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Precise and Rapid Costal Cartilage Graft Sectioning Using a Novel Device:

Clinical Application

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Abstract

IMPORTANCE—The use of costal cartilage as a graft in facial reconstructive surgery requires sectioning the cartilage into a suitable shape.

OBJECTIVE—To evaluate the accuracy of a novel mechanical device for producing uniform slices of costal cartilage and to illustrate the use of the device during nasal surgery.

DESIGN—Basic and clinical study using 100 porcine ex vivo costal cartilage slices and 9 operative cases.

METHODS—This instrument departs from antecedent devices in that it uses compression to secure and stabilize the specimen during sectioning. A total of 75 porcine costal cartilage ribs were clamped with minimal compression just sufficient to secure and stabilize the specimen while cutting. Slices having a length of 4 cm and width of 1 cm were obtained using the cartilage cutter at 3 thicknesses: 1 mm(n = 25), 2 mm(n = 25), and 3 mm(n = 25). The procedure was repeated for the 2-mm thick samples; however, the ribs in this group (n = 25) were clamped using the maximum amount of compression attainable by the device. Thickness was measured using a

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Study concept and design: Foulad, Manuel, Wong.
Acquisition of data: Hamamoto.
Analysis and interpretation of data: Hamamoto.
Drafting of the manuscript: Foulad, Hamamoto.
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Conflict of Interest Disclosures: Dr Foulad is a coinventor of the cartilage cutting guillotine and receives consulting income from Praxis BioSciences, a licensee of the technology. Mr Manuel is a coinventor of the cartilage cutting guillotine and receives consulting income from Praxis BioSciences, a licensee of the technology. Dr Wong is a coinventor of the cartilage cutting guillotine and has equity in Praxis BioSciences, a licensee of the technology. No other disclosures are reported.

digital micrometer. Case presentations illustrate the use of the device in secondary and reconstructive rhinoplasty surgery.

RESULTS—All specimens were highly uniform in thickness on visual inspection and appeared to be adequate for clinical application. Sectioning was completed in several seconds without complication. In the porcine specimens sectioned using minimal compression, the percentage difference in thickness for each individual sample averaged 18%, 10%, and 11% for the 1-mm-, 2-mm-, and 3-mm-thick slices, respectively. Within the specimens sectioned using maximum compression, the percentage difference in thickness for each individual sample averaged 35% for the 2-mm-thick slices. In the setting of nasal reconstructive surgery, slices having a thickness from 1 to 2 mm were found to be well suited for all necessary graft types.

CONCLUSIONS AND RELEVANCE—The simple mechanical device described produces costal cartilage graft slices with highly uniform thickness. Securing the rib by clamping during cutting reduces uniformity of the slices; however, the imperfections are minimal, and all sectioned grafts are adequate for clinical application. The device can be adjusted to produce slices of appropriate thickness for all nasal cartilage grafts. This device is valuable for reconstructive procedures owing to its ease of use, rapid operation, and reproducible results.

LEVEL OF EVIDENCE—NA

Costal cartilage is a valuable reservoir for harvesting grafting material in reconstructive surgical procedures of the ear, nose, and airway. Although septal and auricular cartilage is often favored, costal cartilage is the ideal graft source when a relatively large supply of cartilage is required and other cartilage sources are exhausted or insufficient. In addition to the requirement of a distinct operative field and the associated comorbidities, the use of costal cartilage grafts is hampered by an inherent tendency to warp.[1] To minimize this undesirable postoperative warping, cartilage can be sectioned using the principle of balanced cross-sections and fashioning the graft from the central core of the specimen.[2]

Techniques for predictable sectioning of costal cartilage grafts have had a slow progression. The scalpel currently remains the instrument of choice in the operative setting; however, surgical skill and time-consuming maneuvers are required to obtain uniformly flat slices. Several past studies examining the physical properties of costal cartilage have alluded to some variation of a double-bladed mechanism for obtaining their experimental cartilage specimens.[3–5] Fundamentally, 2 parallel blades are pushed through the cartilage, and a flat central slice is produced having a thickness similar to the distance between the blades. However, the details and accuracy of these devices are lacking.

Advancement in sectioning of costal cartilage was made in 2011, when we developed, optimized, and described a novel costal cartilage cutter.[6] The device consists of a platform to safely secure the rib while providing a guide for a double-bladed cutter to section the rib in a guillotine-like fashion. Optimization of several factors, such as blade edge design and cartilage positioning, were critical for creating highly uniform graft slices of sufficient length as demonstrated in a porcine animal model. A significant disadvantage of the device was mounting and securing the cartilage using tension, which involved several minutes of suturing time.

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Our current study describes a costal cartilage cutter that is modified to be more practical for an operative setting. This approach departs from the former implementation in that it significantly decreases mounting time by using compression to secure and stabilize the specimen during sectioning. The objective of this study is to evaluate the effects of compression while cutting porcine cartilage specimens and assess the accuracy and feasibility of using the modified instrument. We also describe our experience with using the device in 9 major rhinoplasty cases.

Methods

Cartilage Cutter Design and Operation

The fundamental design of the costal cartilage graft cutter (Anthony Products Inc) was previously described in detail by Foulad et al.[6] The device is composed of a platform that secures the specimen and a guillotine cutting mechanism that consists of 2 parallel blades (Figure 1). The costal cartilage is first stabilized in proper orientation by compressing it with 2 vertically oriented and texturized bars, and then the double-bladed cutter is pushed through the specimen using a guide rail. The distance between the blades, which is adjustable by using different sized spacers, determines the thickness of the specimen. The region of the cartilage sectioned is adjusted by moving the cutting guide along a second rail.

Porcine Model Experimentation

Porcine rib was obtained from a local meat packing house, and the cartilage from ribs 3 through 6 was used. The tissue overlying the cartilage was stripped using a scalpel. The perichondrium was also thinned because porcine perichondrium is extremely tough and adherent compared with its human counterpart. The device was used to cut costal cartilage specimens having a 4-cm length and 1-cm width. Twenty-five samples of each of 3 different thicknesses (1 mm, 2 mm, 3 mm) were sectioned using minimal compression. This amount of compression is defined as the least amount of force sufficient to secure the specimen without concern for the specimen moving during cutting. In addition, 25 samples of the 2-mm thickness were sectioned using maximal compression, which is achieved by applying the greatest compression achievable by hand tightening. A digital caliper (Absolute Digimatic, Mitutoyo), which was lubricated and calibrated before each use, was used to measure the thickness of each specimen at 11 distinct points. This included 10 points evenly spaced out around the edge of cartilage slice (4 points along each length and 1 point along each width).A single central point was measured last and required cutting the cartilage in half along the width. A research assistant with no conflict of interest (A.H.) obtained, recorded, and analyzed the measurements.

Rhinoplasty Cases

The device was used in 9 rhinoplasty cases that required rib. Costal cartilage from ribs 5,6, 7, or 8 was harvested from the patients within the same session of the nasal reconstruction procedure. Different thickness spacers were used to cut the cartilage depending on the function of the graft. A variety of grafts were fashioned for cases that ranged from secondary rhinoplasty to total nasal reconstruction requiring a paramedian forehead flap. The required grafts included caudal septal extension grafts, upper and lower lateral cartilage replacements, dorsal onlays, spreader grafts, and rim grafts. Various techniques and adaptations were adopted from the experience gained from the cases.

Results

Porcine Model Experimentation

All porcine specimens cut using minimal compression appeared uniform on visual and manual inspection (Figure 2,A-C). The mean thicknesses of these samples using the 1-mm, 2-mm, and 3-mm spacers was 0.96 mm, 1.9 mm, and 2.9 mm, respectively. The absolute difference between the largest and smallest thickness measured for each of these samples using the 1-mm, 2-mm, and 3-mm space rsranged from 0.04 to 0.34 (mean, 0.17), 0.08 to 0.36 (mean, 0.18), and 0.15 to 0.42 (mean, 0.31), respectively. The percentage difference in thickness for each sample using the 1-mm, 2-mm, and 3-mm spacers ranged from 4.0% to 32% (mean, 18%), 4.3% to 20%(mean, 9.6%), and 5.2% to 15%(mean, 11%), respectively.

Porcine specimens cut with maximum compression had minor deviations in uniformity on visual and manual inspection (Figure 2,D-F).The mean thickness of all of these samples using the 2-mm spacer was 1.65 mm. The absolute difference between the largest and smallest thicknesses measured for each sample ranged from 0.37 to 0.75 mm. The percentage difference in thickness for each sample ranged from 22% to 50% (mean, 35%).

Rhinoplasty Cases

For the operative cases, the patients were 44 to 64 years in age (mean, 54 years). Cartilage specimens ranged from pliable with no evidence of calcification to brittle with significant islands of calcification (Figure 3). The partially calcified specimens were easily sectioned. Cadaveric human costal cartilage was used in 1 case. On visual and manual inspection, all cut cartilage slices appeared to be adequately uniform in thickness for use as rhinoplasty grafts.

Appropriate cartilage graft slices were successfully obtained in all 9 cases. Caudal septal extension grafts were typically constructed from 2-mm slices (Figure 4,A-C). Lateral crural struts and spreader grafts were often fashioned from 1-mm slices; however, slices up to 2 mm in thickness were also used depending on the case (Figure 4,D and E). Alar rim grafts were sectioned from 1-mm–thick cartilage slices. Dorsal onlay grafts were often obtained from the canoe-shaped peripheral slices (Figure 4, F).

Cartilage slices obtained from initially curved donor rib retained the curved shape after cutting (Figure 5). The central cartilage slice demonstrated in Figure 5 was trimmed so that the flat region was used for a caudal septal extension graft, while the curved region was used for lateral alar replacement grafts.

Discussion

Costal cartilage offers an abundant supply of autogenous grafting tissue for major nasal reconstruction. Typically, straight and uniformly thick grafts are desired, such as for caudal septal grafts, spreader grafts, and lateral crural struts. Although a degree of curvature is beneficial in lower alar grafts, these grafts also require a uniform and even surface. In addition to the need for uniform grafts, balanced specimens from the central core of the rib are desired in order to minimize warping. The scalpel is currently the instrument used by most surgeons for carving costal cartilage grafts; however, this method is time consuming, requires a high degree of skill, and is far from ideal for reproducibly attaining uniform slices, even in expert hands.

In an effort to improve traditional carving methods, we have previously developed a practical device to cut costal cartilage slices that are precisely sectioned and uniform.[6] The device securely mounts the rib while a double-bladed cutter is pushed through the tissue, resulting in a slice of cartilage with the desired thickness. Several design optimizations, such as proper blade bevel characteristics, were critical in attaining uniform slices. The device utilizes a method to secure the cartilage with tension during cutting, which also seemed to improve uniformity slices. This came at the expense of considerably increased preparation time, which involved mounting the rib between 2 posts via sutures.

The method used in our current study uses compression to clamp and secure the cartilage during cutting. This modification decreases the cartilage mounting time from several minutes to several seconds and provides increased stability during cutting. When using minimal compression forces just sufficient to secure the cartilage, the percentage difference in thickness for each cut porcine specimen ranged from 4.0% to 32%. Although the resulting slices were less uniform compared with those from our prior[6] study using tension, the differences are imperceptible on simple visual inspection. When increasing the clamping to a maximum pressure achievable by hand, the uniformity in thickness was further decreased such that some noticeable differences in uniformity were visually detectable. However, the imperfections were minimal, and the uniformity of even these specimens appeared to be adequate for clinical application. Therefore, although compression should ideally be limited, the principal priority should be ensuring adequate compression during cutting so that the specimen is sufficiently secure and does not move.

The microstructure and properties of cartilage play an important role in the cutting process. Costal cartilage is a hyaline type connective tissue that contains chondrocytes surrounded by a multi component matrix. The tissue is largely composed of water, and it is the interaction of this fluid with the solid matrix constituents that provides the characteristics and dynamic behavior of cartilage. Specifically, the anionic charge from proteoglycan side chains draws water into the tissue while the collagen network restricts the amount of swelling. This balance provides the compressibility and resilience of cartilage.

Inconsistencies in the uniformity of the cut cartilage slices may be partly due to local variations in the compressibility of cartilage. After the cartilage is cut and unclamped, the resilient tissue will expand or contract to its precompressed state. Therefore, if certain regions within the cartilage were under greater compression during cutting, these regions will expand more and result in increased thickness after cutting. Regional differences that may affect compressibility can be attributed to islands of calcifications and variances in water concentration. Furthermore, if the cartilage is not uniformly shaped, wider regions will be subject to greater compressive forces. Also, clamping curved specimens will straighten the tissue and potentially add an additional element of tension to the concave edge and compression to the convex side. Considering this hypothesis, increasing compression exacerbates the associated effects and decreases uniformity.

Variations in uniformity may also be due to errors in measurement. Measuring the thickness of cartilage requires an element of subjectivity owing to the compressible nature of cartilage and lack of a strict stop point when closing the jaws of the caliper. Also, the generation of pressure by the caliper may displace water from the region being measured and create a long-lasting indentation. However, this type of user error was minimized by having a single research assistant perform all measurements. Evaporative water loss from the fluid-rich tissue, which causes contraction, may also lead to minor differences in thickness. Furthermore, inspection of the porcine slices revealed small grooves and depressions along the cut surface of the cartilage, likely due to heterogeneous matrix components. These natural inconsistencies may exacerbate differences in thickness measurements.

The device was used to successfully cut appropriate costal cartilage grafts in the operative setting for 9 consecutive rhinoplasty cases in which rib was needed. There was no strict system on selecting graft thickness; however, none of the cases required using a spacer greater than 2 mm thick. We tended to use the 2-mm thickness more often for caudal septal extension grafts, whereas the 1-mm spacer was typically used for lateral struts, lateral crural replacements, and rim grafts. Although 1-mm and 2-mm spacers were sufficient for all of our cases, we felt that a 1.5-mm spacer would be a beneficial addition to the device. This spacer was thus manufactured and used in our last 2 cases and appeared to be well suited for most potential grafts used in rhinoplasty.

The thickness of the donor rib dictates the largest spacer size that can be used and thus the resulting thickness of the graft. Ideally, the donor rib should be at least 4 mm thicker than the desired spacer size, so that there is a 2-mm margin on both sides of the desired cartilage slice. A spacer that is too thick for the donor rib will increase the chance of the blade listing off to the periphery of the cartilage and preventing a complete cut. Trimming the edges of the cartilage along the long axis so that there is full contact between the clamping posts and the entire length of the rib also minimizes failure. If trimming is not an ideal option, the cartilage should be rotated so that the region of greatest contact between the cartilage and post is at the base. In 1 of our operative cases, there was concern that the donor rib, which was about 4 mm to 5 mm in total thickness, was not sufficiently thick for a 2-mm spacer. To minimize the risk of the blade listing through the side of the specimen, we appropriately trimmed the cartilage and secured the rib with an extreme amount of clamping pressure. The importance of this maneuver is to increase the stability of the cartilage. Although a much greater force is required to push the blade through the highly compressed rib, controlled and steady pressure successfully yielded the desired cartilage slice.

Curved cartilage slices, which are useful for alar grafts, can be fashioned by using a curved donor rib. The device will initially straighten out the curvature when the rib is clamped and enable simple cutting with the guided blade. However, after the cut is performed and the compression is released, the resulting cartilage slice will have a curvature similar to that of the original donor rib. Harvesting a donor rib with both a straight and curved region provides a method to obtain cartilage slices having shapes suitable for a wide variety of graft usages.

As a result of cutting a central slice with the device, 2 peripheral slices are consequently formed. These additional slices are useful for numerous graft types when the supply of the central slice is exhausted. In our case series, dorsal onlay grafts were often constructed from these peripheral slices. The canoe-like shape is helpful for fashioning the appropriate contour for the dorsum. Nevertheless, care must be taken to minimize the postoperative warping that occurs in these peripheral sections.[1, 7] Typically a percentage of the warping is allowed to equilibrate by intraoperatively placing the cartilage in saline for an extended period of time. Furthermore, the tensile forces that facilitate the warping process can be weakened with cross-hatching techniques. Other options referenced in the literature include using a Kirschner wire to mechanically arrest warping[8] and laser irradiation to accelerate warping to a steady state.[9]

Using the costal cartilage cutting device is straightforward and requires no special skill. However, several practice cuts may increase comfort level with using the device to its full potential. Porcine costal cartilage provides a good practice model because it is fairly similar to its human counterpart, easily accessible, and economical.

Conclusions

The costal cartilage cutter is a practical device for fashioning a wide variety of graft types in nasal reconstruction. The device uses a clamping mechanism to rapidly secure the rib, while a guide facilitates a double-bladed cutter to easily produce a cartilage slice with highly uniform thickness. Although clamping forces reduce uniformity, all cut specimens were well suited for use in facial reconstructive procedures. The versatile device can be adjusted to cut specific graft thicknesses and also be operated using specific techniques to achieve various graft shapes.

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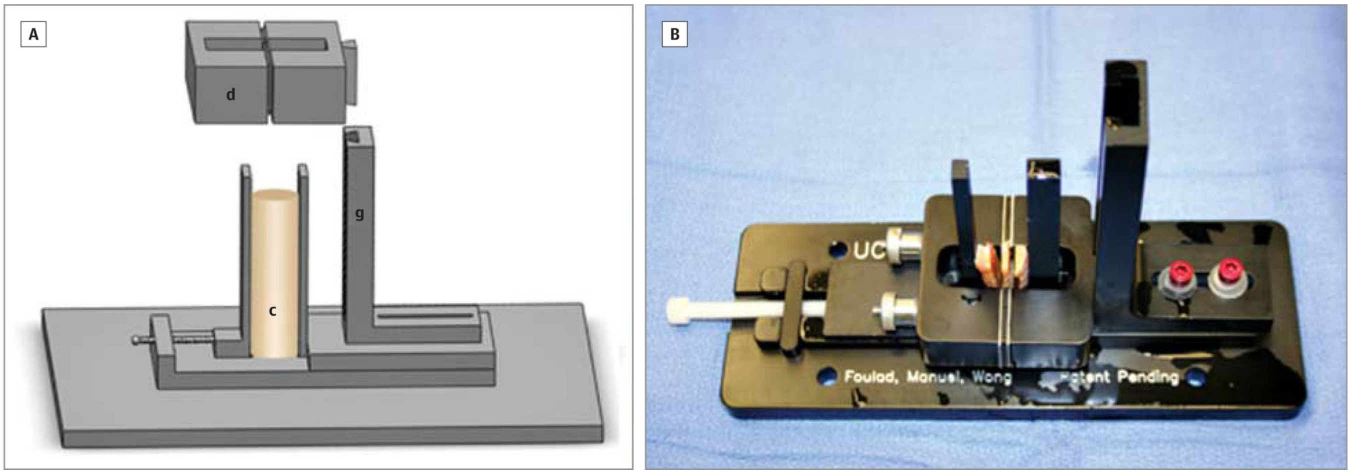

Figure 1.
Costal Cartilage Cutting Device
A, Computer-assisted design rendering of the device; d indicates double-bladed cutter; g, guide rail for cutter; and c, costal cartilage. B, Actual device, with the cutter pushed through the rib cartilage.

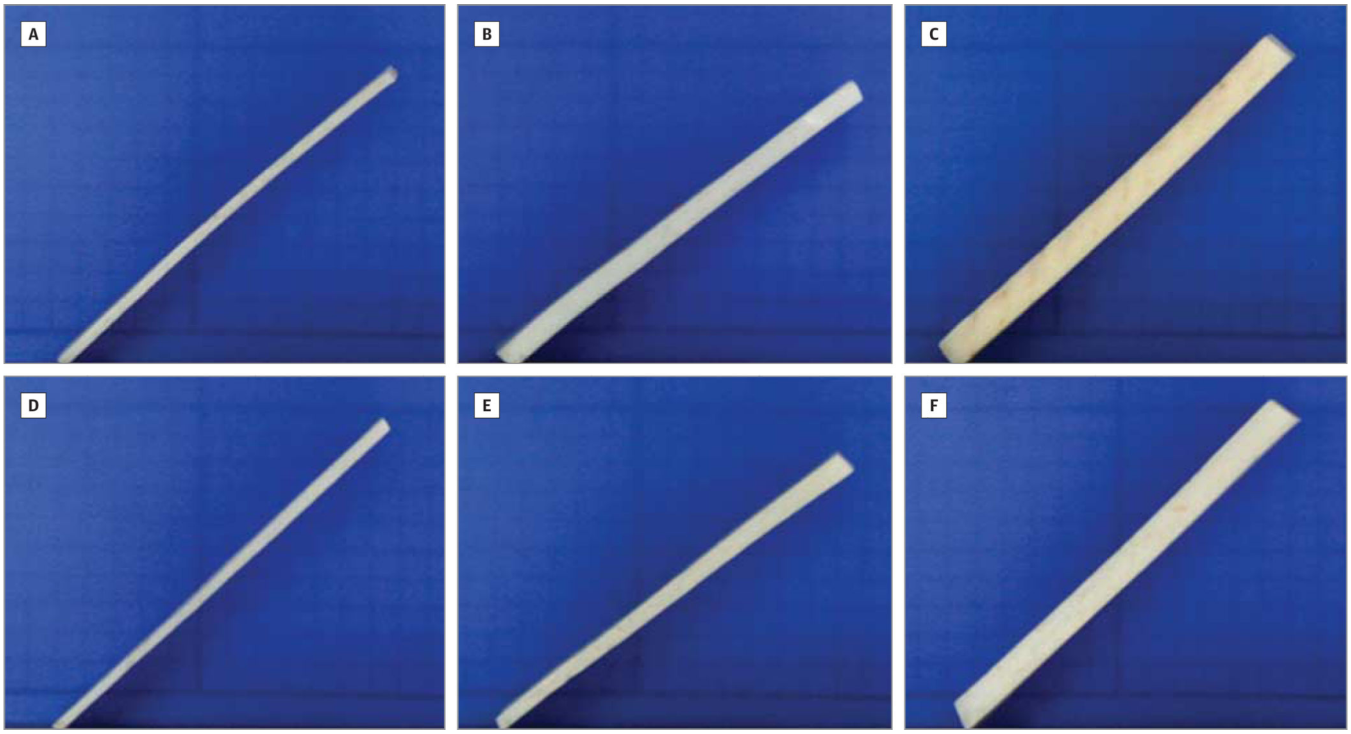

Figure 2.

Cartilage Slices Obtained Using the Costal Cartilage Cutter and Viewed From the Edge

A and D, B and E, and C and F correspond to slices obtained with a spacer thickness of 1 mm, 2 mm, and 3 mm, respectively. A-C, Slices obtained using minimal compression. D-F, Slices obtained using maximal compression. All images are scaled identically.

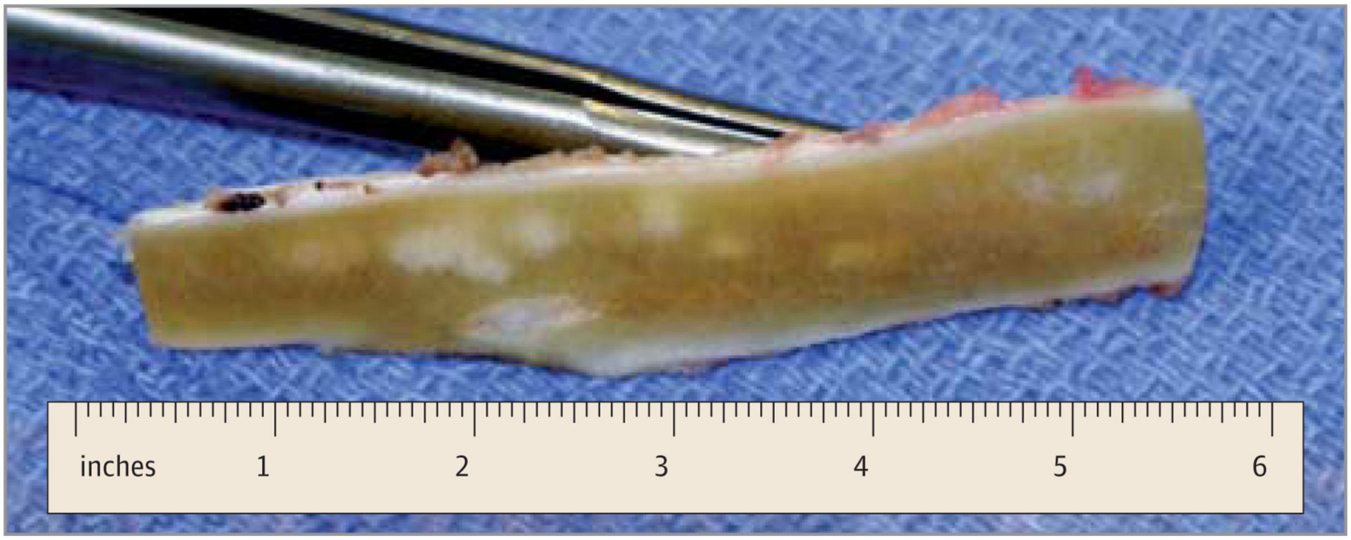

Figure 3.

Human Costal Cartilage Slice With Islands of Calcification That Was Sectioned Using the Cartilage Cutter Device

Ruler is mismarked; unit of measure is centimeters not inches.

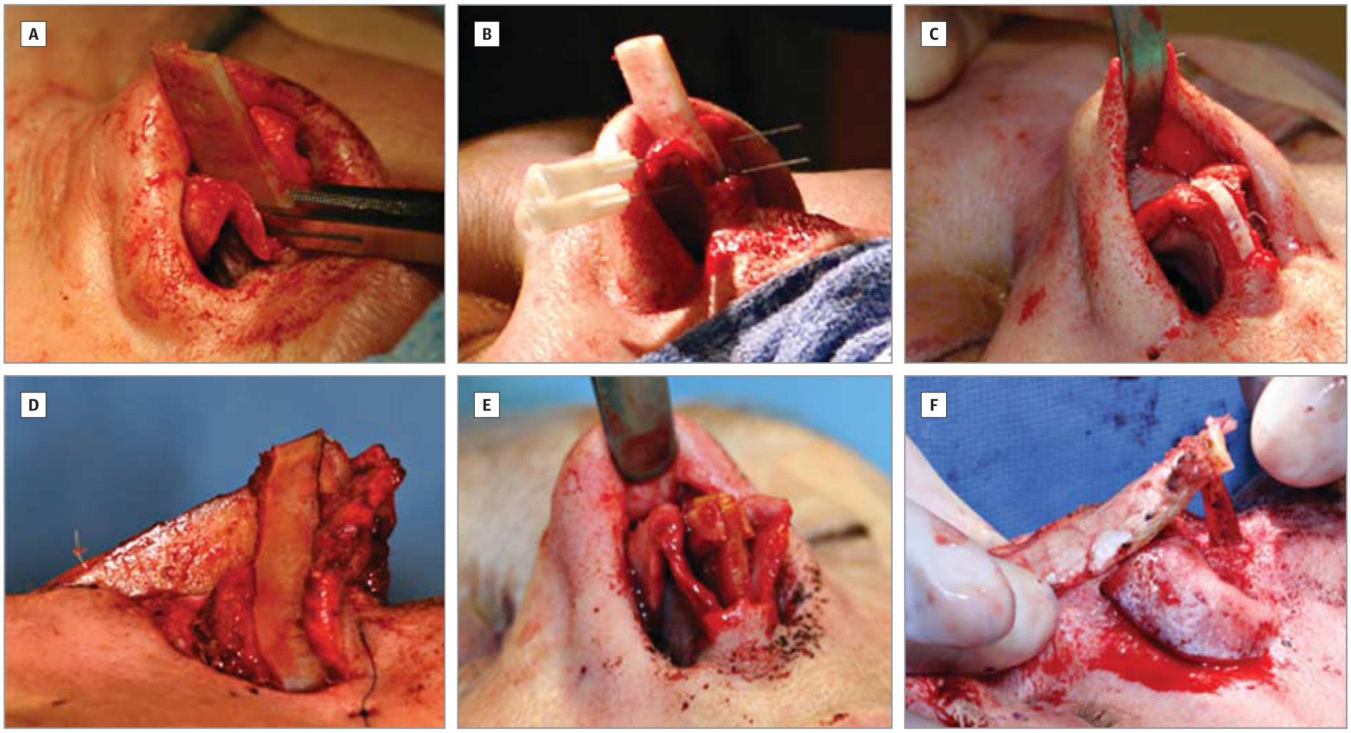

Figure 4.

Graft

A, Graft obtained using the 2-mm spacer and being positioned for use as a caudal septal extension graft. B and C, An additional case using a 2-mm caudal septal extension graft. The graft is temporarily secured with a needle then sutured in final position and trimmed. D, Lateral crural replacement graft obtained using a 2-mm spacer. E, Extended spreader grafts fashioned from a peripheral slice. F, Peripheral slice, still requiring final trimming, being used as a dorsal onlay graft.

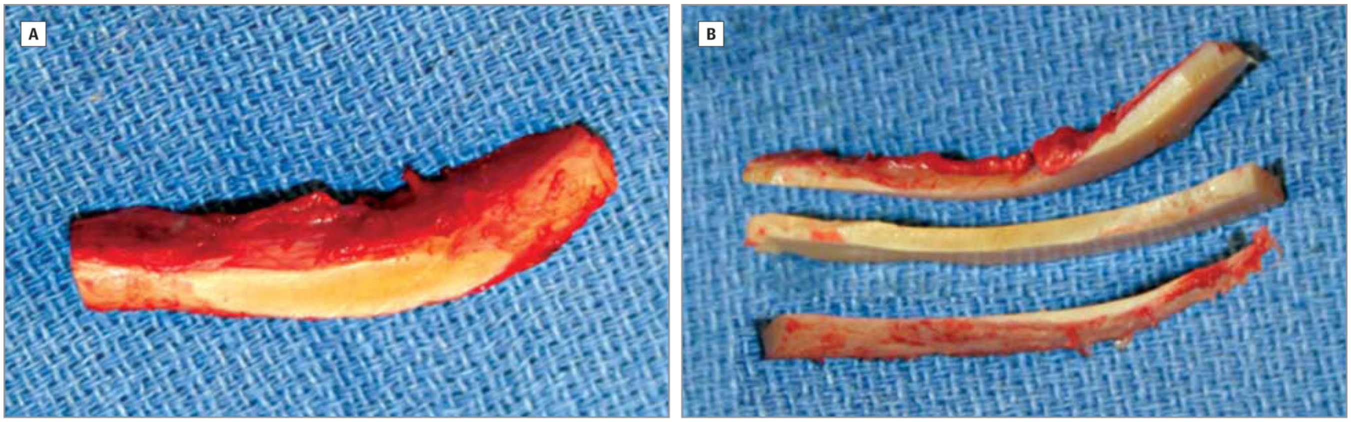

Figure 5.
Curved Donor Rib
Curved donor rib (A) yields similarly curved cartilage slices (B) when using the device.