges properly defined, to minimize exposure time. On removing the bone from its packing, it is cleaned of all bone dust, attached soft tissue and loose fragments and immersed in povidine iodine solution for 10 minutes, followed by brief irrigation with a diluted solution of hydrogen peroxide (1:1 dilution with normal saline). It is then thoroughly rinsed with antibiotic mixed normal saline solution, the entire procedure requiring between 12-15 minutes. The bone flaps are fixed using either titanium plates or silk sutures. Skin is closed with continuous interlocking nylon sutures or stainless steel staples based on the attending surgeon's preference. Prophylactic antibiotics are continued for 24 hours only.

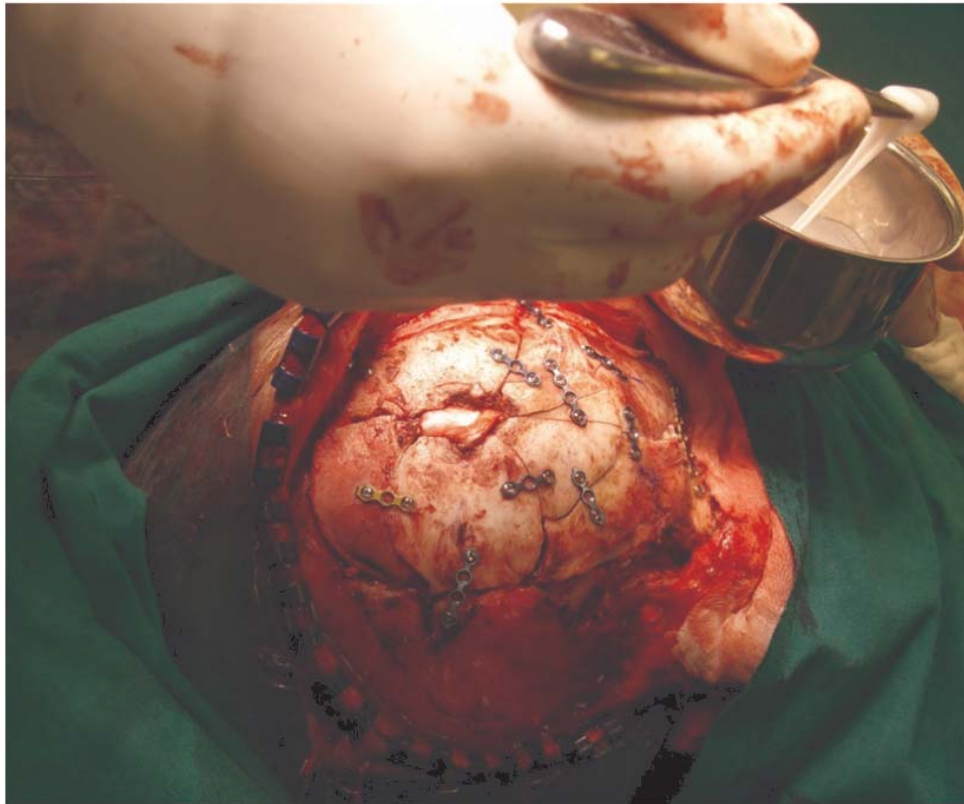
Over a ten year study period (Jan 2001 to Jan 2012), 88 patients have undergone cranioplasty by this technique. The mean age of patients was  $33 \pm 14.8$  years, 77.3% (n = 68) of our patients were males, 22.7% (n = 20) were females. The leading primary pathology was blunt traumatic brain injuries in 45% (n = 45), followed by cerebrovascular accidents in 23% (n = 22), penetrating traumatic brain injuries in 13% (n = 12), and tumors in 40.5% (n = 4) of cases. Of the 88 patients only 3 (%) patients were found to show signs of infection at follow up. Two patients had superficial wound site infection, and one patient had deep wound site infection involving subgaleal space. Both patients with superficial surgical site infections settled on oral antibiotics and the patient with deep wound infection required wound re-exploration and wash out. The tissue culture grew *Staphylococcus aureus*, which was pan sensitive, and patient responded well to three weeks of antibiotics with unremarkable follow ups till two years. Apart from these three cases, the other complications included extradural hematoma in one patient requiring evacuation, and hydrocephalus in two patients, both requiring temporary CSF diversion only.

## CONCLUSION

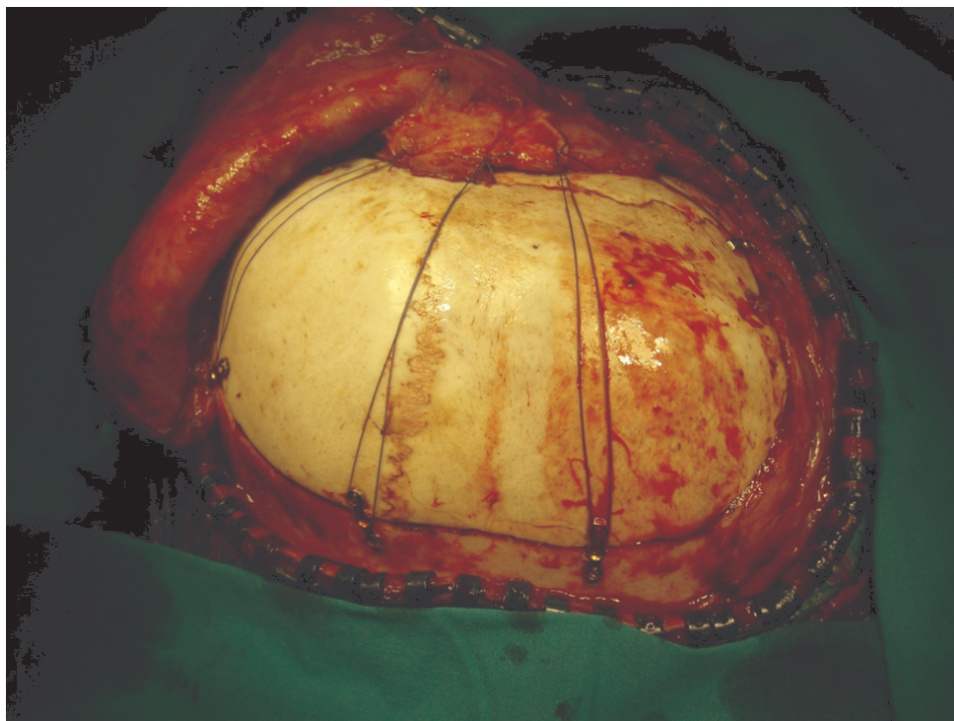
There are many different techniques of cranioplasty. A brief review suggests that the most effective method to be used is autologous bone flaps, due to lesser chances of infection and rejection by the body and cost effectiveness. The type and duration of storage of bone flaps depends on the available logistics and patient related factors. The current literature suggests that storage of bone flaps in freezers is the commonest method.



**Figure 1:** Cranial reconstruction using fractured autologous bone fragments, which still left a small central defect. Bones are secured using titanium plated and screws.



**Figure 2:** Methy-methacrylate is being used to fill the central bone defect.



**Figure 3:** Autologous cranioplasty after decompressive craniectomy for malignant hemispheric infarction. Bone has been secured with titanium plates.



**Figure 4:** Post cranioplasty CT scan, bone windows, which show slight resorption of bone flap.

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