

IDEAS & INNOVATIONS

Piezoelectric Technology for Pediatric Autologous Cranioplasty

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Objective: Pediatric patients with skull defects larger than available sources for splitting bicortical bone have limited options for autogenous cortical bone cranioplasty. Piezoelectric instruments allow donor bone to be chosen based on the best possible contour rather than the presence of bicortical bone. We present the use of piezoelectric technology to split thin unicortical calvarium for autogenous cranioplasty in a series of pediatric patients.

Design: Retrospective review of a series of pediatric patients requiring reconstruction for skull defects.

Patients/Intervention: Our series included a 2-year-old with a parietal skull tumor and resultant 3 × 3-cm defect after craniectomy, a 2-year-old with a 3 × 3-cm defect after excision of an occipital skull tumor, a 10-year-old with a 4 × 5-cm skull defect after excision of an occipital skull tumor, and a 13-year-old who suffered a gunshot to the forehead with a 12 × 7-cm frontal skull defect. We used a piezoelectric saw to precisely and safely split unicortical and bicortical cranium that ranged from 1 to 3 mm in thickness. The inner layer was used to reconstruct the donor site; whereas, the outer layer was used for the craniectomy defect.

Conclusion: The piezoelectric saw allows unicortical bone to be split and used for cortical bone cranioplasty. This technology allows choice of donor site based on the best contour rather than the presence of bicortical bone. This technique expands the possibilities of autogenous cranioplasty and enables primary repair of cranial defects that would otherwise require secondary cranioplasty with remote donor sites, foreign materials, or unstable particulate cranioplasty.

KEY WORDS: *autologous, calvarial bone graft, cranioplasty, pediatric, Piezoelectric, unicortical*

Pediatric skull defects can be acquired or congenital. Before 1 year of age primary bone healing may occur, but thereafter ossification potential decreases and persistent skull defects may remain (Paige et al., 2006; Chao et al., 2009). In situations where cranial reossification is incomplete, cranioplasty may be warranted. Reconstructive

options for critical skull defects include autogenous bone graft, foreign material such as titanium, porous polyethylene, or bone substitutes. Use of split autologous cortical calvarium is preferred because it provides immediate stable protection of the brain, avoids remote donor-site morbidity in bone such as rib and ilium, and may be less likely to resorb (Zin and Whitaker, 1983; Grant et al., 2004). Nevertheless, bicortical autogenous calvarium for splitting is in limited supply in young children, with most of the skull being unicortical until after the age of 4 years, when a diploic space develops (Koenig et al., 1995). Even after 4 years, areas that do develop a diploic space may not have the desired contour to match skull defects in aesthetically sensitive areas such as the forehead. We introduce the use of the piezoelectric saw to safely and easily split thin unicortical calvarium for stable immediate cranioplasty even in young children.

PATIENTS AND INNOVATION

We present the use of piezoelectric technology for autogenous cranioplasty in a series of pediatric patients with a craniectomy defect (Table 1). In each case we created a template of the cranial defect using bone wax and selected either adjacent skull or a remote donor area based on

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TABLE 1 Case Series and Patient Demographics

Age (y)	Sex	Diagnosis	Craniectomy Location	Craniectomy Defect Size (cm)	Cranioplasty Timing	Cranioplasty Harvest Location	Complications	Follow-Up (mo)
2	Female	Eosinophilic granuloma	Right occipital	3 × 3	Immediate	Right occipital	None	6
2	Female	Skull tumor	Right parietal	3 × 3	Immediate	Right parietal	None	15
10	Female	Eosinophilic granuloma	Right occipital	4 × 5	Immediate	Right occipital	None	11
13	Male	Gunshot	Left frontal	12 × 7	Delayed 7 months	Left temporoparietal	None	16

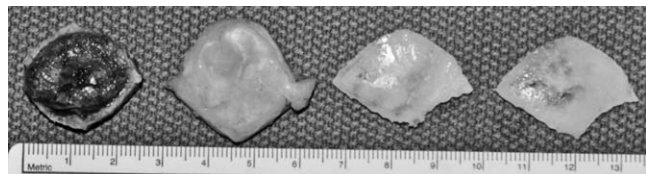


FIGURE 1 A 2-year-old girl with a right occipital skull eosinophilic granuloma was treated with craniectomy and immediate cranioplasty by splitting adjacent unicortical and bicortical occipital skull as thin as 1 mm. From the left: craniectomy specimen with occipital skull lesion, bone wax template, inner component of split skull, outer component of split skull.

matching the desired contour, regardless of the presence or absence of a diploic space and bicortical calvarium. We split the donor calvarium using a piezoelectric saw (Synthes Piezoelectric System, Synthes Inc., West Chester, PA), which uses 29,000 linear microvibrations per second at a

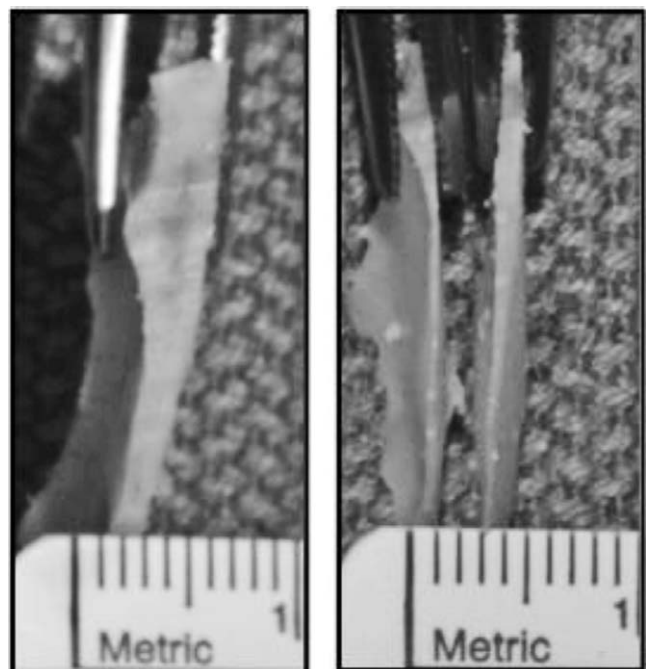


FIGURE 2 Following occipital craniectomy in a 2-year-old girl, adjacent unicortical and bicortical occipital skull as thin as 1 mm (left) is easily and precisely split with a piezoelectric saw. The inner and outer components (right) provide complete cortical coverage of donor and craniectomy sites.

frequency of 28 kHz to selectively cut mineralized bone without injuring soft tissue. Once split, the inner layer was used to reconstruct the donor site; whereas, the outer layer was used for autologous cortical cranioplasty of the skull defect (Fig. 1). We fixed the split cortical skull with absorbable hardware and achieved immediate, complete, and stable autologous cortical bone coverage of both the donor and recipient sites.

Our first patient was a 2-year-old girl, with a 3 × 3-cm skull defect after excision of an occipital skull eosinophilic granuloma, reconstructed with immediate cranioplasty by splitting adjacent unicortical and bicortical occipital skull as thin as 1 mm (Figs. 1 and 2). The second patient was a 2-year-old girl with a parietal skull lesion treated by craniectomy with resultant 3 × 3-cm skull defect and immediate cranioplasty by splitting adjacent unicortical parietal skull. A computed tomography (CT) scan 10 months postoperatively demonstrated that the split unicortical skull healed without defects to form normal-appearing bicortical skull with diploe (Fig. 3). The third

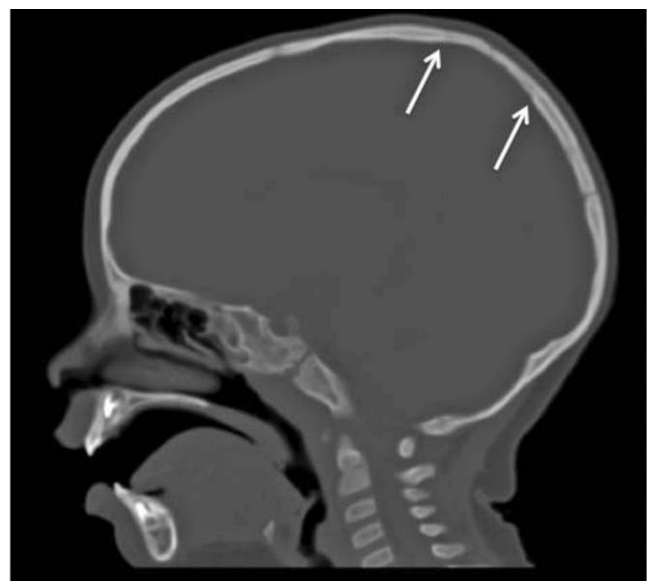


FIGURE 3 A CT scan 10 months postoperatively of a 2-year-old girl with a parietal skull lesion treated by craniectomy and immediate cranioplasty by splitting adjacent unicortical parietal skull. The donor and recipient sites healed without residual defects. Note that the split unicortical cranium healed to form bicortical skull with diploe. Arrows designate edges of cranioplasty and junction with native cranium.

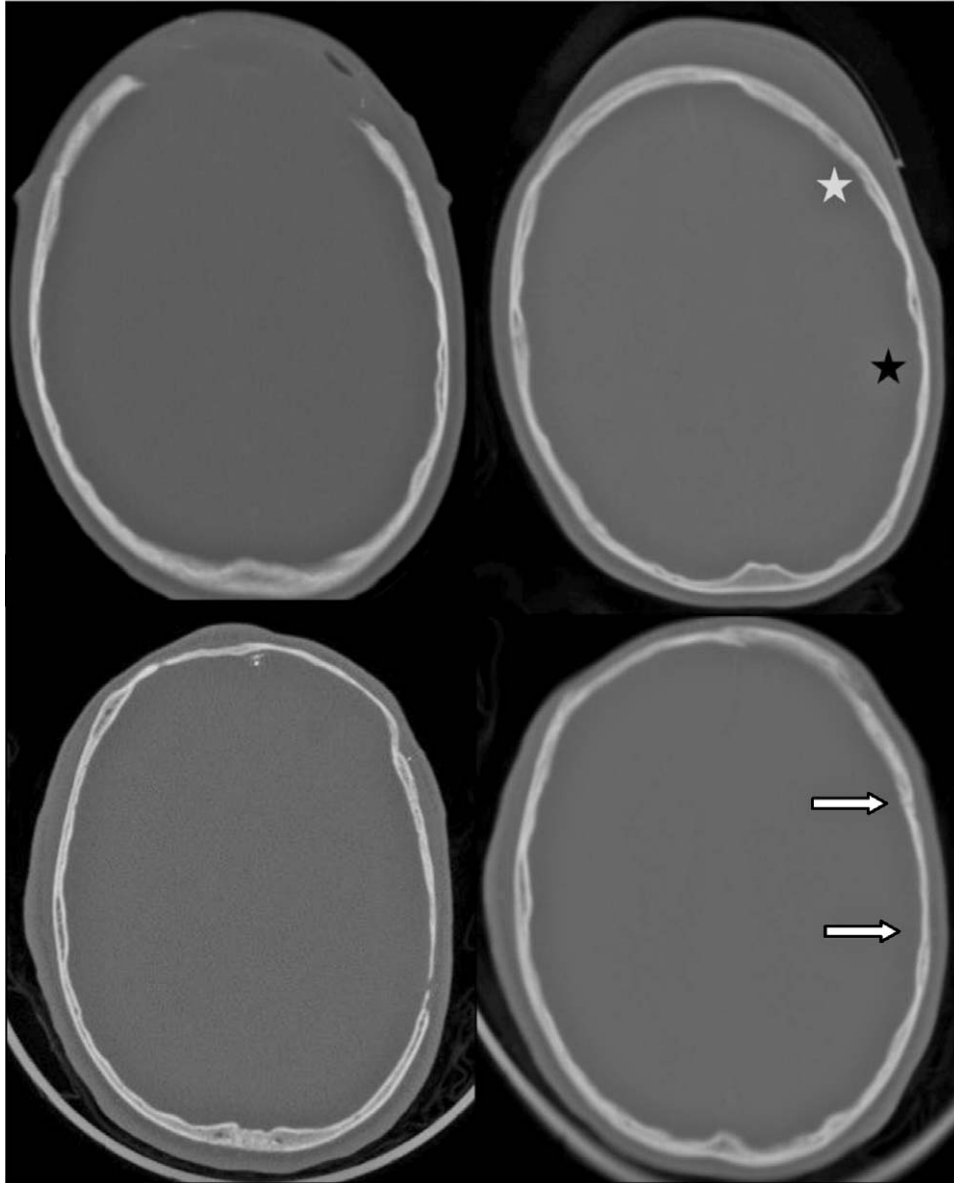


FIGURE 4 A 13-year-old boy who suffered a gunshot to the forehead requiring left frontal craniectomy. Before delayed cranioplasty, the preoperative CT scan demonstrates the frontal skull defect (upper left), chosen donor site with bicortical (gray star) and unicortical (black star) parietal skull (upper right). A CT scan 15 months postoperatively demonstrates healed frontal skull reconstruction with proper contour (lower left) and donor site; white arrows designate junction between repair and native cranium (lower right).

patient was a 10-year-old girl with a 4×5 -cm skull defect after excision of an occipital eosinophilic granuloma reconstructed with immediate cranioplasty by splitting adjacent unicortical occipital skull. The fourth patient was a 13-year-old boy who suffered a gunshot to the forehead requiring craniectomy and subsequent 12×7 -cm frontal skull defect. He presented 7 months postinjury for a delayed cranioplasty and was reconstructed by splitting nonadjacent temporoparietal unicortical and bicortical skull (Fig. 4). The donor site was chosen based on proper contour of the forehead rather than presence of bicortical cranium. All patients healed without complications or residual skull defects.

DISCUSSION

Certain materials have the ability to produce electricity when subjected to mechanical stress; this is termed the *piezoelectric effect*. The French physicist Pierre Curie discovered this phenomenon in 1880 (Curie, 1880). What he described was the direct piezoelectric effect, or the ability of some materials to produce an electrical charge when their crystal lattice framework is deformed by mechanical stress. Gabriel Lippmann hypothesized that polarized piezoelectric materials subjected to electricity would expand in the direction of and contract perpendicular to the polarity, resulting in oscillations (Lippman, 1881). This is termed the

indirect piezoelectric effect and was verified by Pierre and Jacques Curie (Curie and Curie, 1881). Tomaso Vercellotti and colleagues reported using piezoelectric vibrations to make bony osteotomies (Vercellotti et al., 2001), and Javier Mareque described using this technology to harvest calvarial bone grafts (Gonzalez-Lagunas and Mareque, 2007). Piezoelectric technology is now used commonly in dental and oral surgery. Here we contribute to expanding indications for using piezoelectric technology in plastic surgery and neurosurgery.

We used piezoelectric technology to split both bicortical and unicortical calvarium for autogenous cortical bone cranioplasty in children. These operations would not have been possible with traditional techniques using mechanically driven power saws and burrs, which are dependent on macrovibration and an applied force. Although applied force increases the cutting efficacy of power saws and burrs, it decreases their precision. The lack of precision, as well as the bone consumed in the osteotomy site using these tools, means that only bicortical bone is amenable to this traditional technique. Furthermore, power saws and burrs generate significant heat because the mechanical energy dissipates as thermal energy. In the absence of a diploic space, the operation is tedious, with bone necrosis at the osteotomy site (Horton et al., 1975). As a result, options for autologous cortical cranioplasty in young children, individuals with large skull defects, and those with predominantly unicortical calvarium are limited.

Piezoelectric technology provides a new opportunity and offers a number of advantages to conventional power devices. Piezoelectric saws use microvibrations and generate less heat, which create a fine osteotomy line and may protect osteoblasts from thermal damage, minimize bony necrosis, and preserve osteogenic potential (Gleizal et al., 2007). The device is coupled with an irrigation system, which transforms the solution into a cooling aerosol that clears the operative field of blood and debris, increasing visibility and safety. The microvibrations also provide an increased level of precision and control with minimal bone loss. Such precision allows splitting of even very thin unicortical bone that lacks a diploic layer and discernible plane. This technology also allows the surgeon to choose the calvarial donor site based on the best possible contour rather than the presence of “splittable” bicortical bone, even in young children. Last, the piezoelectric saw provides an increased level of safety for the patient and the surgeon because it cuts only mineralized structures, without injuring adjacent soft tissue structures. One

drawback may be the increased time required for splitting the calvarium using the piezoelectric saw, but this time has become negligible as practitioners have become more facile with the device. Nevertheless, traditional power saws are faster and may still be the preferred technique when splitting adult cranium or well-formed bicortical skull with a diploic space.

This technique expands the possibilities of autogenous cranioplasty in young children and enables coverage of cranial defects that would otherwise require remote donor sites, foreign materials, or unstable particulate cranioplasty. Piezoelectric technology can also improve safety and precision in other areas of plastic surgery or neurosurgery, such as harvesting osseous free flaps, performing hand-bone osteotomies, or performing a craniectomy or laminectomy without injuring the underlying neural or vascular structures.

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