Madreporic coral: a new bone graft substitute for cranial surgery

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Since 1985, the authors have been using madreporic coral fragments (genera Porites) as a bone graft substitute. Of the 167 coral grafts implanted, 150 were coral "corks" used to obliterate burr holes (diameter 10 mm), five were large implants (length 20 to 40 mm) to repair skull defects, and 12 were coral blocks to reconstruct the floor of the anterior cranial fossa. Previous experimental studies suggested that coral grafts would be well tolerated and become partially reossified as the calcific skeleton was resorbed. The authors describe their experience and detail the main biological properties of these materials, which appear to be very promising for use in cranial reconstructive surgery.

KEY WORDS • madreporic coral • cranioplasty • bone graft substitute

Cranial reconstructive surgery often requires bone implants. Currently, cranial reconstruction is performed with autogenous bone taken from the ribs or iliac crests, or from the inner table of the bone flap itself. Harvest of an autologous graft prolongs the surgical procedure and often requires a second incision. In some instances the thoracic or more often the iliac scar remains painful for a considerable time. In order to shorten the surgical procedure and to avoid painful scars, we have been searching for an efficient bone substitute. Substitutes for autologous bone must have the capability of being at least partly reossified. Madreporic coral grafts appeared to be a satisfactory material. The aims of this paper are to describe the biological properties of corals that can be used as bone substitutes, and to present a 3-year clinical experience with madreporic coral used for cranial reconstruction.

Materials and Methods

In selecting graft material, it was decided to utilize coral belonging to the Madrepora group, genus Porites, based on results from histological studies and animal experiments performed by Guillemin, et al. The skeletons of these corals are composed of 99% calcium carbonate in the form of aragonite (the high-pressure form of calcite) and 1% amino acids. The pores intercommunicate completely, both laterally and longitudinally, through small tubules, the diameter of which measures approximately 230 μ. The coral is prepared by ultrasonic treatment which preserves its structural integrity. It can then be cut, shaped, and sized to different dimensions and forms.

This coral is available in several dimensions.* These include: 1) precut cone-shaped "corks" (larger diameter 11 mm, smaller diameter 9 mm) which can be used to fill burr holes 10 mm in diameter; and 2) precut rectangular blocks that can be used for larger bone defects either on the convexity of the skull or on the cranial base. These madreporic blocks are made in the following dimensions: 10 × 15 × 20 mm and 10 × 20 × 30, 40, 50 or 60 mm. They can be easily reshaped with a grinding wheel or bone forceps during the operation. Preoperatively, they are sterilized in an autoclave at 130°C for 60 minutes.

Our initial clinical experience consisted of 42 patients, in whom coral corks were placed into burr holes after the bone flap had been replaced and fixed by transosseous sutures. Between one and three corks were placed in each patient, for a total of 100 corks implanted from January, 1985, to March, 1986. The pre-

* Biocoral manufactured by Inoteb Cy, Saint-Gonnery, Noyal Pontivy, France.
Madreporic coral for cranioplasty

FIG. 1. Postoperative tomograms, immediately (left), 3 months (center), and 8 months after placement of a coral block in a patient with posttraumatic rhinorrhea. Arrow indicates the coral block.

FIG. 2. X-ray films, immediately (left) and 8 months after placement of coral block and burr-hole “corks” (arrows), showing partial resorption of the graft material.

Preliminary results were encouraging and the use of the material was broadened. From April, 1986, to June, 1987, an additional 22 patients underwent placement of Porites coral fragment grafts. Fifty burr holes were filled with corks. Five coral implants (length 20 to 40 mm, diameter 5 to 11 mm) were used to repair traumatic or surgical defects in the skull. For this, the implants were precisely shaped to fit the defect and fixed in place with transosseous transcortical sutures. Twelve large coral grafts were used instead of autologous spongy bone to repair the floor of the anterior fossa after a large sphenoidomoidal and/or frontoethmoidal procedure had been performed for posttraumatic rhinorrhea in three cases and for tumors of the ethmoid sinuses extending to the cribiform plates in nine. The lengths of the blocks were 30 mm (six cases), 40 mm (five cases), and 50 mm (one case). The precut coral fragment was slightly larger than the defect to be reconstructed; it was then recontoured until it could be pressed firmly into place. Four transosseous transcortical sutures ensured immobilization of the graft.

Results

The follow-up period ranged from 2 to 30 months (average 17 months) in 64 patients with a total of 167 coral graft implantations. Resorption and reossification of the implants were monitored with standard craniofacial x-ray studies, tomograms, and computerized tomography (CT) scans. Reossification was not well demonstrated by any of the radiographic studies; however, resorption of the coral structure could be followed easily for many months on radiograms and CT scans (Figs. 1 and 2). Eight to 10 months postoperatively, a significant
decrease in volume of the small implants (such as the "corks") was noted. By 1 year postoperatively, the coral skeleton appeared to be almost completely resorbed in 50% of cases; resorption was partial in the other 50%. The resorption of the coral structure of the larger implants did not exceed 40% of their volume, even at 1 year.

The coral grafts were well tolerated. No infectious complications have been noted. The burr-hole corks and the five convexity implants have quite successfully avoided the poor cosmetic appearance of a skin depression. The 12 skull-base reconstructions performed with coral blocks seem to be quite satisfactory 1 year after operation; no cerebrospinal fluid leakage has been observed.

Discussion

Once the polyp (that is, the organic soft part of the coral) has been destroyed by drying in the sun, because it is an almost inert material biologically the coral skeleton is close to an ideal bone graft substitute. It is composed of 99% calcium carbonate and 1% amino acids. The three-dimensional structure of the coral favors the ingrowth of the host bone and, as new bone develops, more or less complete resorption of the implant is observed.

Corals, and particularly Porites, appear to be more efficient bone graft substitutes than artificial corals (calcium phosphate replamine) when the bone defect exceeds 10 mm. Reossification is more complete and reaches 50% to 60% of the graft volume. This figure is similar to that of autologous bone grafts and exceeds that of heterogeneous grafts. Guillemin, et al. showed that the biological structure of madreporic corals is comparable to bone. Based on structure, the four genera of coral that were tested can be classified into two groups: Porites and Goniopora have a structure very similar to trabecular bone; by comparison, Favites and Lobophyllia more closely resemble compact bone as they present a dense outer wall surrounding thin inner septa. The pores of all of these corals intercommunicate, which enhances preoperative sterilization and facilitates the invasion of the coral structure by granulation tissue, thereby increasing the chances of its mineralization.

This granulation tissue has been shown histologically to originate from the bone marrow and is accompanied

![Fig. 3. Histological pattern of a coral "cork" 6 weeks after implantation. The patient was first operated on for a craniopharyngioma; 6 weeks later an intraventricular shunt was placed in the right frontal ventricle. During the second procedure a coral cork was removed for histological examination. The specimen shows invasion of the central structure (C) by granulation tissue, blood vessels (V), and bone marrow elements. Probably a few osteoclasts can be seen (Oc) as well as a fine layer of new bone and osteoblasts (arrows). Inset: Location of the specimen in the removed cork. Hematoxylin PAS stain after decalcification of the coral graft, × 60.](image)
Madreporic coral for cranioplasty

by ingrowth of blood vessels (Fig. 3). The size of the pores allows blood circulation through the entire implant. After 6 or 7 weeks, osteoblastic apposition is followed by a Haversian remodeling process. At the same time, the coral is progressively resorbed by an osteoclastic process. This osteoblastic and osteoclastic process may proceed to its completion, in which case the whole implant becomes resorbed and replaced by newly formed bone. In our experience, complete resorption and replacement by newly formed bone was confined essentially to small implants such as burr-hole corks, (35% of cases by the 10th postoperative month). Souyris, et al.,14 observed the evolution of a Porites cranioplasty in an adult baboon. At 4 months postreconstruction, the structure of the original coral implant had disappeared and the bone defect was found to be partially reossified. A similar temporal evolution seems to have occurred in our patients as demonstrated by regular x-ray studies. Resorption of the larger implants (coral blocks) was always incomplete, but the repair of the skull base remained very satisfactory. Seemingly, the rate of resorption depends on the graft volume and on the implant site.

Coral resorption is governed by an enzymatic process:7,9 the role of carbonic anhydrase present in the osteoclasts has been suggested by the inhibition of this process with acetazolamide. This substance acts as a specific inhibitor of carbonic anhydrase and presents dissolution of the carbonated materials. The degradation of the coral skeleton liberates calcium ions which precipitate and are incorporated by the new bone.

The biocompatibility and host tolerance dependent on the chemical structure of the coral skeleton were first tested in animals.8,9,13,14 Prior to our own surgical experience, several patients had been successfully implanted with Porites either in limbs (femur, tibia, humerus) or in the maxilla.11,14 There were no reports of coralline cranioplasties having been tested or performed except in baboons.14 None of our patients experienced any sign of intolerance or rejection of the coral implants.

During the surgical procedure, the precut coral corks or blocks can be easily adapted to fit the bone defect if necessary, exactly as with autologous bone implants. In all cases, the implant must be slightly larger than the defect since a firm fit is the best way to avoid the graft slipping postoperatively. It is advisable to fix the large coral implants (used for skull base repairs, for instance) with a few transosseous sutures. Since metal sutures would create artifacts on CT and magnetic resonance imaging controls, only silk stitches were used.

Coral implants are inexpensive and easy to sterilize, and they simplify the surgical procedure. The use of madreporic coral shortens the time of cranial reconstruction since it is no longer necessary to harvest a bone graft from the rib or iliac crest. All these data, as well as the fact that the coral skeleton has mechanical properties quite similar to that of bone,3 justify the wider utilization of coral implants as bone substitutes, not only for craniofacial and plastic surgery but also for maxillofacial and orthopedic surgery.

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References


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