Technical Advances in Ear Reconstruction with Autogenous Rib Cartilage Grafts: Personal Experience with 1200 Cases

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Through the author's experience with 1200 cases during a 25-year period, this article presents technical improvements in ear reconstruction and proposes and discusses possible directions for further technical advancement. This article presents the rationale for the author's current methods of managing total ear repair. Throughout the article, the author stresses and demonstrates cartilage-sparing techniques that are designed to minimize the amount of cartilage used in a repair to preserve maximum chest wall integrity. This article also presents the latest method of framework fabrication, showing differences in construction between younger and older patients; a new method that constructs a tragus as an integral part of the framework; a method that maintains ear projection with a scalp-banked cartilage wedge; and a method that solves the always frustrating low hairline by presurgical laser treatment. In addition, the concept of creating autogenous frameworks by tissue engineering is pursued and discussed in practical clinical terms. A survey of 1000 microtia patients indicates that surgically constructed ears remain durable, withstand trauma well, and provide consistent emotional relief and psychological benefits through the repair. (*Plast. Reconstr. Surg.* 104: 319, 1999.)

Perhaps no area in plastic surgery demands more attention to detail than ear reconstruction, for which autogenous tissue clearly continues to be the material of choice for repair. It is the purpose of this article to focus on technical improvements that have evolved from my 25-year experience with more than 1200 cases and to introduce and discuss future directions of this challenging surgical art form.

The material presented herein is derived from clinical experience with congenital microtia (1094 completed ears in 1000 patients; 94 cases were bilateral) and traumatic injuries (125 completed cases of total ear reconstruction). This article focuses on total repair of major congenital ear defects but includes relevant supplementary input from experience gained by managing traumatic auricular deformities. All repairs used autogenous rib cartilage grafts.

Patients

Of the 1000 microtia patients in this series, 582 were right (58.2 percent), 324 were left (32.4 percent), and 94 were bilateral (9.4 percent). A total of 631 (63.1 percent) of the patients were male, and 369 (36.9 percent) were female (Table I). Problems associated with microtia were frequent. Among these, the most common were branchial arch deformities; 36.5 percent had some flattening of the involved facial half, and 15.2 percent exhibited facial nerve weakness. Other common problems included cleft lip and/or palate (4.3 percent), urogenital defects (4 percent), cardiovascular malformations (2.5 percent); and macrostomia (2.5 percent) (Table II). Family history revealed 4.9 percent recurrence within the immediate family. When distant relatives were included, this number increased to 10.3 percent.

Initiating the Surgery

At consultation, the family is anxious to have the ear repaired as soon as possible, but it is important for the surgeon to wait until it is technically feasible. There usually is enough

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TABLE I
Series of 1000 Microtia Patients

Side	Cases (n = 1000)	Percent	Total Ears (n = 1094)	Sex	n	Percent
Right	582	58.2	582	M	631	63.1
Left	324	32.4	324	F	369	36.9
Bilateral	94	9.4	188			

rib cartilage to serve as the sculpting medium by age 6, and at the urging of the parents, I often begin at that time. If not pressured by the family, my favored age to begin surgery is between 7 and 8 years, when the child is more aware of, and concerned with, the problem, usually wants it resolved as much as family members do, and is helpful and cooperative during the postoperative care phase.

Of the 1000 microtia patients in this series, 28 (2.8 percent) were operated on at 5½ years, 472 (47.2 percent) at age 6 or 7, 211 (21.1 percent) between ages 8 and 10, 143 (14.3 percent) between ages 11 and 15, 74 (7.4 percent) between ages 16 and 20, 65 (6.5 percent) between ages 21 and 40, and 7 (0.7 percent) between ages 41 and 62 (Table III).

Selecting the Method of Framework Fabrication

In contrast to alloplastic frameworks, which often fail,[1] and homologous cartilage, which absorbs,[2] autogenous cartilage produces favorable results, experiences few complications, and withstands trauma.[3–5] I have seen silicone ear frameworks lost to even minor trauma as many as 12 years after implantation. Despite some investigators' enthusiasm with Medpore frameworks[6–8] (Porex Surgical, Inc., College Park, Ga.), these foreign substances seem to encounter the same problems that have plagued silicone. Most recently, a patient came to my consultation with an infected sinus tract that had been draining from her Medpore implant for 2 years; another patient presented with three separate exposed areas of Medpore in his reconstructed ear. On the other hand, after the 10th postoperative day has passed safely, I have never lost an autogenous ear framework in a microtia patient; only one framework has been lost in a trauma patient with poor compliance to postoperative instructions. To date, among my patients, more than 70 reconstructed ears have survived major trauma.

For many years, there has been considerable interest in creating a prefabricated framework from autogenous cartilage to circumvent the necessity of sculpting an ear framework during a prolonged reconstructive procedure or to circumvent the need for artistic ability to create a realistic ear framework from rib cartilage. In the 1940s, Young[9] and Peer[10] first conceived the idea of framework prefabrication before the actual auricular reconstruction. This innovative technique was accomplished by means of diced pieces of autogenous rib cartilage, which were placed in a fenestrated two-piece, ear-shaped Vitallium mold, which in turn was banked in the patient's abdominal wall. After several months, the banked mold was retrieved and opened, and the framework of cartilage chips, which had united by connective tissue that had grown through the openings of the mold, was harvested. However, the results were not consistent, perhaps because contraction of the fibrous tissue surrounding the multiple car-

TABLE II
Associated Deformities

Type	Percent
Branchial arch deformities	
Obvious bony and soft-tissue deficit	36.5
Family perceives it as "significant"	49.4
Overt facial nerve weakness	15.2
Of these, more than one branch involved	42.6
Macrostomia	2.5
Cleft lip and/or palate	4.3
Urogenital defects	4.0
Cardiovascular malformations	2.5
Miscellaneous deformities	1.7

TABLE III
Ages Operated On

Age Range (years)	Patients n = 1000	Percent of Total
5½	28	2.8
6–7	472	47.2
8–10	211	21.1
11–15	143	14.3
16–20	74	7.4
21–40	65	6.5
41–62	7	0.7

tilage islands distorted the resulting framework.

Recently, interest in this prefabrication concept has been rekindled through modern techniques of tissue engineering, in which bovine cartilage cells are grown in the laboratory and seeded upon a synthetic, biodegradable ear form, which is then implanted beneath the skin of an immuno-incompetent mouse.[11] The early results are interesting, but one should note that the trial work does not take place in conditions that are comparable to those of a clinical human ear reconstruction—the investigators' framework is placed under the loose skin of the back of an animal, whereas a surgeon's framework for ear repair is placed underneath tight skin, just anterior to the scalp hairline in the ear region.

Although these new laboratory studies are intriguing, unless a very firm, substantial three-dimensional framework can be produced from autogenous tissues, it will likely suffer the same fate I observed of the prefabricated frameworks of Young[9] and Peer[10]; i.e., the framework was flattened by the pressure of the taut, two-dimensional skin envelope under which it was placed to complete the ear reconstruction. The other obvious limitation of prefabricated ear frameworks is the difficulty in producing the great variation in size and shape that is necessary to match the opposite, normal ear. When sculpting directly from rib cartilage, these lim-

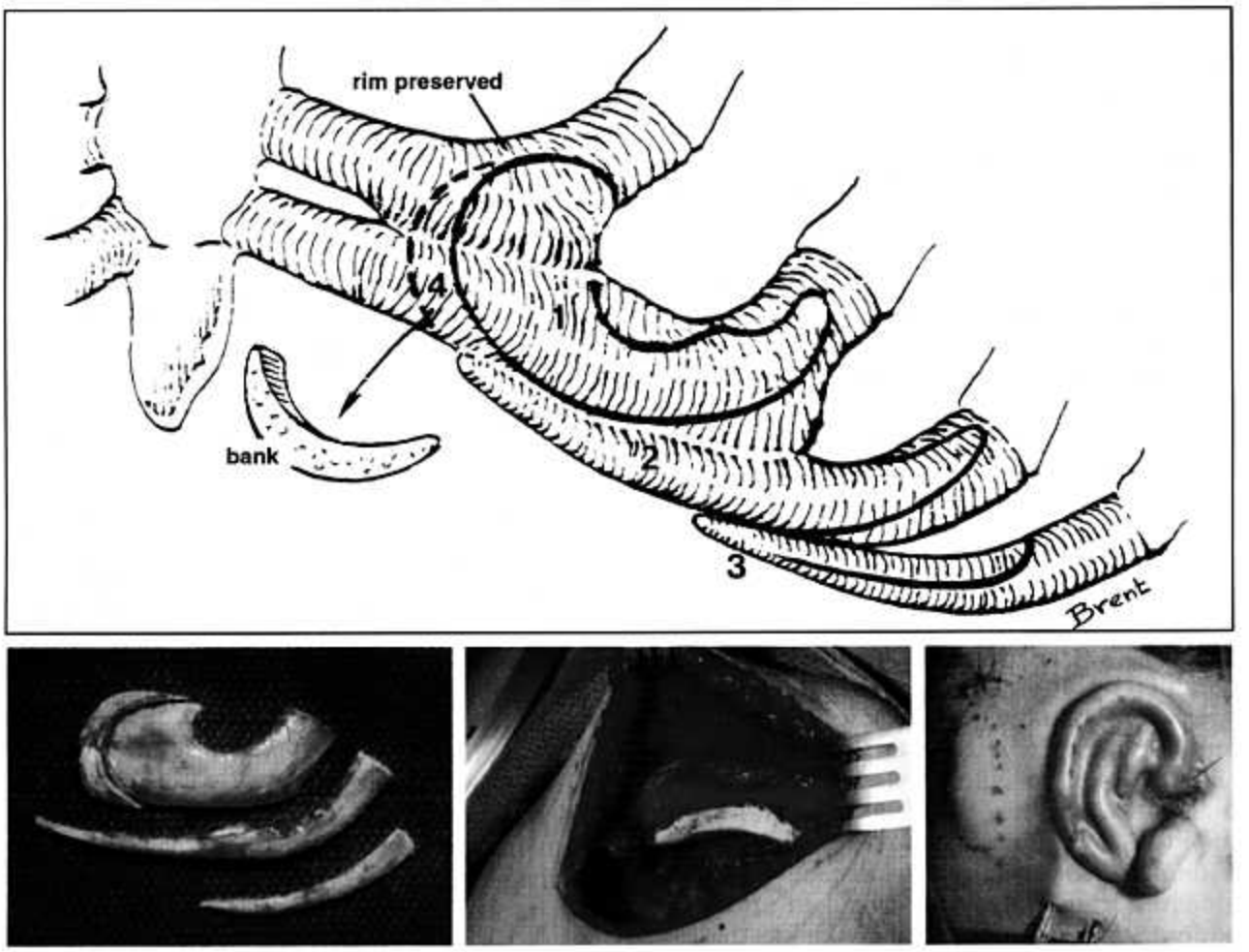

FIG. 1. Preserving maximum chest wall integrity: harvesting minimal rib cartilage for ear framework fabrication. (*Above*) Rib cartilages used in total ear construction: 1, synchondrotic block used for body of framework; 2, floating rib used for helix; 3, strut used for tragus (see Figs. 2 and 3); 4, extra cartilage wedge to be banked for use during the elevation procedure. (*Below, left*) Harvested rib cartilages, as depicted in the drawing above. (*Below, center*) Preserved rim maintains chest wall integrity by tethering 6th cartilage to sternum (see text). (*Below, right*) Banking the extra cartilage wedge under the scalp, posterior to but not in continuity with the main ear "pocket." This banked wedge will be harvested and used during the elevation procedure (see text and Fig. 9). Note position of suction drains: the anterior drain passes under frame, through conchal region, then over the inferior crus; the posterior drain courses behind the frame then above the helix.

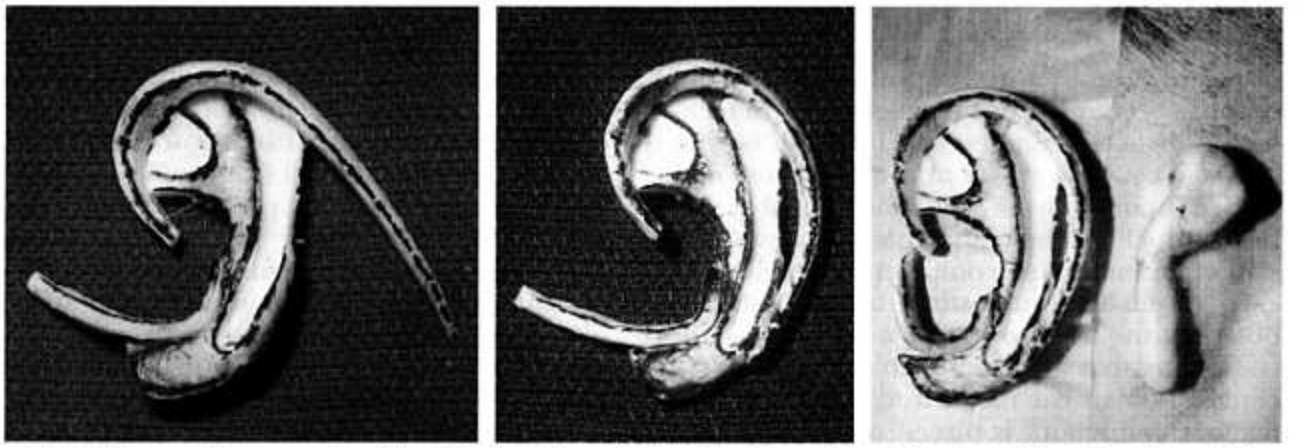

FIG. 2. Framework construction with minimal cartilage: dealing with skimpy rib configurations. When there is insufficient cartilage for the main block, I employ the "expansile" design[18] and gain frame width by bowing out the helix and leaving an open space in the scaphal region. This is preferable to violating the 6th rib margin to get more width, which risks deforming the chest wall (see text).

itations do not exist because the surgeon creates the required specific size and shape for each ear reconstruction.

However, even I have long been intrigued by the concept of creating a prefabricated cartilaginous ear framework. Consequently, I am working with researchers at New York University Medical Center[12] to explore the possibilities of bioengineering frameworks of firm, autogenous cartilage, to see if some of the aforementioned limitations can be overcome.[13] Our direction involves growing autogenous costal cartilage in molds of varying sizes made from idealized frameworks that I have sculpted and cast. But to fill these molds with chondrocytes obtained by digesting a large volume of rib cartilage would merely be reproducing Young's and Peer's work using modern technology. Our goal is to exploit the technology by using a small piece of cartilage (perhaps obtained by biopsy from the microtia patient at age 3 to 4 years, when neochondrogenic potential is high), to extract the chondrocytes, to expand them in culture, and then to infuse them into the ideal matricial substrate within the ideal ear framework mold for each specific patient. Once generated to satisfaction, the engineered framework is then banked under the patient's hairless periauricular skin, as the first reconstructive surgical phase. For this technique to be successful, the major problems entail replicating sufficient chondrocytes from a small cartilage sample (25 to 50 million cells/ml are necessary for neocartilage formation in a construct, and the ear mold volume is approximately 5 cc); and regenerating firm cartilage matrix from those chondrocytes so that the engineered three-dimensional framework can withstand the pressure caused by the constraints of a two-dimensional skin cover that is taut, inelastic, and restrictive.

In my experience, until tissue engineering evolves beyond the aforementioned problems, sculpted autogenous rib cartilage remains the material of choice for surgical repair of the ear.

SURGICAL STAGING

Because a framework of well-sculpted cartilage is the foundation of the repair, it must be created under ideal conditions. Ideally, this is accomplished as the first surgical stage, in which one usually finds scar-free skin with optimal circulation and elasticity. Secondary procedures such as repositioning the earlobe and creating the auriculocephalic sulcus take place only after sound healing of the grafted cartilage framework foundation. Combining procedures to reduce surgical stages[14] must be done with caution to prevent complications[15] and to ensure predictability of the repair. One will not be thanked by a patient for taking short cuts, but instead will suffer with the family during management of a complication that arises from doing so.

THE FIRST SURGICAL STAGE

Harvesting the Rib Cartilage

To avoid deforming the thorax, certain precautions must be followed to obtain the ideal sculpting material. In a survey addressing my first 500 microtia patients, I learned that 35.2

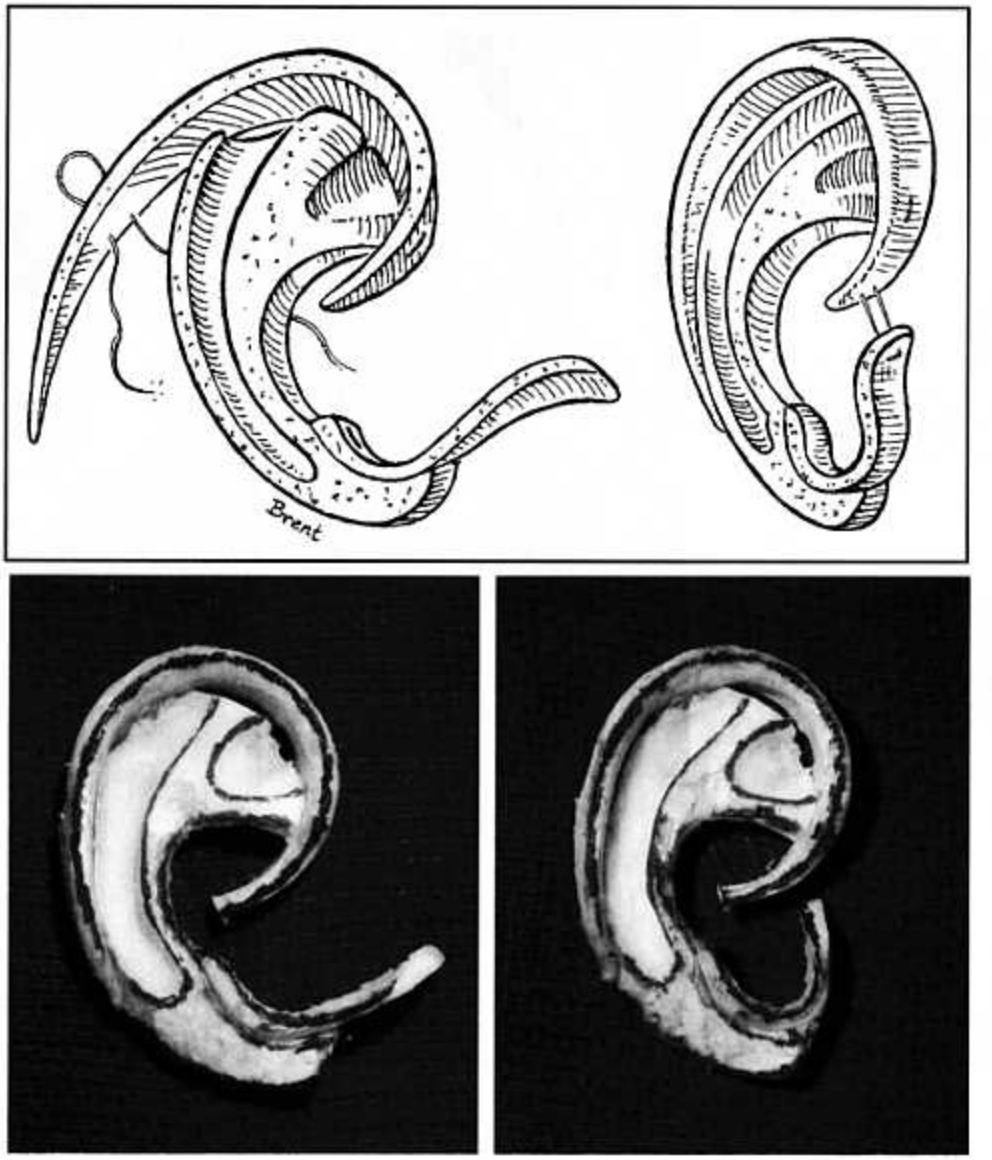

FIG. 3. Ear framework fabrication with integral tragal strut. (*Above*) Construction of the frame. The floating cartilage creates a helix, and second strut is arched around to form the antitragus, intertragal notch, and tragus. This arch is completed when the tip of the strut is affixed to the crus helix of the main frame with horizontal mattress suture of clear nylon. (*Below*) Actual framework fabrication with the patient's rib cartilage.

percent of patients rated the scar and/or chest contour as "noticeable, but worth the trade-off."[5] One only has to observe a surgically deformed thorax to realize the importance of harvesting only what is needed to create the framework, thus preserving maximum integrity of the chest wall. Obvious chest deformities[16,17] can be decreased significantly by preserving even a minimal rim of the upper margin of the sixth rib cartilage to obtain the basic ear shape of the framework (Fig. 1). This precautionary measure retains a tether to the sternum so that the rib does not flare outward, thus distorting the chest as the child grows. If the synchondrotic region seems inadequate in width, one can compensate for framework width by bowing the helix away from the framework body (the expansile design[18]) rather than violating the sixth rib margin and sacrificing chest wall integrity (Fig. 2). To acquire cartilage of appropriate configuration, I prefer to use the contralateral chest.

Fabricating the Framework

The framework must be treated as a living sculpture. During fabrication, I avoid the use

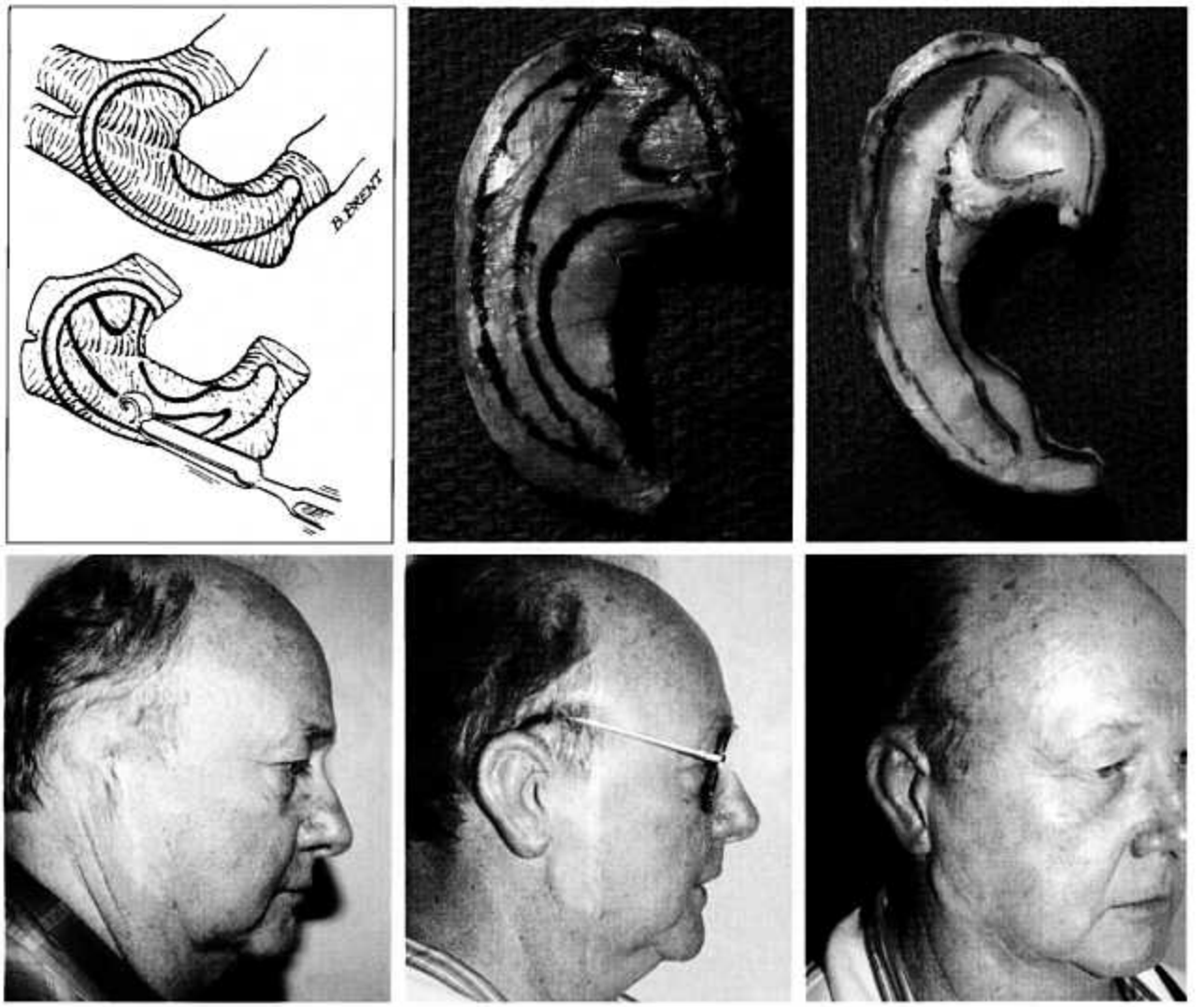

FIG. 4. Framework modifications in the adult patient. (*Above, left*) When a solid, fused cartilage block is encountered, the framework is sculpted in one piece. (*Above, center*) Cartilage block marked for carving. (*Above, right*) Completed framework, sculpted from the block. (*Below, left*) A 60-year-old man with traumatic total ear loss. (*Below, center* and *right*) Result achieved with a one-piece sculpture from a fused cartilage block, 1 year postoperatively. Simulation of the absent earlobe was achieved by sculpting its likeness in the framework's inferior pole.

of power tools by carving the tissue with scalpels and chisels; the cartilage is intermittently bathed in saline to prevent desiccation. I remove muscle and connective tissue scraps from the cartilage graft before carving, but I preserve perichondrium, when possible, to facilitate adherence to and subsequent nourishment from the skin cover. Upon forming the basic shape of the ear, the helix is created by thinning the floating rib cartilage. To decrease the amount of foreign bodies, the helix is wrapped around the ear silhouette with a minimal number of 4-0 and 5-0 clear nylon sutures (Fig. 3, *above*). The knots are placed on the undersurface of the framework. I find that nylon causes far fewer problems than wire sutures, which commonly extrude from reconstructed ears.[19,20]

Although in the past I relied almost totally on creating the tragus with composite grafts during a separate procedure,[21] I have recently developed a new method to create the tragal strut as part of the original framework itself (Fig. 3). This is particularly useful in the case of bilateral microtia, where an appropriate donor site for composite tissue is unavailable. As with the original principle of expansile framework,[18] this new method of tragus construction uses cartilage more efficiently so that one needs only a minimal extra strut of rib tissue

(Figs. 2 and 3). As mentioned before, such considerations are preeminent in preserving chest wall integrity and contour.

Framework Modifications in Older Patients

In adult patients, I usually find that basic differences in rib cartilage quality and configuration require that I modify the framework fabrication. Adult rib cartilages often are fused into a solid block (Fig. 4, *above, center*), which invites one to sculpt the framework as one piece—not unlike a wood carving (Fig. 4, *above, right*). In my experience, this is particularly advantageous because adult cartilage is often calcified; it is difficult, if not impossible, to create a separate helix that will bend without breaking. If a one-piece carving produces insufficient helical projection, one can detach the helix and slide it up the framework body to augment the protrusion of rim (Fig. 5, *above left*). This improved contour is maintained by reattaching the helix to the framework with several permanent sutures (Fig. 5, *below*).

The Cutaneous Cover

On completion of the framework of carved cartilage, meticulous technique is used to create a skin pocket in the proposed auricular region that will provide a nourishing, protective covering for the newly introduced ear framework. As time elapses during the rib harvest and framework fabrication, I minimize contamination risk by preparing and scrubbing the ear region just before beginning the skin dissection.

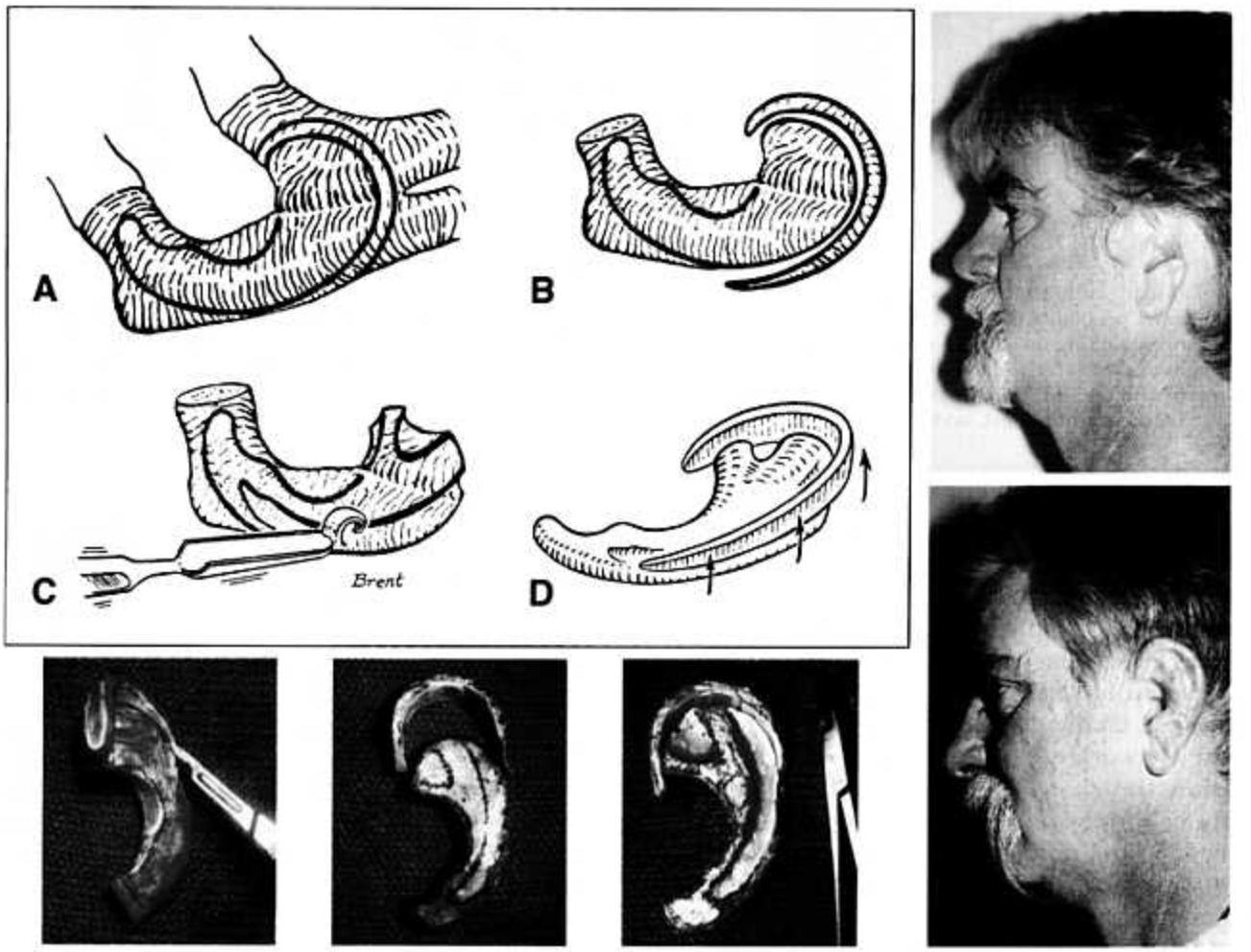

FIG. 5. Maximizing rim projection in adult patient with sliding helical advancement. (*Above, left*) A and B, harvesting fused rib cartilage block and separating the inflexible helical portion; C, sculpting body of framework; D, sliding and reattaching the helix to maximize its projection. (*Above, right*) A 50-year-old man with ear loss from a dog bite. (*Below, left, second from left,* and *third from left*) Construction of the framework using the technique illustrated in the drawings. (*Below, right*) The completed repair. This patient had his hairline "idealized" by laser treatment before the rib cartilage graft (See Fig. 6).

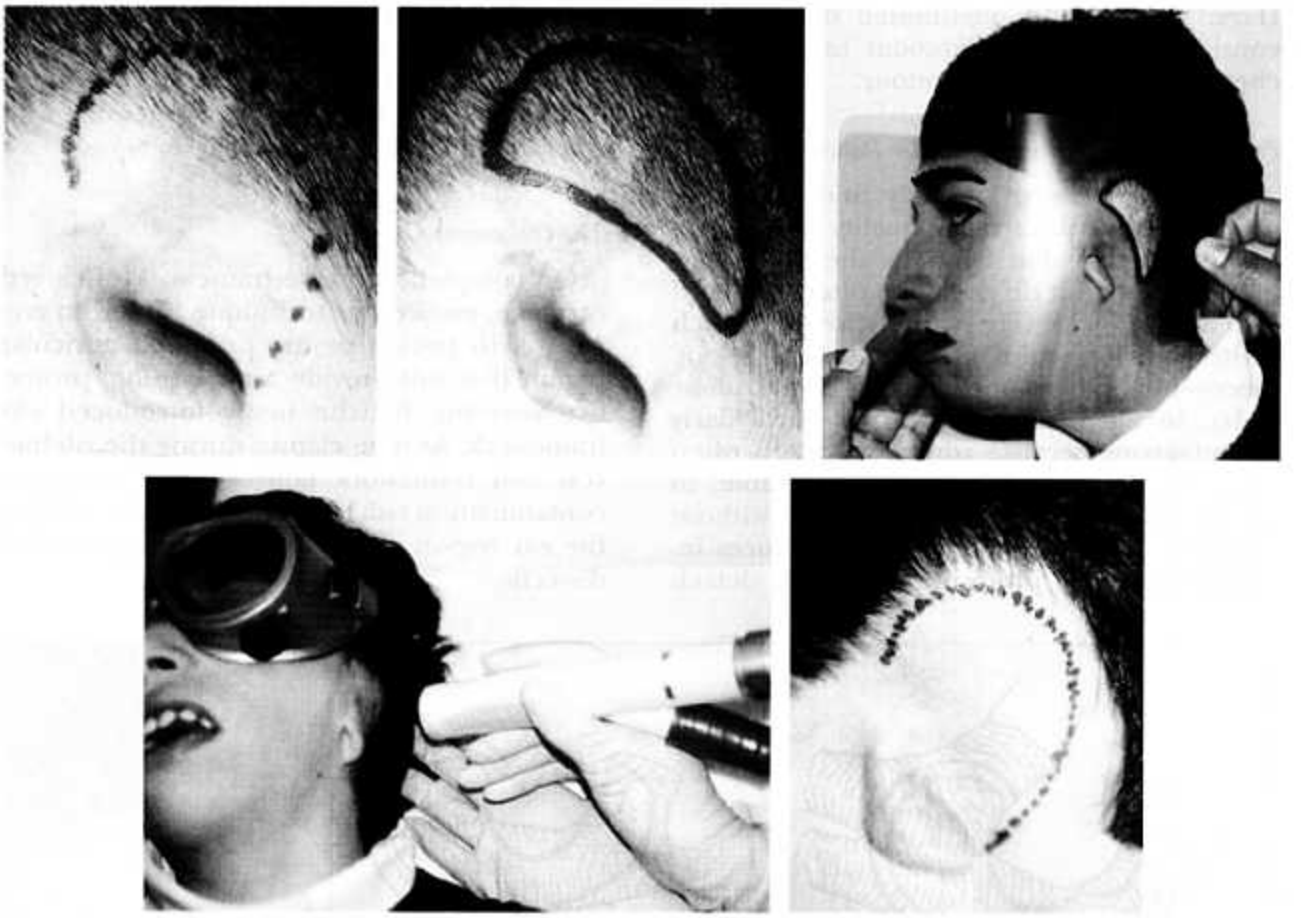

FIG. 6. "Hairline idealization" by presurgical laser treatment. (*Above, left*) Microtia with typical low hairline, which would cover the upper portion of the proposed auricular construction. (*Above, center*) Crescent-shaped area designated for laser de-epilation before embarking on surgical ear repair. (*Above, right*) Film template to aid in relocating the exact crescent during serial laser treatments. Note aids in applying the template: cut-out area slips over vestige; eyebrow, lateral canthus, and oral commissure are marked on film. (*Below, left*) The laser treatment in progress. (*Below, right*) The same microtia after several laser treatments. The hairline is now ideal, and surgical construction of the ear will begin (see Fig. 5, *below, right*).

Using the film template and preoperatively determined measurements, I mark the position of the ear and make a small incision along the backside of the ear vestige. Once I have dissected out and removed the gnarled remnant of cartilage beneath the skin, I use fine dissection scissors to develop a thin skin pocket, taking great care to prevent damage of the network of small blood vessels that nourishes the skin. To furnish sufficient, tension-free skin coverage, I carry the dissection well beyond the marked ear outline. After securing hemostasis, I insert two small silicone drains beneath and behind the framework (Fig. 1, *below, right*), which are attached to vacuum test tubes. This creates a continuous suction that promotes adherence of the nourishing skin flap to the cartilage sculpture and prevents disastrous hematomas.

Postoperative Course

I pack the convolutions of the constructed ear with Vaseline gauze, then apply a bulky, noncompressive dressing. Because the vacuum system provides both skin adherence and hemostasis, pressure is unnecessary and contraindicated. On the first day, the tubes are changed frequently by the ward nurses. The patient leaves the hospital in 24 to 48 hours, after which time I teach the parents to change the tubes several times daily. I remove the drains on the fifth postoperative day, when drainage is minimal and the skin is well adhered to the cartilage framework.

The first day after surgery, the patient often experiences chest discomfort from the rib surgery and nausea from the anesthesia. Both of these are easily controlled with medications. Most patients do not experience significant ear