Analysis of the Physical Properties of Costal Cartilage in a Porcine Model

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Objective: To determine the impact of interventions on the degree of warping of costal cartilage.

Methods: The project was conducted at a large university animal research laboratory. The costal cartilage of eight 30-kg domestic pigs was harvested. The cartilage was cut into central and peripheral segments with a standard cutting die. Two sizes of rectangular cubes were compared. The central portions of costal cartilage were segmented and glued with octyl-2-cyanoacrylate. The shape of the cartilage was documented with both digital and film photography. The cartilage was placed into subdermal pockets on the dorsum of the pigs. The animals were killed at 4 weeks, and the cartilage was photographed. Adobe Photoshop software was used to measure the degree of warping. Statistical analysis was calculated by t test analysis.

Results: A total of 115 rectangular costal cartilage blocks were treated. Large blocks warped less than small blocks ($P < .02$). Centrally cut blocks warped less than peripherally cut blocks ($P < .03$). The octyl-2-cyanoacrylate incited a significant sterile inflammatory response such that the blocks could not be accurately assessed for warpage.

Conclusion: Costal cartilage can be effectively used for grafting in rhinoplasty with minimal warping if large grafts from the central portion of cartilage are used.

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SECONDARY RHINOPLASTY IS A difficult operation. Scar tissue and deformities that the previous surgeon left behind must be dealt with systematically. Often it is not what the previous surgeon left but what was taken away that complicates the rhinoplasty. To correct tip deformities, augment the dorsum, and provide structural support to the nose, a large amount of grafting material is often needed. Deformities such as a severe saddle nose are difficult to correct using only septal cartilage, especially since the cause of the deformity is most often a paucity of septal cartilage. Autologous costal cartilage provides an abundant amount of grafting material that provides significant resiliency to counteract the inherent forces acting on the nose. The disadvantage of costal cartilage is its tendency to warp (change shape over time) postoperatively. While this warping does not affect the postoperative course in structural grafts such as spreader grafts or columellar struts, even minimal warping in costal cartilage used to augment the dorsum can lead to an obvious external deformity (Figure 1).

There are a variety of other options for augmenting the nasal dorsum. Auricular cartilage can be used to augment the dorsum; however, the contour of the cartilage increases the possibility of a visible edge deformity postoperatively. In addition, auricular cartilage will often not supply enough material to augment the dorsum and correct tip deformities. Alloplastic materials have been used in nasal reconstruction, and there are long-term studies showing minimal problems. The availability and ease of use are seductive; however, extrusion, infection, and the possibility of autoimmune complications can leave the patient with a bigger problem than they initially had. Irradiated costal cartilage has been shown to be a viable option and provides a significant amount of grafting material without any donor site morbidity; however, there remains the question of long-term resorption.

The properties of costal cartilage responsible for warping have been examined in previous studies. Fry demonstrated that protein polysaccharides within cartilage produce internal tensile stresses that cause the cartilage to change shape. It is the quest of the rhinoplasty surgeon to control these stresses to get a predictable postoperative result. Gibson and Davis showed that using balanced cross sections could diminish the chance of the
cartilage warping. When the central portion of the cartilage is carved, the stresses are balanced and the chance of warping decreased. However, even when the core of the costal cartilage is used, warping can still occur. In response to this dilemma, Gunter et al showed that inserting a metal wire through the cartilage decreased the incidence of warping, but there were problems such as wire extrusion and a tooth root being devitalized.

In the present study, we have attempted to balance the internal stresses by carving the central component of the costal cartilage. The central symmetrically carved component will be compared with the peripheral components of the costal cartilage. In addition, we have evaluated whether the cross-sectional area of the graft affects the tendency of the cartilage to warp. Finally, we segmented a subset of grafts to assess whether segmenting the cartilage and then reapproximating the segments with cyanoacrylate glue would decrease the amount of warping of the grafts.

We have hypothesized that by symmetrically carving the central segments of cartilage we will see less warp than in the peripherally cut grafts. Moreover, we believe that the larger the graft, the more the cartilage is able to withstand the internal forces that cause the warp to occur; therefore, the larger segments should warp less than the smaller segments. Finally, we believe that by interrupting the internal stresses by segmenting and reapproximating the cartilage segments, we will decrease the degree of warping.

METHODS

Eight 30-kg domestic pigs were used in this study. The operations were performed under the guidance of a licensed large animal veterinarian using general endotracheal anesthesia in sterile conditions. The chest and abdomen of the pigs were prepared with povidone-iodine solution. Bilateral 10-cm subcostal incisions were made, and the cartilaginous component of the inferior confluent ribs of each domestic pig was harvested. The ribs were then completely stripped of perichondrium.

The cartilages were then carved into 2 sizes of rectangular cubes, $4 \times 4 \times 20$-mm blocks and $2 \times 2 \times 20$-mm blocks, using a cartilage-cutting device similar to that described in previous studies. The $2 \times 2 \times 20$-mm cartilage blocks were divided into the following 4 groups: (1) centrally cut; (2) peripherally cut; (3) centrally cut, segmented, and glued; and (4) peripherally cut, segmented, and glued. The $4 \times 4 \times 20$-mm cartilage blocks were divided into the following 2 groups: (1) centrally cut and (2) centrally cut, segmented, and glued. The blocks of cartilage that were segmented and glued were cut perpendicular to the longitudinal plane with a No. 15 Bard Parker blade (BD Medical, Franklin Lakes, NJ) at 5-mm increments. The octyl-2-cyanoacrylate glue was placed between each segment. The segments were held in place until the glue was fixed.

Digital as well as 35-mm photographs were taken at a fixed distance from the specimens. The cutting die carved a rectangular cube of cartilage such that the side of the cartilage that was photographed was irrelevant. The pigs were then placed in the prone position, and the dorsum was prepared with povidone-iodine solution. The specimens were inserted into subdermal pockets on the dorsum of the domestic pigs. The pockets were labeled using a tattoo gun. The domestic pigs were then housed according to the protocol of the large animal care committee of the University of Illinois at Chicago. Four weeks after the intervention, the pigs were killed, and the cartilage blocks were harvested.

Digital and 35-mm photographs were taken at the same distance from the specimens. The cutting die carved a rectangular cube of cartilage such that the side of the cartilage that was photographed was irrelevant. The angle of warpage was calculated using Adobe Photoshop software (San Jose, Calif) by using the measure tool. The angle of warpage was defined by the angle created by 2 lateral portions of the rib connected with the point of maximal warpage.

Statistical analysis was calculated by a paired t test for means for pretreatment and posttreatment differences within treat-
ment groups, and comparison between treatment groups was calculated by comparing a 1-tailed $t$ test, 2 samples of unequal variances. A $P$ value less than .05 was considered significant.

Histologic evaluation was performed to assess the effect of the cyanoacrylate glue on the surrounding tissue of the segmented specimens, and these results were compared with findings in the nonsegmented specimens. All samples were fixed in paraffin and stained with hematoxylin-eosin.

**RESULTS**

A total of 115 rectangular costal cartilage blocks were treated according to group assignment, resulting in 26 large central unsegmented, 26 large central segmented, 17 small central unsegmented, 15 small central segmented, 15 small peripheral unsegmented, and 17 small peripheral segmented blocks (Table). Assessment of warpage was undertaken at baseline and at 4 weeks within each treatment group to determine if the degree of warping was statistically significant. In the large central core group, the mean baseline angle of warpage (176.8°) did not differ significantly from the mean warpage at 4 weeks (177.1°). However, in the small central core group, there was a significant difference between baseline (176.8°) and 4 weeks (174.4°) ($P<.02$). There was also a significant difference in the small peripheral group between baseline (176.7°) and 4 weeks (171.0°) ($P<.002$) (Figure 5).

To analyze the effect of the various treatment techniques on warping, the warping differences between baseline and 4 weeks were calculated within groups and compared. The warping differences are calculated values that demonstrated an increase in warping between baseline and 4 weeks. In the groups where warping was not observed, the value of 0 was assigned. Comparing the mean difference between small peripheral (6.47°) and small central (3.00°) treatment groups with a 1-tailed $t$ test revealed a significant difference between the 2 treatment techniques ($P<.03$). Similarly, a comparison between the small central treatment group (3.00°) with the large central group (1.12°) also revealed a statistically significant result ($P<.02$).

Gross evaluation of the treatment groups receiving cyanoacrylate glue revealed resorption of cartilage and fibrosis of the surrounding tissue that displaced the segmented cartilages. Histologic evaluation confirmed these findings, showing microscopic erosion and a proliferation of inflammatory cells surrounding the cyanoacrylate glue (Figure 6). Owing to these reactive changes, statistical measures were not obtained, and analysis could not be performed.

**COMMENT**

In 1900, von Mangoldt11 first described the use of autologous costal cartilage as grafting material for nasal reconstruction. Long-term follow-up has shown that cos-
Costal cartilage in nasal reconstruction provides durable bulk with minimal resorption. Autologous costal cartilage provides a large amount of grafting material, which is often needed in secondary rhinoplasty. Costal cartilage is easily contoured and rigid enough to provide structural support to the tip, but its tendency to warp can complicate the postoperative course.

Causes of a low nasal dorsum include traumatic disruption of the septal cartilage with or without a septal hematoma and/or abscess that results in a classic saddle-nose deformity; overaggressive reduction of a cartilaginous or bony hump; or a congenitally low dorsum. The therapeutic options available to correct this deformity are numerous. Autologous costal cartilage is the best-tolerated grafting material with the least incidence of infection and extrusion. The resorption rates of cartilage have been shown to be low. However, costal cartilage has the propensity to warp. When the graft is placed on the nasal dorsum, warping can lead to a significant physical deformity. Various techniques have been described to attempt to reduce the incidence of warping. One of us (D.M.T.) has routinely used the central portion of costal cartilage to augment the nasal dorsum.

To our knowledge, the present study is the first to quantitatively evaluate the degree of warping of costal cartilage in an in vivo model. Earlier studies have evaluated costal cartilage in an in vitro model to assess the factors that affect warping and the rate at which the warping occurs. Gibson and Davis studied 46 patients who had undergone costal cartilage augmentation of the nasal dorsum and determined that no warping had occurred. Those authors carved the costal cartilage grafts from the central portion of cartilage. The method of evaluation was a review of the patients’ charts for reports of clinical warping.

The benefit of the present study is that we were able to directly measure the degree of warping in costal cartilage and determine if there was a difference in the amount of warping associated with the intervention to the costal cartilage. We found that there was a significant difference in the degree of warping between cartilage cut from the periphery and that cut from the central portion. This agrees with the hypothesis that the internal subperichondrial forces of costal cartilage must be balanced to eliminate warping. Clinically, it is recommended to carve the costal cartilage in a balanced manner and allow the cartilage to soak in a saline solution, periodically evaluate the cartilage for areas of early warping, and compensate for the warping by carving the cartilage on the concave side. This process should be continued until a straight piece of cartilage is obtained, and then the graft can be placed with a high degree of certainty that it will not warp.

We also found that the smaller the cross-sectional area of the costal cartilage graft was, the more likely it was to warp. This is important because most patients who benefit from costal cartilage augmentation of the nasal dorsum require significant augmentation. For situations in which the patient only needs slight augmentation, auricular or septal cartilage might be the preferred grafting material owing to the higher probability of costal cartilage to warp.

The third portion of our study attempted to disrupt the internal subperichondrial forces of the costal cartilage. The costal cartilage grafts were cut into segments and glued together using octyl-2-cyanoacrylate. When compared with the nonsegmented grafts, the segmented and glued grafts displayed a significant amount of soft tissue inflammation. The histotoxic effects of cyanoacrylates have been shown in previous studies. We attempted to control the amount of cyanoacrylate that contacted the surrounding soft tissue by using minimal amounts. However, the slightest amount of cyanoacrylate initiated a significant sterile inflammatory response. The intensity of the response was so great that the grafts that were segmented and glued could not be accurately measured for warping. Owing to the significant histotoxic effects, we believe that cyanoacrylates should not be used to fix cartilage within the soft tissue of the nose.

A shortcoming of this study is that although this is an in vivo model, the inspiratory and expiratory forces that act on the nose were not duplicated. The grafts were purposefully placed on the dorsum of the pigs so that external forces acting on the cartilage would be minimized. Therefore, the degree of warping would be primarily due to the intrinsic forces of the costal cartilage. A human study would need to be done to incorporate the inspiratory and expiratory forces. Unfortunately, the possibility of that type of study is unlikely given the cosmetic deformities that may result. A better understanding of the physical properties of costal cartilage is still needed, but based on this study and preceding studies, the warping phenomenon can be minimized by carving symmetrically from the center of the rib and by using large cross-sectional areas.

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REFERENCES


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