ELSEVIER

*Technique*

# Bone Autografting of the Calvaria and Craniofacial Skeleton: Historical Background, Surgical Results in a Series of 15 Patients, and Review of the Literature

Marco Artico,* Luigi Ferrante,† Francesco Saverio Pastore,¶ Epimenio Orlando Ramundo,† Davide Cantarelli,* Domenico Scopelliti,§ and Giorgio Iannetti‡

**Department of Pharmacology of Natural Molecules and General Physiology, Section of Human Anatomy, †II University Medical School, Division of Neurosurgery, ‡Chair of Maxillo-Facial Surgery I University Medical School, University of Rome "La Sapienza", §ASL RME, Division of Maxillo-Facial Surgery, ¶Tor Vergata University Medical School, Division of Neurosurgery, Rome, Italy*

Artico M, Ferrante L, Pastore FS, Ramundo EO, Cantarelli D, Scopelliti D, Iannetti G. Bone autografting of the calvaria and craniofacial skeleton: historical background, surgical results in a series of 15 patients and review of the literature. Surg Neurol 2003;60:71–9.

**BACKGROUND**
Although the use of autologous bone for reconstruction of the cranial and facial skeleton underwent a partial reappraisal following the introduction of a vast range of alloplastic materials for this purpose, it has demonstrated definite advantages over the last century and, particularly, during the last decade.

**METHODS**
Fifteen patients underwent cranial and/or cranio-facial reconstruction using autologous bone grafting in the Department of Neurologic Sciences-Neurosurgery and the Division of Maxillo-Facial Surgery of the Rome "La Sapienza" University between 1987 and 1995. This group of patients consisted of 8 females and 7 males whose average age was 29.5 years (range 7.5 to 59 years, mean age 30). In all these patients cranioplasty and/or cranio-facial reconstruction had been performed to repair bone defects secondary to benign tumors or tumor-like lesions (12 cases), trauma (2 cases), or, in the remaining case, to wound infection after craniotomy for a neurosurgical operation.

**RESULTS**
The results obtained in a series of 15 patients treated using this method are described with reference to the abundant data published on this topic.

**CONCLUSION**
The mechanical, immunologic, and technical-grafting properties of autologous bone, together with its superior esthetic and psychological effects, probably make it the best material for cranioplasty. 

**KEY WORDS**
*Autologous bone, cranial bone grafts, cranioplasty, skull defect.*

Effective repair of bone defects of the skull and facial bones secondary to traumatic, inflammatory, neoplastic, or iatrogenic lesions has always represented a challenging problem for neurosurgeons and plastic surgeons. The evolution and experimentation of cranioplasty has been closely linked to the incidence of war injuries and road accidents as well as the rising number of neurosurgical operations, and knowledge of this topic has significantly improved during recent decades.

The main objectives of cranioplasty are to restore the normal barriers protecting the intracranial structures (together with a satisfactory cosmetic result) and obtain a permanent or very durable reconstruction using biologically inert materials. Actually, cranial reconstruction techniques go back to ancient times, even before the beginning of brain surgery. Archeological studies have shown that in prehistoric times some of the South Pacific populations used coconut shells to repair gaps in

Address reprint requests to: Prof. Marco Artico, University of Rome "La Sapienza," Department of Pharmacology of Natural, Molecules and General Physiology, P.le Aldo Moro 5, 00185 Rome, Italy.
Received July 10, 2002; accepted December 11, 2002.


360 Park Avenue South, New York, NY 10010–1710

0090-3019/03/$–see front matter
doi:10.1016/S0090-3019(03)00031-4

the skull, and that even prehistoric Peruvians performed a type of cranioplasty using gold plates [23,73]. In fact, the latter technique was reproposed by Falloppio [29] and later by Paré [59] in 1634, as well as by French surgeons during the First World War [27,70]. During the last century, in particular, there has been a marked increase in the use of alloplastic materials for cranioplasty [24] comprising a wide variety of materials [20,24,37,62–64,70]: celluloid, aluminum, gold, vitallium (an alloy of cobalt, chrome, and molibdene), tantalium, stainless steel, titanium, acrylic resins (particularly methylmethacrylate with good results), polyethylene, silicone elastomeres, and ceramics. Recently, an alloplastic material named BOP [52,71] (biocompatible orthopaedic polymer) consisting of a copolymer of N-vinyl-pyrrolidone and methylmethacrylate has been introduced.

However, alloplastic materials are not the best solution to this problem because they present various drawbacks and complications mainly related to the way the material responds to mechanical, thermal, and electrical stress; the need to be able to manipulate the material and adapt it to the individual bone defect; the need for absolute biologic inertia and atoxicity; possible facilitation of infectious complications; inflammatory scarring; or even neoproliferative reactions in the neighboring tissues.

The complications connected with the use of alloplastic materials in the past and especially more recently has prompted a reassessment of the role of autologous bone for reconstruction of the skull and facial bones.

The decline of heterologous and homologous bone grafts coincided with improved knowledge of immunologic processes (particularly histocompatibility) and the transmission of diseases, especially viruses, following transplant of organs or parts of cadavers. As a result of this, autologous bone that had been partially set aside in favor of new alloplastic materials was reinstated as the most suitable, safe, and natural material for cranial and craniofacial reconstruction.

Grafts of fresh autogenous bone for cranioplasty were also performed using the iliac crest [48,50,53,60,61,85], whole ribs [36,45], parts of rib [10,15,16,28,32,39,49,55,62,65,75], sternum, and scapula [13,14,51]. Pretreated, frozen autogenous bone was also successfully used [1,7,40,57,63,81].

Since the first decade of this century, the numerous advantages of autologous bone for cranioplasty (coupled with very few, quite unimportant drawbacks) have been emphasized by many workers in adults as well as in newborns and infants [72,75]. Its perfect histocompatibility and natural affinity, accompanied by good cosmetic results (whose psychological repercussions on the patient should not be underestimated) and excellent fusion of the vital autologous bone graft and bone tissue adjacent to the cranial and/or facial defect, persuaded us to re-evaluate the role of autologous bone for cranioplasty and reappraise our personal experience in the light of the most recent literature on this topic.

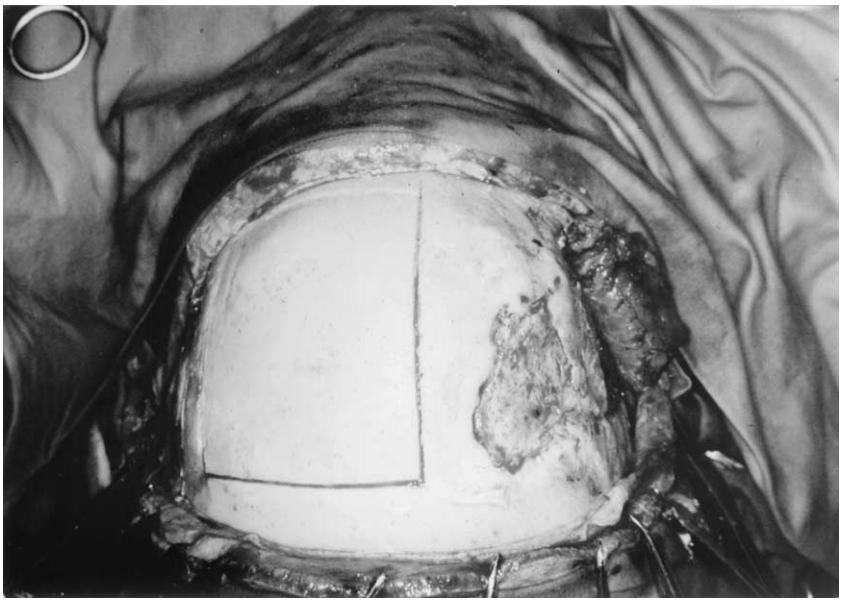
**1** Cranioplasty and/or Facial Reconstruction with Autologous Bone: Clinical Data in 15 Cases

| CASE # | AGE | SEX | PATHOLOGY |
|---|---|---|---|
| 1 | 11 | F | Fibrous dysplasia |
| 2 | 13 | F | Fibrous dysplasia |
| 3 | 52 | M | Zygomatic bone angioma |
| 4 | 41 | M | Osteoma |
| 5 | 18 | F | Skull osteomyelitis |
| 6 | 26 | M | Ossifying fibroma |
| 7 | 32 | M | Cranio-facial trauma |
| 8 | 50 | F | Fibrous dysplasia |
| 9 | 10 | F | Fibrous dysplasia |
| 10 | 30 | M | Cranio-facial trauma |
| 11 | 17 | M | Fibrous dysplasia |
| 12 | 59 | F | Recurrence of ACF mening. |
| 13 | 7.5 | F | Bony orbital angioma |
| 14 | 38 | F | Fibrous dysplasia |
| 15 | 37 | M | Fibrous dysplasia |

## Clinical Material and Method

Fifteen patients underwent cranial and/or craniofacial reconstruction using autologous bone grafting in the Department of Neurologic Sciences-Neurosurgery and the Division of Maxillo-Facial Surgery of the Rome "La Sapienza" University between 1987 and 1995. This group of patients consisted of 8 females and 7 males whose average age was 29.5 years (range 7.5 to 59 years, mean age 30). In all these patients cranioplasty and/or craniofacial reconstruction had been performed to repair bone defects secondary to benign tumors or tumor-like lesions (12 cases), trauma (2 cases) or, in the remaining case, wound infection after craniotomy for a neurosurgical operation.

Some relevant clinical data are presented in Table 1. The primary lesion was fibrous dysplasia (Figure 1 and 2) in 7 cases, trauma in 2, osseous angioma in 2 as well as ossifying fibroma, recurrence of anterior cranial fossa meningioma and osteomyelitis of the craniotomy flap in one case each. A follow-up evaluation of all patients (October 2001) confirmed good clinical and cosmetic results in all cases.



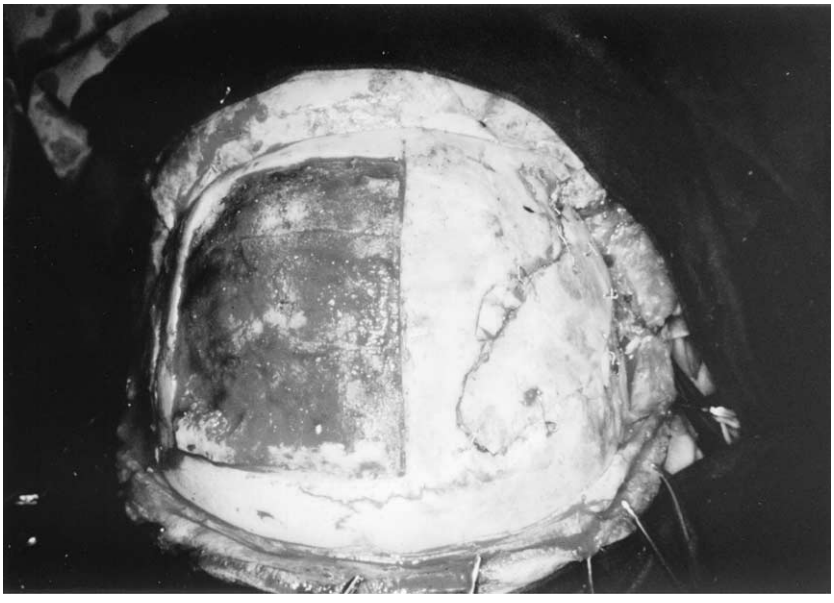
**1** Case 2. Intraoperative appearance of the lesion. It is possible to see the lesion (on the right) and the calvarial bone prepared for the reconstruction (on the left).

Apart from an accurate assessment of the amount of bone necessary, no particular preparations were necessary for removal of the bone graft that was carried out, taking care not to damage the graft itself. In recent years, removal of bone from various areas of the skull has become increasingly less common because it yields only fragments that are difficult to adapt to the final host site. This does not always guarantee a satisfactory outcome because the fragments have to be assembled or reshaped intraoperatively to perform the cranioplasty.

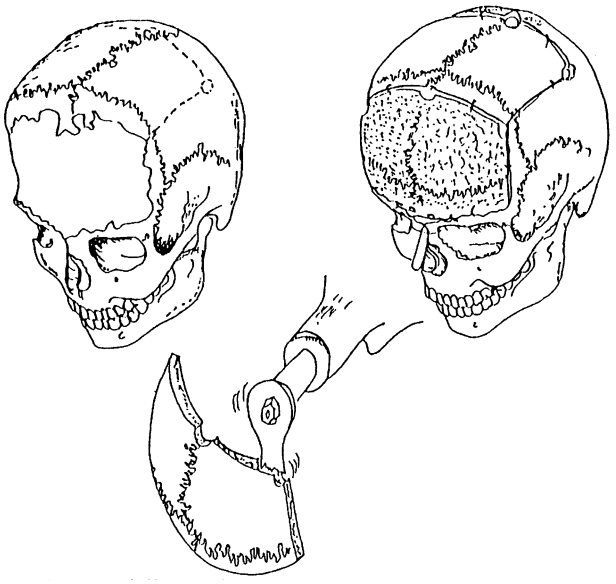
The best removal technique seems to be the one in which the graft is harvested from the internal surface of the skull [70]. Although this method is obviously the most suitable one for skull defects, it may not give such good results when the defect is cranio-facial because of the differences in morphology.

Other problems, which nowadays play a decidedly minor role, are preservation and sterilization of the autologous bone graft. In the past, these posed a serious problem because it was common practice to harvest the graft from donors or, at any rate, before performing reconstructive surgery.

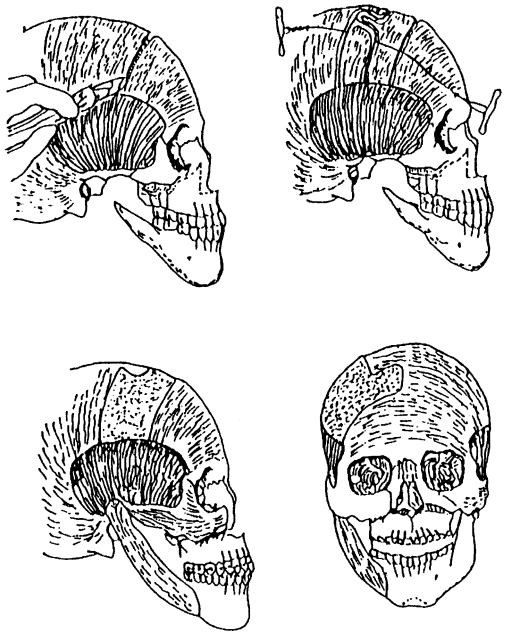
The skin incision generally preferred is the coronal one because it provides a wide exposure of the skull surface and may often proffer simultaneous visualization of the bony defect and the area iden-



**2** Case 2. Final appearance of the intraoperative view as it appears after the reconstruction by autologous bone has been made (on the left the internal surface of the skull after removal of the external surface; on the right the autologous bone replaced to reconstruct the area destroyed by the lesion).



**3** Full-thickness craniotomy followed by separation of the internal and external surfaces by intradiploic route using a pneumatic saw according to Psillakis et al (1979) [66].



**4** Parietal osteoperiosteal flap (cutting laterally to the parasagittal line with a pneumatic saw and then inserting a pediatric Gigli saw along this cutting line for the separation of the two surfaces by intradiploic route) according to Psillakis et al (1986) [67].

tified for harvest of the graft [70]. The external surface of the skull is then exposed by subgaleal dissection. Subsequently, the outlines of the cranial defect are traced onto a sheet of transparent plastic and then transferred onto the surface of the skull chosen as a harvest area. The next step is resection of the graft for which several different techniques can be employed. In 1969, Santoni-Rugiu [70] proposed making a series of small contiguous holes in the external skull surface using a small drill, following the outline of the graft to be harvested, and then removing the graft using scalpels, subsequently attaching it to the skull using 2 or 3 stitches of chromic catgut. Psillakis et al [66] performed a full-thickness craniotomy in a parietal region followed by separation of the internal and external surfaces by intradiploic route using a pneumatic saw, repositioning the two bone planes obtained in the donor area and in the bony gap respectively (Figure 3), and anchoring the two bone fragments to the adjacent bone with metal wires. In 1986, the same team of workers headed by Psillakis [18,67] suggested fashioning a parietal osteoperiosteal flap, cutting laterally to the parasagittal line with a pneumatic saw, and then inserting a pediatric Gigli saw along this cutting line (Figure 4). In this way it is possible to separate the external and internal tables, sawing through the diploe to obtain a flap, which is pedicled at the level of the fascia innominata and temporal aponeurosis [76,77]; this is extremely useful and functional for reconstruction of the homolateral zygomatic and mandibular bones. The latter method is the one we used in our study, and a reappraisal of it has been recently reported [35,43].

Multiple bone grafts taken from sites other than the calvarium present not only a technical pitfall related to the difficulties involved in joining the fragments together but also an important cosmetic drawback, namely that the final result may present a rough or undulated surface that the patient may find unsatisfactory or even unacceptable [84].

## Results

Our experience confirmed the positive characteristics of the method used for cranioplasty. In fact, our group of patients was fairly heterogenous for age, nature and extent of the primary pathology, as well as for timing of reconstructive surgery. The ages of our patients ranged from I to IV decades and the series included subjects with different levels of bone production and different biologic features. The primary pathology mainly consisted of lesions susceptible to noncomplex surgical treatment with a varying degree of cranial and/or cranio-facial involvement, ranging from small benign bone tumors to the extensive, complex involvement of parts of the skull base and orbito-maxillary region that characterized fibrous dysplasia in some of our cases.

The steps of reconstruction were not always the same for several reasons: In some cases it was possible to perform cranioplasty at the same time as surgical removal of the primary lesion while in others, whose conditions contraindicated this procedure (e.g., severe traumatic damage with edema and/or loss of materia, risk of infection), reconstruction had to be postponed.

The above-mentioned aspects, associated with the absence of complications and mortality and morbidity rates similar to those of cranioplasty using autologous bone, should not be interpreted as a limitation to the results obtained but as confirmation of the reliability and versatility of this method. In our series, in fact, there were no significant complications connected with use of autologous bone and neither were there any infections. Cosmetic-reconstructive outcome was good in 5 cases and excellent in the other 7, with an average follow-up of 17 months (range 6 to 42 months) in the 11 cases where it was possible. Only one case presented a complication not related to the use of autologous bone, consisting of unsatisfactory restoration of dural continuity in the right anterior cranial fossa followed by hypertensive pneumocephalus. This required a second operation to obliterate the communication between the nasal fossae and the intracranial compartment.

No particular technical difficulties related to graft reimplantation were encountered in our series, probably because the bone graft used was almost always harvested from the external calvarium (11 cases out of 12), usually in a single piece, simplifying fixation to the patient's skull with metal thread or silk sutures. Outcome was good, even in those cases where an articulated procedure was mandatory because of the complexity of the segment to reconstruct, which required several fragments joined together. For this purpose, metal microplates and microscrews were used to attach the fragments solidly and in a stable manner both to one another and to the skull.

In some cases, human fibrin glue was also helpful because it favored a better, faster stabilization of the graft by acting as a biologic adhesive holding the fragments together. In our experience, the technique that employs the external table, separating it from the internal one by intradiploic route, was extremely useful for the following reasons. First, it made harvesting of the graft quicker and easier; second, the dura below the donor area was not deprived of its natural protection even for an instant (contrary to the technique that employs full-thickness bone); last, in comparison to the full-thickness technique, use of the external table alone eliminates the need to repair both defects. This makes the procedure quicker and simpler and ensures greater stability of the graft itself.

The 5 cases of fibrous dysplasia in our series were successfully treated, achieving good reconstruction of the structures involved even though the disease was fairly extensive and required a complex operation to remove the lesions. In our cases of fibrous dysplasia (Figure 1 and 2) the bone involved was carefully eliminated and we were able to use "normal," not involved bone, for reconstruction in all cases.

## Discussion

The first attempt to use bone for cranial reconstruction was made as far back as 1670 by Van Meekren [4,82], who repaired a cranial bone defect in a Russian soldier using bone from a dog. As the patient was excommunicated as a result of this procedure, Van Meekren removed the graft 2 years later so that the patient could return to his church. In 1821, Von Walther [83] performed the first autologous bone graft, and in 1867 Ollier [58] emphasized the role of periosteum in bone regeneration. Further numerous attempts were performed to reconstruct the skull by treated or fresh bone grafts [19,47,62,63]. The studies performed by Mueller [54] and Koenig [38] made a very important contribution to improving techniques for cranial reconstruction using autologous bone; each of these authors separately proposed using the external cranial table together with a flap of overlying periosteum [29,43,50]. This method, reproposed by Backdahl in 1966 [9], is still one of the best and functionally most satisfying techniques for cranial reconstruction. The first osteo-periosteal autotransplant of fresh skull (bone) was performed by Bunge in 1903; subsequently, Sicard, Dambrin and Roger, between 1917 and 1919, used cadaver skull for cranioplasty while Babcock (1917) used heterologous bone grafts from sheep and cows [62,85].

The main causes of defects of the cranial and facial bones are traumas; penetrating head injuries, particularly in the armed forces; and infected, depressed, or open fractures in civilians.

Other prominent causes are surgical bone demolition for tumors (osteomas, meningiomas, hemangiomas, eosinophylic granulomas, epidermoids, metastases, fibrous dysplasia, chondromas, sarcomas, aneurysmatic bone cysts); for infections (osteomyelitis, infected cranial flaps); for radionecrosis and electrical lesions of the skull; and for congenital cranial and cranio-facial anomalies (en-

cephaloceles, congenital parietal defects). It is commonly accepted that the fundamental indications for cranioplasty are bone defects larger than 2 cm situated on the cerebral convexity and bone defects of the glabrous frontal region. Defects below the temporal and occipital muscles and those in very elderly patients are not usually considered to require repair.

The two main arguments supporting reconstruction are the need to protect the brain and soft cranial and/or facial tissues and esthetic requirements. While the latter are easy to comprehend and almost universally accepted, the former (in particular the prophylactic value of cranioplasty for prevention of seizures) are still a matter of debate [26,33,73,74]. Moreover, in children less than 6 years of age in whom the dura is not damaged, regeneration of a portion of the skull may be observed. Thus, it is necessary to wait at least a year after craniectomy in a child before deciding whether reconstruction is necessary.

From a practical point of view, the timing of reconstructive surgery is essential. It is generally agreed that the interval between complex wounds and cranioplasty should be between 3 and 6 months and as long as a year when there is a wound infection. In this context, one should recall the experience, published in 1979, of Rish and coworkers [69], who reviewed 491 cranioplasties and concluded that it was necessary to wait at least a year after penetrating or complex head injuries to ensure a good outcome.

There is almost unanimous agreement that autogenous calvarium possesses far better characteristics and quality than the most widely used alloplastic materials currently available. Calvarial autograft is the most "natural" material of all because not only does it possess all the ideal qualities for cranioplasty but it is also vital and has excellent biologic properties: It has a good growth potential and resistance to infections; it is radiotransparent; sterilizable; stable; a poor thermal conductor; resistant to ionization and corrosion; inert (atoxic, nonantigenic, noncancerogenous); malleable and easy to model; inexpensive; guarantees good cosmetic and biomechanical outcome; and is readily available. Obviously, as there is no type of metal, acrylic resin, or other type of alloplastic material that fulfills this wide range of requisites, it is much simpler, less expensive, [34] and safer for the patient to use autologous bone whenever possible. There can be no doubt that fresh autologous bone is the most suitable material for reconstruction of cranial defects in view of its perfect histocompatibility, optimal mechanical properties, and good anatomofunctional fusion of the graft with the adjacent bone, as well as the possibility of partial or total revitalization of the graft itself. Autologous bone also ensures the best possible physiologic and cosmetic results (in theory at least). In fact, autologous bone grafts usually display bone regeneration processes, do not have a *foreign body* reaction, and present a low incidence of infections [2]. Satisfactory cranial grafting relies on careful harvesting, preservation, eventual sterilization, and reimplantation of the autologous bone graft. For this purpose, a variety of methods for preservation and/or sterilization have been tried and tested such as boiling, freeze-drying, merthiolate, autoclave, irradiation with radioactive cobalt, decalcification, sublimation, treatment with gamma rays, and many others [17,46,80]. Live tissue is biologically active and fuses quickly with the adjacent bone, giving excellent results. The last statement is confirmed by experimental and clinical findings: there is, in fact, histologic and radiologic evidence of intense revascularization in the bone graft followed by perivascular formation of new bone and appositional substitution with bone remodeling [22,41,42]. In fact, as early as 1907, Axhausen [8] carried out the first study and described in detail the histologic aspects of the reparative phenomenon. The latter consists of vascular invasion along pre-existing channels followed by dynamic resorption and remodeling processes with formation of new bone by apposition: "Schleichender Ersaetz" or "Creeping substitution," a term first used by Barth and Marchand [65].

The osteoinductive processes are in fact mediated by a low molecular-weight glicoprotein called BMP (bone morphogenetic protein) by English-speaking authors [3,6,24,79]. Together with bone growth factors, this protein plays a crucial role in the mechanisms of bone trophism and is, unfortunately, destroyed by many preservation techniques [3,12,68]. Recently, some interesting perspectives in the use of osteoinductive biomaterials have been reported [5].

Lastly, the undebatable superiority of fresh autologous bone is linked to its fresh, vital cell content as well as the presence of whole periosteum, endosteum, and bone marrow. The studies performed by Prolo and coworkers [63,64] also confirm the overall superiority of fresh autologous bone in comparison to other materials.

To conclude this brief review of operative technique, the report by Elisevich et al deserves to be mentioned [25]: It describes a useful technical innovation consisting of a simulation of reparative surgery using reconstructed 3-D computerized im-

ages of the skull. This method makes it possible to simulate rotation and translation of the selected bone fragment onto the defect using images of the individual patient's skull, thus facilitating surgical planning by reproducing the characteristics of the graft and implantation sites and obtaining a preview of the final morphologic outcome.

One indispensable condition for good outcome of cranioplasty with autologous bone seems to be careful removal of the primary lesion so that the apparently healthy bone is exposed. Not only does this ensure better preparation of the site to be repaired but may also avoid the graft being affected by residues of the primary pathology or failing to fuse with the adjacent bone.

The presence of inflammatory alterations at the site of reimplantation represent a contraindication [21]. In fact, the good outcome of bone grafting depends on the formation of bone bridges across the gap between the reimplanted fragment and adjacent skull. During this process, resorption of the graft and formation of new bone occur simultaneously, also as an effect of a substance that induces bone formation [44,78] that is liberated during resorption of the graft and stimulates new bone growth in the host. This also occurs because while the channels of Havers of the inorganic matrix of the graft are reabsorbed and act as a guide and support for osteocytic growth in the host [30,44], the organic matrix is reabsorbed [11]. However, in our experience, this contraindication may be successfully treated. In fact, the efficacy of autologous bone cranioplasty remains relevant even in cases of osteomyelitis, keeping in mind that removal of the infected bone should be complete: one of the cases of our series had a good result after total removal of osteomyelitic bone (until "normal" bone had been exposed). This observation may be considered innovative in the use of this technique because until now the presence of osteomyelitis has been considered an absolute contraindication for the choice of autologous bone cranioplasty. Another important aspect for successful cranioplasty is to ensure that the graft fits the defect closely to allow faster fixation and fusion [56].

The final functional and cosmetic outcome is far better because autologous bone, contrary to alloplastic material that is in any case a foreign body, fuses perfectly and is transformed into new, vital tissue and remodeled accordingly.

Future applications will include antibiotic-impregnated implants and computer-generated models to improve the precision of cranioplasty fit and cosmesis [31].

## REFERENCES

1. Abbott KH. Use of frozen cranial bone flaps for autogenous and homologous grafts in cranioplasty and spinal interbody fusion. J Neurosurg 1953;10:380–8.
2. Açikgoz B, Ozcan OE, Erbengi A, Bertan V, Ruacan S, Gokhan Açikgoz H. Histopathologic and microdensitometric analysis of craniotomy bone flaps preserved between abdominal fat and muscle. Surg Neurol 1986; 26:557–61.
3. Amstutz HC, Johnson EE, Finerman GAM, et al. New advances in bone research. Interdepartmental conference. University of California, Los Angeles (Specialty Conference). West J Med 1984;141:71–87.
4. Arden RL, Burgio DL. Bone autografting of the craniofacial skeleton: clinical and biological considerations. Am J Otolaryngol 1992;13:328–41.
5. Arnaud E. Advances in cranioplasty with osteoinductive biomaterials: summary of experimental studies and clinical prospects. Child Nerv Syst 2000;16:659–68.
6. Arnaud E, De Pollak C, Meunier A, Sedel L, Damien C, Petiter H. Osteogenesis with coral is increased by BMP and BMC in a rat cranioplasty. Biomaterials 2000;20:1909–18.
7. Asano Y, Ryuke Y, Hasuo M, Simosawa S. Cranioplasty using criopreserved autogenous bone. No to Shinkey 1993;45:1145–50.
8. Axhausen G. Histologische Untersuchungen ueber Knochentransplantation am Menschen. Deutsche Zeitschr f Chir 1907;91:388–428.
9. Backdahl EO, Eriksson G. X Meeting della Società Scandinava di Chirurgia Plastica. Stockholm, 1966.
10. Ballin M. A method of cranioplasty. Surg Gynecol Obstet 1921;33:79–83.
11. Baschkirzew NJ, Petrow NN. Beitrage zur freien Knochenubupflanzung. Dtsch Z Chir 1912;113:490.
12. Bassett CAL. Clinical implications of cell function in bone grafting. Clin Orthop 1972;87:49–59.
13. Beumer J III, Firtell DN, Curtis TA. Current concepts in cranioplasty. J Prosthet Dent 1979;42:67–77.
14. Blair GAS, Gordon DS, Simpson DA. Cranioplasty in children. Child's Brain 1980;6:82–91.
15. Brown RC. The repair of skull defects. Med J Aust 1917;2:409.
16. Brown RC. Cranioplasty by split-rib method. J Coll Surg Aust 1928;1:238.
17. Cantore G, De Felip G. Su un nuovo metodo di depurazione, sterilizzazione e conservazione del tessuto osseo. Lav Neuropsichiatr 1971;49:2–3.
18. Casanova R, Cavalcante D, Grotting JC, Vasconez LO, Psillakis JM. Anatomical basis for vascularized outer-table calvarial bone flaps. Plast Reconstr Surg 1986; 78:300–8.
19. Chase SW, Herndon CH. The fate of autogenous and homogenous bone grafts. A historical review. J Bone Joint Surg (Am) 1955;37A:809–41.
20. Choi SH, Levy ML, Mc Comb JG. A method of cranioplasty using coralline hydroxyapatite. Pediatr Neurosurg 1998;29:324–7.
21. Crotti FM, Mangiagalli EP. Cranial defects repair by replacing bone flaps. J Neurosurg Sci 1979;23:289–94.
22. Cutting CB, McCarthy JG, Berenstein A. Blood supply of the upper craniofacial skeleton: the search for composite calvarial bone flaps. Plast Reconstr Surg 1984;74:603–10.

23. Durand JL, Reiner D, Marchac D. The history of cranioplasty. Ann Chir Plast Esthet 1997;42:75–83.
24. Edwards MSB, Ousterhout DK. Autogeneic skull bone grafts to reconstruct large or complex skull defects in children and adolescents. Neurosurgery 1987;20:273–80.
25. Elisevich K, Bite U. En bloc forehead reconstruction with split-thickness cranial bone. Surg Neurol 1991; 35:384–8.
26. Erculei F, Walker AE. Post-traumatic epilepsy and early cranioplasty. J Neurosurg 1963;20:1085–9.
27. Estor E. Cent cas de prothése cranienne par plaque d'or. Bull et Mém Soc de Chir de Paris 1917;48:463.
28. Fagarasano J. Procede de cranioplastie par des greffons costaux reboubles: procede due "grillage protecteur." Technique Chir 1937;29:57.
29. Falloppio G (quoted by Longacre JJ). Deformities of the forehead, scalp and cranium. In: Converse JM (ed.) Reconstructive & Plastic Surgery. Philadelphia: WB Saunders Co., 1964:564-97.
30. Firschein HE, Marshall R, Urist MR. Enzyme induction, accumulation of collagen and calcification in implants of bone matrix. Clin Orthop 1972;84:263–75.
31. Gladstone HB, Mc Dermott MW, Cooke DD. Implants for cranioplasty. Otolaryngol Clin North Am 1995;28: 381–400.
32. Grant FC, Norcross NC. Repair of cranial defects by cranioplasty. Ann Surg 1939;110:488–512.
33. Grantham EG, Landis HP. Cranioplasty and the posttraumatic syndrome. J Neurosurg 1948;5:19–22.
34. Hayward RD. Cranioplasty: don't forget the patient's own bone is cheaper than titanium. Br J Neurosurg 1999;13:490–1.
35. Inoue A, Satoh S, Sekiguchi K, Ibuchi Y, Katoh S, Ota K, Fujimori S. Cranioplasty with split-thickness calvarial bone. Neurol Med Chir (Tokyo) 1995;35:804–7.
36. Kappis A. Zur Deckung von Schaedeldefekten. Zentralbl Chir 1915;42:897–8.
37. Kobayashi S, Hara H, Okudera H, Takemae T, Sugita K. Usefulness of ceramic implants in neurosurgery. Neurosurgery 1987;21:751–5.
38. König F. Über die Implantation von Elfenbein zum Ersatz von Knochen und Gelenkenden. Nach experimentellen und klinischen Beobachtungen. Beitr z Klin Chir 1913;85:91–114.
39. Korlof B, Nylen B, Rietz K. Bone grafting of skull defects. Plast Reconstr Surg 1973;52:378.
40. Kreuz FP, Hyatt GW, Turner TC, Bassett AL. The preservation and clinical use of freeze-dried bone. J Bone Joint Surg (Am) 1951;33A:863–72.
41. Kusiak JF, Zins JE, Whitaker LA. The early revascularization of membranous bone. Plast Reconstr Surg 1985;76:510–4.
42. Langer K. Ueber die Blutgefasse der Knochen des Schadeldaches und der harten Hirnhaut. Denkschr Akad Wiss 1877;37:217.
43. Lee C, Antonyshyn OM, Forrest CR. Cranioplasty: indications, technique, and early results of autogenous split skull cranial vault reconstruction. J Maxillofac Surg 1995;23:133–42.
44. Linden GJ. Bone induction in implants of decalcified bone and dentine. J Anat 1975;119:359–67.
45. Longacre JJ, de Stefano GA. Reconstruction of extensive defects of the skull with split rib grafts. Plast Reconstr Surg 1957;19:186.
46. Maatz R, Bauermeister A. A method of bone maceration. Results in animal experiments. J Bone Joint Surg 1957;39A:153–62.
47. Macewen W. The Growth of Bone. Observations on Osteogenesis. Glasgow, Scotland: Maclehose & Sons, 1912.
48. Macomber DW. Cancellous iliac bone in depression of forehead, nose and chin. Plast Reconstr Surg 1949;4: 157.
49. Marchac D. Radical forehead remodeling for craniostenosis. Plast Reconstr Surg 1978;61:823–35.
50. Mauclaire H. Breche cranienne restauree par la prosthese metallique. Bull Mem Soc Chir Paris 1908;34: 232.
51. McCarthy JG, Zide BM. The spectrum of calvarial bone grafting: introduction of the vascularized calvarial bone flap. Plast Reconstr Surg 1984;74:10–7.
52. Merendino J, Sertl G, Skondia V. Use of biocompatible orthopaedic polymer (BOP) for fracture treatment and reconstructive orthopaedic procedures. J Int Med Res 1984;12:351–5.
53. Mowlen R. Cancellous chip bone grafts. Report on 75 cases. Lancet 1944;2:746.
54. Mueller W. Zur Frage der temporaren Schadelresektion an Stelle der Trepanation. Zentralbl f Chir 1890; 17:65.
55. Munro IR, Guyuron B. Split-rib cranioplasty. Ann Plast Surg 1981;7:341–6.
56. Nikoshin LI. Compression method of experimental plastic closure of osteal defects in the vault of the skull. Vopr Nejrokhir 1974;6:40–3.
57. Odom GY, Woodhall B, Wrenn FR. The use of refrigerated autogenous bone flaps for cranioplasty. J Neurosurg 1952;9:606–10.
58. Ollier L. Traité experimental et clinique de la regeneration des os et de la production artificielle du tissu osseoux. Paris, France: Masson, 1867:461.
59. Paré A. Of wounds made by gunshot, other fierie engines and all sorts of weapons. In: Works of that famous surgeon Ambrose Parey. London, 1634.
60. Phemister DB. The fate of transplanted bone and regeneration of its various constituents. Surg Gynecol Obstet 1914;19:303.
61. Pickerill P. New method of osteoplastic restoration of the skull. Med J Aust 1931;2:228.
62. Prolo DJ. Difetti cranici e cranioplastica. In: Wilkins RH II, Rengachary SS, eds. Trattato di Neurochirurgia, Chap. 204. Palermo: Medical Books, 1987.
63. Prolo DJ, Oklund SA. Composite autogeneic human cranioplasty. Frozen skull supplemented with fresh iliac corticocancellous bone. Neurosurgery 1984;15: 846–851.
64. Prolo DJ, Burres KP, McLaughlin WT, Christensen AH. Autogenous skull cranioplasty: fresh and preserved (frozen), with consideration of the cellular response. Neurosurgery 1979;4:18–29.
65. Prolo DJ, Rodrigo JJ. Contemporary bone graft physiology and surgery. Clin Orthop 1985;200:322–42.
66. Psillakis JM, Nocchi VLB, Zanini SA. Repair of large defect of frontal bone with free graft of outer table parietal bones. Plast Reconstr Surg 1979;64:827–30.
67. Psillakis JM, Grotting JC, Casanova R, Cavalcante D, Vasconez LO. Vascularized outer-table calvarial bone flaps. Plast Reconstr Surg 1986;78:309–17.

68. Raisz LG, Kream BE. Regulation of bone formation. N Engl J Med 1983;309:83–9.
69. Rish BL, Dillon JD, Meirowsky AM, et al. Cranioplasty: a review of 1030 cases of penetrating head injury. Neurosurgery 1979;4:381–5.
70. Santoni-Rugiu P. Repair of skull defects by outer table osteoperiosteal free grafts. Plast Reconstr Surg 1969; 43:157–61.
71. Skondia V, Davydov AB, Belykh SI, Heusghem C. Chemical and physico-mechanical aspects of Biocompatible Orthopaedic Polymer (BOP) in bone surgery. J Int Med Res 1987;15:293–302.
72. Steinbok P. Repair of a congenital cranial defect in a newborn with autologous calvarial bone. Childs Nerv Syst 2000;16:659–68.
73. Stula D, Mueller HR. Schadeldachplastic nach grossen dekompressiven Kraniotomien mit Massenverschieburg. CT analyse. Neurochirurgia (Stuttg) 1980; 23:41–6.
74. Tabaddor K, La Morgese J. Complication of a large cranial defect: case report. J Neurosurg 1976;44: 506–8.
75. Taggard DA, Menezes AH. Successful use of rib grafts for cranioplasty in children. Pediatr Neurosurg 2001; 34:149–55.
76. Testut L, Jacob O. Anatomia Topografica, Volume 1, 8th ed., Barcellona: Salvat Editores, S. A., 1967:232–40.
77. Testut L, Jacob O. Traité d'Anatomie Topographique, Avec Applications Medico-Chirurgicales. Tome Première. Deuxience Edition. Paris: Octave Doin et fils Editeurs, 1909:36–51.
78. Urist MR. The bone induction principle. Clin Orthop 1967;53:243–83.
79. Urist MR, DeLange RJ, Finerman GAM. Bone cell differentiation and growth factors. Science 1983;220: 680–6.
80. Vanaclocha V, Saiz-Sapena N, Garcia-Casasola C, De Alava E. Cranioplasty with autogenous autoclaved calvarial bone flap in the cases of tumoral invasion. Acta Neurochir (Wien) 1997;139:970–6.
81. Vanaclocha V, Bazan A, Saiz-Sapena N, Paloma V, Idoate M. Use of frozen cranial vault bone allografts in the repair of extensive cranial bone defects. Acta Neurochir (Wien) 2000;139:653–60.
82. Van Meekren J. Observationes medico-chirurgicales. Amsterdam: Henrici, T. Bloom, 1682:392.
83. Von Walther P. Wiedereinheilung der bei Trepanation ausgebohrten Knochenscheibe. J Chir U Augenh 1821; 2:571–83.
84. Weber RS, Kearns DB, Smith RJH. Split calvarium cranioplasty. Arch Otolaryngol Head Neck Surg 1987; 113:84–9.
85. Woolf JI, Walker AE. Cranioplasty: collective review. Int Abst Surg 1945;81:1–23.