Cranioplasty With Hydroxyapatite Implants: A Multidisciplinary Approach of Neurosurgeon and Plastic Surgeons to Improve Surgical Technique and Clinical Outcome

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Abstract: Cranioplasty using Hydroxyapatite prosthesis is a conceptually simple procedure, but it may harbor several challenges for the surgeons. Several papers in the literature deal with cranioplasty using porous hydroxyapatite. The results are not homogeneous both because of the variability of the patients treated but also because Hydroxyapatite requires a more careful surgical technique to achieve maximum performance. The aim of the present study is to offer an insight of a single institution, multidisciplinary experience with custom-made Hydroxyapatite cranioplasty with surgical tips and tricks based on personal opinion and literature evidence. We will provide an overview of all the fundamental steps we believe to be useful to optimize surgical outcomes, including preoperative planning of cranioplasty; as cranioplasty flap/soft tissue coverage planning, infectious prophylaxis, patient positioning, incisional patterns, tissue dissection, primary bone demolition, and preparation of the craniectomy margins before implant positioning. The authors will also discuss methods for dural suspension, implant fixation and anchorage, margins polishing, drainage, suturing, and dressing. Cranioplasty using hydroxyapatite prosthesis is a valuable alternative for skull reconstruction with heterologous implants, and in our opinion a multidisciplinary approach integrating plastic surgeons and neurosurgeons' specific skills can facilitate surgical planning, reducing complications and allowing to achieve better functional and aesthetic results.

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Decompressive craniectomy (DC)[1] is a surgical procedure performed to relieve increased intracranial pressure by removing part of the skull, often required after severe head trauma or surgical removal of cranial tumors, resulting in skull defects that may necessitate subsequent reconstructive surgery. The aim of cranioplasty is to reconstruct the cranial vault to ensure protection of the underlying brain parenchyma, re-establish cerebrospinal fluid dynamics and cerebral blood flow, and normalize intracranial pressure.[2] Furthermore, cranioplasty plays a significant role in restoring the aesthetic of the skull, thereby preventing the psychological implications associated with cranial vault defects.[2–8]

Cranioplasty can be performed using autologous or prosthetic bone substitutes. Autologous bone represents the ideal solution for cranioplasty, nevertheless the rate of complications (i.e., bone resorption) is high and the availability of autologous bone can can be limited due to underlying pathology (i.e., traumatic skull defects and infection).[7] When autologous bone is not available, prosthetic bone substitutes provide an alternative solution for cranial reconstruction. Despite the availability of different synthetic bone substitutes, none of them currently meet all the criteria required for an ideal implant.[9]

Among alloplastic materials, bioceramics such as porous hydroxyapatite (HA), are used as bone graft substitutes. The crystalline phase of HA is very similar to the trabecular structure of bone making HA a biocompatible material: HA porosity promotes osteoblasts homing, colonization, and proliferation, resulting in new bone formation and osteointegration.[10]

Several papers in the literature examine the surgical technique of HA cranioplasty using porous hydroxyapatite. The results are not homogeneous due to both the variability of the patients treated (in terms of age and underlying pathology) and the necessity for a more meticulous surgical technique when using HAP to achieve optimal results.

The aim of the present study is to offer an insight of a single institution, multidisciplinary experience with custom-made HA cranioplasty with surgical tips and tricks based on clinical experience and literature evidence. The implementation of neurosurgeons and plastic surgeons in the experience of the authors is essential to ensure good clinical results both in simple and more complex cranial reconstructive procedures. Furthermore, we present a series of cases in which this technique has been used, with the aim of providing additional illustrations of its applications and efficacy in a range of clinical contexts.

MATERIALS AND METHODS

Planning

Planning in HA cranioplasty involves 2 main steps.

Analysis of Bone Defect

A correct assessment of bone defect, whether resulting from a traumatic event, malformation or oncological resection, must include identification of the involved structures, functional deficits, and the quality of residual soft tissue coverage.

In the context of craniectomy planning particularly in the case of tumor resection, the use of neuronavigation software based on preoperative 3-dimensional (3D) images reconstruction [magnetic resonance imaging (MRI) and computed tomography (CT) scan] is a useful tool that helps anticipating the boundaries of bone resection. Custom-made HA prosthesis offer the advantage of an online-based plateform (Finceramica's CustumeBone) that allows the surgeon to design the prosthesis using a 3D digital model of the skull vault based on CT scan images.

Evaluation of Adjacent Tissues Potentially Suitable for Reconstruction

Local skin flaps represent the gold standard for surgical techniques used in head reconstruction due to the extensive clinical experience. The main limitation of local flaps is the prevalence of compromised tissues surrounding the cranioplasty area due to ischemia, infection or trauma. The alternative to local flaps for scalp reconstruction are distant pedicled or free flaps. Tissue expansion is an intermediate option between local flaps and free flaps, presenting better color and thickness matching than distant flaps.

Given the complexity and variability of cranial defects, the preoperative evaluation of potential reconstruction options should be thoroughly discussed with a qualified plastic surgeon to ensure a comprehensive multidisciplinary approach. This collaboration is essential to optimize surgical outcomes and select the most appropriate reconstructive technique (aggiungerei questa frase per sottolineare l'aspetto multisiciplinare).

On the basis of our experience, we present our algorithm for the choice of soft tissue reconstruction in cranioplasty, depending on the size of the skin defect, as follows.

Limited loss of substance (maximum diameter of 5 cm): direct suture after wide margin release and galea release incisions or local rotational flap.
Medium-sized losses of substance (maximum diameter of 10 cm): wide local rotational flaps multiple local rotational flap "Orticochea technique" or skin expansion (1–3 mo).
Large loss of substance (maximum diameter >10 cm): skin expansion (2–4 mo), distant pedicled flaps (e.g., Trapezius, Latissimus Dorsi) or microsurgical free flaps.

Infectious Profilaxis

The administration of antibiotic prophylaxis is an established evidence-based step for all patients undergoing cranioplasty. The surgeon should administer antibiotic prophylaxis before skin incision and repeat it at specific intervals according to the half-life of the selected antibiotic.[11] Although not supported by the literature evidence and in case of complex procedures, such as free-flap reconstructions. We propose extending the duration of antibiotic prophylaxis up to 3 days postoperatively with cefazolin 2 g/day orally.

Furthermore, all HA prostheses are immersed in a sterile antibiotic solution of 600 mg of Rifampicin (Rifocin, Lepetit Group) diluted in 100 ml of saline solution for 20 minutes prior its insertion and fixation. This method has been demonstrated to effectively reduce the risk of infection in our previous publication.[16]

Patient Positioning

We recommend the use of Mayfield's three-point fixation clamp to secure patient's head in the optimal surgical position (Fig. 1F). The use of Mayfield clamp purposes provides greater safety and precision during the surgery and it is essential to implement neuronavigation during the procedure.

In addition, we find it beneficial to have the plastic surgeon present during patient positioning to ensure that the position is appropriate for both the resective and reconstructive phases.

Incision

Although the majority of cranioplasty procedures are performed through a pre-existing skin incision, accurate planning of the skin access can significantly improve aesthetic and clinical outcomes. Multidisciplinary collaboration between neurosurgeons and plastic surgeons is essential in the presence of complex skin incisions such as non-linear or radial scars diastased margins or surgical wounds in particular anatomic areas (such as the frontal region). (Fig. 1E)

In some cases, trimming of the skin margins may be required to achieve better aesthetic results and other factors, such as blood supply and innervation must also be carefully considered. When possible, linear incisions are preferred and planned parallel to the neurovascular bundles. Linear incisions are less traumatic and provide better aesthetic results. In our experience, the horseshoe and inverted L incisions have shown the worst aesthetic outcomes.

In single-stage procedures with bone and skin resection and direct reconstruction, multidisciplinary collaboration is essential to define the optimal surgical incision design to maximize flap vascularization. (Fig. 1F)

Furthermore, lesions with extracranial extrinsic extension that cause outward expansion may have excess skin that needs to be partially removed. Conversely, in cases of skin retraction, tissue expansion may be achieved through the use of subgaleal fascia incisions with parallel cuts perpendicular to the direction of the required lengthening. In case of major skin flap retraction, adequate surgical planning may anticipate the placement of subcutaneous expanders.

If the previous scar is located over a crater away from the edges of the craniolacunia before drawing a larger flap, extending to the craniectomic margin, with the relevant risk of creating avascular areas, one should evaluate the possibility incising along the old scar and divaricating of the soft tissues to achieve exposure of the bony border. Only when faced with the real impossibility of doing so we suggest making a radial incision perpendicular to the external border of the previous scar.

Tissue Dissection

In case of demolition reconstruction, the procedure is not dissimilar to the usual in carrying out any neurosurgical approach. In contrast, dissection of previous surgical scar tissue is essential to maintain an intact dura and to avoid persistent cerebrospinal fluid (CSF) fistulas, which may lead to extradural or subgaleal CSF collection and failure of cranial reconstruction. In case of an accidental dura tear, watertight sutures are used to repair the defect. If the dura is torn, it must be repaired with 'watertight' sutures, as extradural or subgaleal

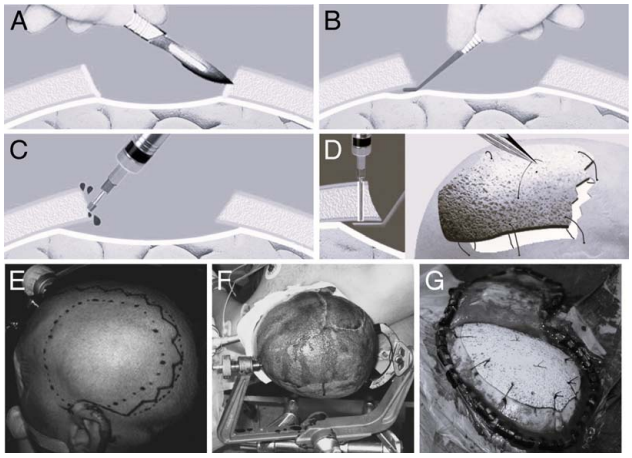

FIGURE 1. (A) Debriding of entire bone defect perimeter from fibrous tissue. (B) Blunt dissection of dural plane from bone edge to facilitate implant lodging. (C) Milling of bone edges by gentle drilling until bleeding trabecular bone is reached. (D) Holes for anchorage; preformed or drilled as needed with diamond tip. (E) Markings of surgical incision for ideal cranioplasty flap and dotted line for cranioplasty margins. (F) Demonstration of preferred patient positioning using Mayfield head clamp. (G) HA prosthesis anchored with polyester O-thread.

CSF leak may prevent or delay soft tissue adhesion to the underlying prosthesis. In case of large dura defects, the use of dural substitutes, such as Duraform (dura graft implant), is required to ensure watertight closure.

During subgaleal dissection, temporalis muscle dissection requires special care must be taken to elevate the temporalis muscle, which may be ischemic or atrophic in the pterional area and the goal should be to avoid further muscular insult. When the temporalis muscle is left attached to the dura and trapped between the prosthesis the bone margins, it may impede implant integration and cause pain during mastication.

Primary-bone Demolition

The use of a neuronavigation for one-step procedures with single-stage and reconstruction can be useful to define the craniectomy boundaries The neuronavigation system is used to define and draw the perimetral resection area. The craniectomy is performed slightly within the line identified by the neuronavigator.

Solid contact between the margin of HA prosthesis and bone is essential to facilitate osteointegration. Therefore, the use of neuronavigation may allow a slightly smaller bone operculum to be defined compared with the HA prosthesis to achieve compression between the prosthesis and the native bone margins. The use of neuronavigation with a precise definition of the cranial defect limits is important to avoid unnecessary prosthesis manipulation. to maintain the mechanical properties of the hydroxyapatite prosthesis

Preparation of Craniectomy Margins

The cranial defect margins must be completely freed from the overlying skin with adequate subdural dissection to avoid persisting lifting of the HA proesthesis with suboptimal allocation.

In addition, the bone usually presents with smooth and blunt edges with continuity between the inner and outer bone plateaux. Therefore, it is necessary to delicately mill them to favor the optimal exchange of biological elements between the bone and prosthesis (Fig. 1C).

Dural Suspensions

Central suspensions are recommended for of one-stage demolition reconstruction because the dura is largely dissected during craniotomy. Dural suspensions are usually not necessary in secondary cranioplasties because fibrotic adhesions at the margins prevent them from detaching.

Special mention must be made when dealing with large dural introflections due to a lack of underlying encephalic substances. In such cases, great care must be taken when lifting the central suspension. If the dura is pulled too far, parenchymal lacerations may occur in the case of the cortex adhering to the dura or the bridging veins may rupture, resulting in a subdural hematoma.

Prosthesis Fixation and Implant Anchorage

HA prosthesis are supplied with preformed anchorage holes. The surgeon during he design of the HA prosthesis defines the number and the location of the suture holes. If additional anchorage holes are required it is possible to drill additional holes in the HA prosthesis using a diamond bur at speeds between 7000 and 12,000 rpm under continuous irrigation (Fig. 1C).

The HA prosthesis will achieve complete osteointegration if there is close contact between the prosthesis margins and the rest of the theca. If this is not the case, the osteoblastic colonization process may be compromised.

To achieve solid contact between HA prosthesis and skull vault, only anchoring threads (e.g., polyester O-thread, braided, coated, and non-absorbable) should be used as recommended by the producer.[12]We recommend a "figure of 8" anchorage to achieve stable prosthesis fixation. As a final precaution, it is advisable o ensure that the suture knot is placed in the fixation hole to avoid potential palpable or even visible subcutaneous scalp lumps. (Fig. 1G)

Other fixation devices than suture threads are available for cranioplasty. Whereas titanium fixation implants (plates, screws, and clamps) have excessive rigidity that may result in HA prosthesis fracture, resorbable polyglycolic acid devices (plates and screws) have decreasing mechanical stability along with their biodegradation. Furthermore, their implantation is technically demanding with risk of intracranial migration in ~10% to 14% of cases and the risk of accidental dural tear.[13,14]

Clamp-like polyetheretherketone (PEEK) fixation devices, such has Cranial LOOP (produced by NEOS Surgery S.L., Barcelona, Spain), have excellent mechanical properties for flap fixation in cranioplasty and they have been shown to be safe and effective both in adult and pediatric patients when used with autologous and heterologous flaps[15] Clamplike PEEK devices could represent a valid alternative for HA prosthesis fixation as they deserve initial mechanical stability of the prosthesis (avoiding prosthesis displacement) together with complete biocompatibility (avoiding adverse reactions and cranioplasty failure). Cranial Loop also have the advantage to be radiolucent, thus reducing imaging artifacts and they are available in different sizes for pediatric and adult burr-holes defects (16, 22 mm diameter) as well as craniotomy lines (14 mm diameter).

Emphasis must be placed on pterional access; correct repositioning of the temporalis muscle is imperative, as is its tight anchorage. Otherwise, there is a risk of descent of the temporalis muscle and the occurrence of two concomitant events: significant aesthetic damage and impairment of the masticatory act. If necessary, pre-drilled holes in a fronto-temporo-parietal prosthesis can be arranged to form an arch between the lower and upper temporal lines.

Margin Polishing

If the HA prosthesis does not adequately fit the bone defect, the edges of the prosethesis can also be beveled with a diamond bur under continuous irrigation.

Despite subdural hemostasis may be achieved using hemostatic substances such as cellulose patches (Tabopatm) or thrombin-based products (Surgiflo). We suggest avoiding hemostasis of the bone margins with bone wax or any other substance on the prosthesis-bone interface, as it could prevent cell colonization of the HA operculum.

Drainage

The authors suggest the placement of subgaleal suction drain and in case of large tissue dissections, the placement of 2 closed-circuit suction drains is recommended. To reduce the risk of persistence CSF leaks, non-vacuum drains could be preferred in case of accidental dural tears during the surgical procedure.

Skin Suture

Resection of exuberant, atrophic, hypertrophic, or keloidal skin margins may be necessary in flap reopening, or to straighten them in traumatic wounds. When tissue expansion is performed, the skin flap must be optimally adapted to maintain optimal skin vascularization.

The authors suggest the use of monofilament suture threads sized from 2-0 to 6-0 according to skin thickness. Surgeons' preferences range from silk to polyamides. Classic layered sutures are generally used, but there are variations due to operator practice. It is essential that tissue layers are aligned on the same plane, without inward or outward folds. Sutures should be removed after 7 days in case of primary wounds and after 10 to 15 days in case of secondary wound closure

Bandage and Dressing

Wound margins may be covered with sterile gauzes and a bandage is placed around the surgical site. It's important to avoid compressive bandages as they can impede blood flow to the skin flap and also dislocate or damage the HA prosthesis. Wound dressing can be removed on day 2 leaving the wound open hair with regular clinical follow-up. The patient can undergo a shower with delicate soaps after dressing removal

Complications

Postoperative complications after HA cranioplasty include prosthesis infection and dislocation. If infected, the prosthesis must be removed, and debridement of soft tissue is required with a further reconstructive procedure after adequate antibiotic treatment. To reduce infection risk, we suggest the use of an antibiotic solution to soak the HA prosthesis before implantation in addition to antibiotic prophylaxis.[16] If prosthesis dislocation occurs, reoperation and prosthesis repositioning may be required depending on the degree of dislocation.

Epidural Blood Collection Ex Vacuo

Epidural hematomas are common in patients with large areas of brain necrosis. We recommend routine postoperative native CT scan. In case of asymptomatic, thin epidural collections, simple follow-up is sufficient. In case of large epidural collection with neurological compromise, surgical re-intervention is necessary for hematoma evacuation.

Subgaleal Hematoma

Subgaleal hematomas may develop postoperatively despite the use of surgical drains. In the majority of cases, these complications are asymptomatic and resolve spontaneously. In case of large subgaleal hematomas under tension, tissue perfusion may be compromised and sterile subtractive punctures may be required

Cerebrospinal Fluid Fistula

Persistent CSF leakage and pseudomeingocele (CSF collection between the skin flap and the prosthesis) may occur after cranioplasty with accidental dural tears. In the majority of cases, psedomeningoceles are self-resolving conditions. In case of large, persistent pseudomeningocele formation, it may be necessary to place either a subdural shunt or less frequently a ventriculoperitoneal shunt or lumbar CSF drainage if the main cause for the persistent leak is an underlying hydrocephalus.

Wound Complications

Wound complications are frequent after cranioplasty and can lead to implant exposure, extrusion, and infection, necessitating revision surgery and implant removal. To minimize the potential risks associated with the procedure, the plastic surgeon plays a crucial role in assisting the neurosurgeon by meticulously designing incisions and flaps in relation to the vascular territory. This collaborative approach is essential to ensure optimal vascularization and tissue healing, which in turn helps to prevent complications and enhance patient outcomes.

Patient Cohort and Data Collection

A total of 77 pediatric and adult patients who underwent hydroxyapatite cranioplasty after the surgical approach detailed in this study were included in the analysis. These procedures were performed between April 2003 and May 2018 at the single institution of Santa Maria della Misericordia Hospital in Udine. Data were collected on each patient's age, sex, and the initial pathology that led to cranioplasty. Additional data included the location of the craniotomy, duration of follow-up, occurrence of any adverse events and the need for prosthesis explantation. This comprehensive dataset was subjected to analysis to assess the safety and effectiveness of the surgical technique in question.

As this was an observational study of an established surgical practice, ethical approval was not required.

A comparison with the existing literature was performed to compare our results with previously reported results and to assess differences between different surgical techniques.

Data were collected and organized using Microsoft Excel, which was also used to create tables and graphs. Statistical analysis was performed using IBM SPSS Statistics, version 28.0.0.0 (190).

RESULTS

Between April 2003 and May 2018, a total of 77 patients underwent hydroxyapatite cranioplasty at the Santa Maria della Misericordia Hospital in Udine using the multidisciplinary approach detailed in this article. The study population comprised 30 female and 47 male patients, with a mean age of 44 years (median age of 40 y, ranging from 13 to 80 y). See supplemntal table 1, Supplemental Digital Content 1, http://links.lww.com/SCS/H21.

The primary indication for craniotomy was traumatic brain injury in 37 cases (47.4%), osseous tumors in 36 cases (46.2%), cerebral tumors in 3 cases (3.8%) and vascular causes in 1 case (1.3%). Of the presented cases, 13 were revision cranioplasties, performed due to the removal of autologous bone or other materials previously used for cranial reconstruction.

The most common approaches for decompressive craniotomy flaps in this study were parieto-temporal (20 cases, 25.6%)

and frontal (16 cases, 20.5%). Other approaches included fronto-parietal (6 cases, 7.7%), fronto-parieto-temporal (5 cases, 6.4%), temporal (5 cases, 6.4%) and fronto-temporal (4 cases, 5.1%). The bifrontal and crown approaches were used less frequently, with 3 cases each. These findings are consistent with standard neurosurgical approaches to decompressive craniotomy, where the choice of surgical corridor is determined by the location and extent of the underlying pathology, the degree of cerebral edema, and the need to achieve optimal decompression while preserving critical neurovascular structures.

Almost all patients were followed for at least 1 year, with 97% of the initial cohort completing the 12-month assessment. At the 3-year follow-up, 48% of patients were still in the study, whereas only 12% were still being followed at the 5-year mark. This gradual decline in the number of patients lost to follow-up highlights the challenges of maintaining long-term patient engagement in clinical trials.

A total of 77 patients underwent cranioplasty using the porous hydroxyapatite technique. Within this cohort, 6 adverse events were recorded, corresponding to a complication rate of 7.8%. The complications included two cases of tumor recurrence, two instances of cicatricial retraction, one early superficial infection, and one instance of prosthesis displacement. Of the aforementioned complications, 3 necessitated prosthesis explantation, resulting in an explantation rate of 3.9% (2 due to tumor recurrence, 1 due to cicatricial retraction). All adverse events were directly related to the surgical procedure. The average time to complication onset was 31 months, with a range of 0 to 106 months.

DISCUSSION

Cranioplasty using hydroxyapatite (HA) prostheses is a procedure that, although conceptually straightforward, can present several technical challenges for surgeons due to the intricate nature of the surgical technique. A review of the literature indicates that poor outcomes may occur in up to 8.7% of cases.[17–20] It is therefore essential to approach each case with the same level of care and precision, regardless of its apparent simplicity.[21].

As previously documented in the literature, hydroxyapatite possesses a number of advantages in comparison to alternative cranioplasty materials. The material is associated with the lowest risk of infection, is highly biocompatible, and by mimicking the mineral structure of human bone, it reduces foreign body reactions. Furthermore, it has been demonstrated to exhibit exceptional osteointegration capabilities[10,22–24] which may contribute to its favorable complication rates[10,24] Conversely, before bone integration, HA is brittle and susceptible to fracture and implant displacement, necessitating meticulous handling, as previously outlined.[25,26]

HA also displays hydrophilic properties, which, in conjunction with its porous structure and rough surface, are pivotal for biocompatibility and osteointegration. Recent studies indicate that these characteristics also play a role in preventing early bacterial adhesion and proliferation, thus reducing the risk of infection.[27,28]

Despite all these positive features of HA-based cranioplasty, achieving optimal results with this material requires a multidisciplinary approach. The integration of neurosurgeons and plastic surgeons can facilitate surgical planning, thereby enabling a more streamlined procedure and superior outcomes, both in terms of functionality and aesthetics.[29]

Measuring craniofacial cosmesis can be challenging and cosmetic results are rarely reported in the literature, probably because they are generally considered less important than the functional outcomes. However, it has been shown that without cranial reconstruction, patients may avoid inpatient/outpatient settings due to their appearance and lack of confidence, which can affect rehabilitation, self-esteem, and mental health.[12] The "Rostock Functional and Cosmetic Cranioplasty Score" was developed to evaluate objective factors like scar/skin, CP fit, symmetry, and function for cranioplasty cosmesis[30] but objective measures of cosmetic outcome are not widely utilized in clinical practice, and cosmetic results are often overlooked in studies regarding cranioplasty.[17]

In their study, Satapathy[31] and colleagues identified a number of factors that can contribute to unsatisfactory cosmetic results after cranioplasty.

Interestingly, they focused on implant materials, fixation, and indications for cranioplasty, whereas soft tissue envelope, incisions, flap design, and skin coverage in general were largely overlooked.

Scalp thinning is known to occur almost invariably after a cranioplasty with autogenous and alloplastic materials. This can cause wound complications such as dehiscence, implant extrusion, and infection.[32] Optimal soft tissue handling, and incision planning are essential to preserve vascularity and soft tissue trophism and ultimately protect the implant.

Wound complications after cranioplasty are rarely reported in the literature. Di Rienzo et al[33] highlighted the lack of knowledge on this topic and attempted to elucidate the etiology of flap lesions in cases of wound complications after cranioplasty. They observed that dehiscence occurred in many cases due to poor preoperative flap conditions (sinking and multiple surgeries), and flap necrosis was ascribed to inadvertent sacrifice of the residual arterial supply after flap reopening or, more rarely, venous congestion. They found a direct correlation between flap incisions and wound complications. They also argued that constant cooperation and case-by-case discussions with plastic surgeons led to the development of new strategies aimed at reducing the incidence of adverse events.[33]

In our study, which analyzed 77 patients undergoing hydroxyapatite cranioplasty using a multidisciplinary approach, we reported a complication rate of 7.8%, which is consistent with the complication rates reported in the literature. Our complication rate included cases of tumor recurrence, cicatricial retraction, early superficial infection, and prosthesis displacement, with an explantation rate of 3.9%.

These findings underscore the efficacy of our surgical technique and the value of a multidisciplinary approach in the management of cranioplasty procedures. The mean time to the onset of complications was 31 months, indicating that such complications can manifest long after the initial surgical procedure. This highlights the necessity for long-term follow-up and meticulous patient selection to minimize risks.

CONCLUSIONS

Cranioplasty using hydroxyapatite prostheses represents a valuable alternative for skull reconstruction with heterologous implants, offering several advantages over traditional techniques. These include a reduced incidence of infection and superior osteointegration, as evidenced by recent literature. The present study lends further support to these findings, demonstrating a low complication rate and positive outcomes associated with this technique. Our experience indicates that a multidisciplinary approach, which incorporates the unique expertise of plastic surgeons and neurosurgeons, streamlines

surgical planning, minimizes complications, and results in superior functional and aesthetic outcomes.

In light of these findings, it is recommended that a multidisciplinary team be considered for all complex cranial reconstructive procedures to optimize patient outcomes. Further studies should be conducted with the aim of investigating long-term outcomes and comparing different surgical techniques and materials. This will enable the building of on these initial findings and the refinement of best practices in cranioplasty.

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