Effects of Carving Plane, Level of Harvest, and Oppositional Suturing Techniques on Costal Cartilage Warping

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Background: Cartilage warping has plagued reconstructive and cosmetic rhinoplasty since the introduction of extra-anatomical cartilage use. With the present level of knowledge, there is no evidence of the warping properties with respect to cartilage harvest and suture techniques and level of rib harvest. This report aims to improve understanding of costal cartilage warping.

Methods: The sixth through tenth costal cartilages were harvested from six fresh cadavers aged 54 to 90 years. Warping characteristics were followed with respect to level of harvest (i.e., sixth versus seventh), carving orientation, and oppositional suturing. Digital photography of the specimens was performed at various time points (immediately, 1 hour, and 1 month postoperatively).

Results: All specimens showed signs of warping beyond 1 hour of carving that continued in a linear fashion to 1 month. There was no statistical difference in the amount of warping specific to the level of harvest, orientation, or with or without oppositional suturing ($p < 0.05$).

Conclusions: Cartilage warping remains a problematic obstacle in nasal reconstruction and revision rhinoplasty, but costal cartilage remains the workhorse graft and is an excellent autologous option. Our findings are the first to be described in the literature regarding warping characteristics of costal cartilage with regard to the level of harvest, orientation of carving, and oppositional suturing techniques in a cadaveric model. (*Plast. Reconstr. Surg.* 132: 319, 2013.)

Autogenous costal cartilage grafts are commonly used for nasal reconstruction and revision rhinoplasty. The ease of harvest, abundant supply, strength of cartilage, and versatility all make its selection an easy one when compared with other extraanatomical autologous tissue, synthetic implants, or allografts. Other extraanatomical autologous cartilage grafts such as auricular and nasal septal cartilage are still very useful and excellent options but have limitations on account of their volume and strength.[1–4] Synthetic/alloplastic implants have been beleaguered by their predisposition to foreign body reactions and extrusion, and heterografts were virtually abandoned after their unavoidable resorption rate and limitations with longevity.[4–20] Historically, one of the major obstacles of costal cartilage use that had plagued rhinoplasty and plastic surgeons was its inherent warping characteristics. Over the years, various costal cartilage harvesting and prefabrication techniques (e.g., combining an osseous portion or using irradiated cartilage, perichondrial preservation, carving principles, and hardware placement) have all been implemented by pioneers in rhinoplasty such as Gillies, Gibson, Davis, Fry, Millard, Gunter, and Daniel to counteract the unpredictability and to decrease the intrinsic warping tendencies of rib cartilage.[1–3,21–31]

In 1958, Gibson and Davis published their landmark work on the distortion of costal cartilage with thick versus thin carving, popularizing the current concept of balanced cross-sectional cartilage with central cartilage harvest to minimize the degree of rib cartilage warping and distortion.[1,13] This report dispelled the common technique of perichondrial preservation introduced by Gillies almost 40 years earlier, and provided excellent evidence regarding the principles of cartilage warping over time in a human cadaveric model.[27] Fry

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and colleagues expanded on the intrinsic interlocked stresses and mechanical characteristics of cartilage to lay the foundation for understanding the complexities of warping.[2,26] The novel concept of balanced cross-sectional carving and central harvest introduced by Gibson and Davis was further supported and reproduced by work from others, including Harris et al. and Adams et al., and had significantly decreased the high incidence of warping originally commonly seen with costal cartilage grafts for nasal reconstruction and rhinoplasty.[32,33]

Central and balanced cross-sectional carving assisted in decreasing the degree of warping observed with costal cartilage but, unfortunately, does not eliminate it. Techniques such as variation in level of harvest, cartilage irradiation, inclusion of an osseous component, and internal Kirschner wire placement have all been introduced in attempts to prevent intrinsic warping of costal cartilage.[7,21,28,34–40] Unfortunately, irradiated cartilage was not shown to decrease the incidence of warping over time when compared with autologous rib and Kirschner wire placement which, however beneficial, comes with the unavoidable and undesirable rigidity of internal fixation. There is sound evidence investigating the kinetics of the cartilage warping and the importance of understanding that cartilage will inherently warp with time, which should be taken into account with graft inset.

Interlocking stresses are created from the collagen scaffolding that is the infrastructure of all cartilage. These stresses create the intrinsic forces that lead to warping.[3,26] Our group theorized that instead of attempting to combat the unpredictable interlocking stresses intrinsic in the cartilage graft, it may be possible to redirect the stressors toward themselves and use these forces by specific carving and oppositional suturing techniques. This report provides (1) novel information with regard to the nature of costal cartilage warping with respect to level in Caucasian cadavers and (2) insight into warping characteristics with technical modification in carving plane and oppositional suturing techniques.

MATERIALS AND METHODS

Costal cartilage was obtained from six fresh cadaver specimens, four male and two female cadavers, from the University of Texas Southwestern Medical School Willed Body Program (aged 54 to 90 years) (Table 1). Bilateral cartilaginous ribs (sixth through tenth) were harvested from each cadaver. Rib segments were stripped of perichondrium and marked with latex dye to preserve orientation before any carving was begun. Following harvest, pieces were wrapped in saline-soaked gauze, sealed in airtight plastic hardware, and stored at room temperature. The specimens were divided into three groups, and standardized digital photographs were taken immediately after carving or suturing, at 1 hour, and at 1 month. To standardize the digital photography, an apparatus was developed to ensure the same focal length (15 cm) and orientation relative to the specimen for consistent imaging (Table 1).

Table 1. Comparison of the Three Groups*

	Group 1	Group 2	Group 3
No. of cadavers	2	2	2
Age, yr			
Mean	72	82	68
Range	54–90	67–90	64–83
Sex			
Male	1	1	2
Female	1	1	—

*Group 1, comparison of carving plane (anteroposterior vs. cephalocaudal). Group 2, comparison of anteroposterior carving plane vs. oppositional suturing in the anteroposterior plane. Group 3, comparison of cephalocaudal carving plane vs. oppositional suturing in the cephalocaudal plane.

Group 1: Anteroposterior versus Cephalocaudal Carving

Using two separate cadavers (one male and one female cadaver) the rib cartilage was harvested with a no. 15 blade into $4 \times 2.5 \times 20$-mm balanced cross-sections as described previously by Gibson (Fig. 1). Right segments ($n = 10$) were carved in

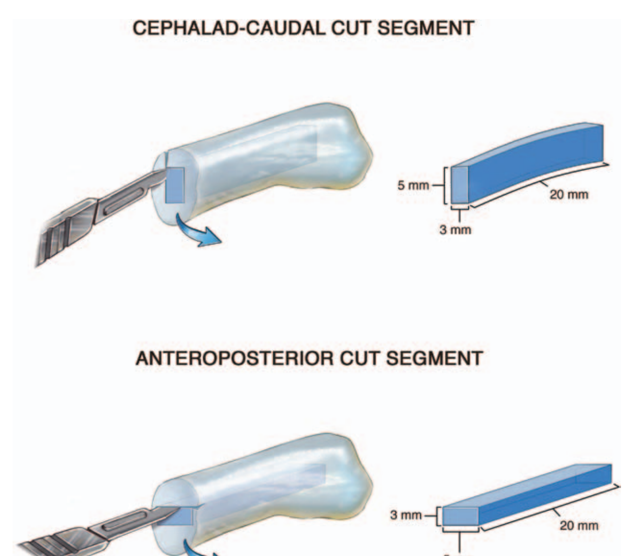

Fig. 1. Depiction of the anteroposterior versus cephalocaudad carving technique. (Created by MediVisuals, Inc.)

the anteroposterior axis and the matched contralateral segment ($n = 10$) was carved in the cephalocaudal axis, and each cadaver served as their own control. Photographs were taken immediately after dissection. Then, segments were wrapped in saline-soaked gauzed and stored at room temperature for further warping analysis, and photographs were taken at 1 hour after carving and 1 at month.

Group 2: Oppositional Suture Technique, Anteroposterior Plane

Using two separate cadavers (one male and one female cadaver) the rib cartilage was harvested with a no. 15 blade into 4 × 2.5 × 20-mm balanced central cross-sections in the anteroposterior plane. The central cross-section from each rib harvest from the left hemithorax ($n = 10$) was divided manually through the midline to create two 2 × 2.5 × 20-mm segments. These cartilaginous segments were then reversed onto each other and sutured together by means of two simple interrupted stitches and 6-0 polydioxanone suture (Fig. 2). Right hemithorax costal cartilage blocks ($n = 10$) underwent no oppositional suturing and were compared with the left segments from the same cadaveric specimen following oppositional suturing. Photographs were taken immediately after dissection and then segments were wrapped in saline-soaked gauzed and stored at room temperature until the aforementioned time points for digital photographic analysis.

Group 3: Oppositional Suture Technique, Cephalocaudal Plane

Using two separate cadavers (two male cadavers), the rib cartilage was harvested with a no. 15 blade into 4 × 2.5 × 20-mm balanced central cross-sections in the cephalocaudal plane. Right cartilage blocks ($n = 10$) were then compared with left segments ($n = 10$) that underwent the identical oppositional suture technique in the manner described in the previous models (Fig. 3). Photographs were taken immediately after dissection and analyzed in a similar fashion as in the previous models.

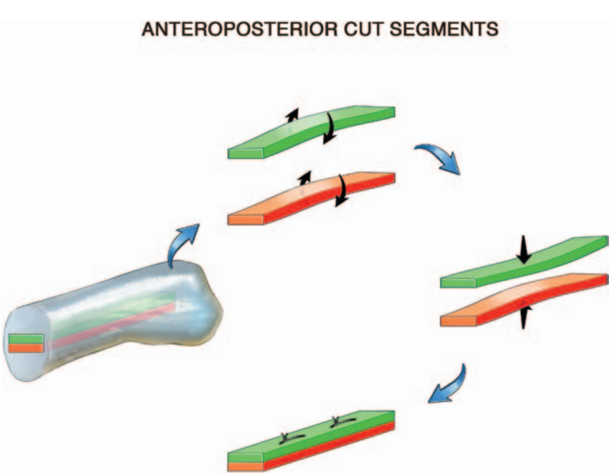

Fig. 2. Illustration depicting anteroposterior oppositional suturing technique. (Created by MediVisuals, Inc.)

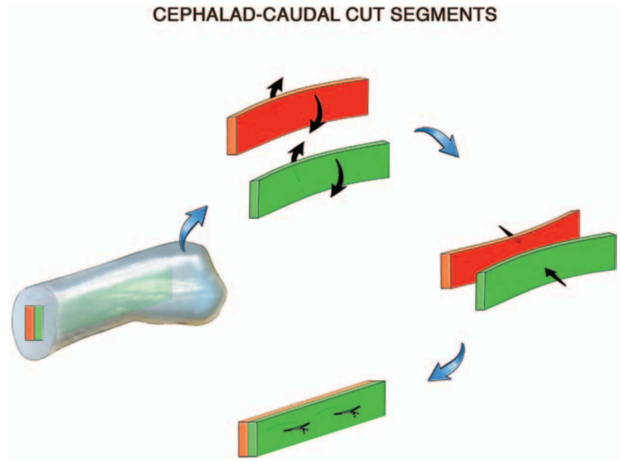

Fig. 3. Illustrated oppositional suture technique in the cephalocaudal plane. (Created by MediVisuals, Inc.)

Warping Analysis

Photographs were examined and analyzed to determine the degree of cartilaginous warping in the manner described by Foulad et al.[41,42] Briefly, digital images were uploaded into Adobe Photoshop CS5.1 (Adobe Systems, Inc., San Jose, Calif.), and the Magic Wand Tool was used to isolate the convex surface of the cartilaginous segment. A new image is created using this selection and this image is imported into Engauge Digitizer (freeware, Mark Mitchell). This software translates the arc of our image into discrete data points, which were then exported into Microsoft Excel (Microsoft Corp., Redmond, Wash.), and a quadratic regression is fit to the model. The parabolic coefficient (a) in this regression is then used as an objective numerical measure of warping. Statistical analysis was performed using IBM SPSS Statistics V19 (IBM Corp., Armonk, N.Y.). Comparisons were made between subgroups using two-sided paired t tests. One-way analysis of variance was used to compare change in warping over time for anteroposterior and cephalocaudal cut segments, and for detecting differences in warping by rib segment. The level of statistical significance was set at $p < 0.05$.

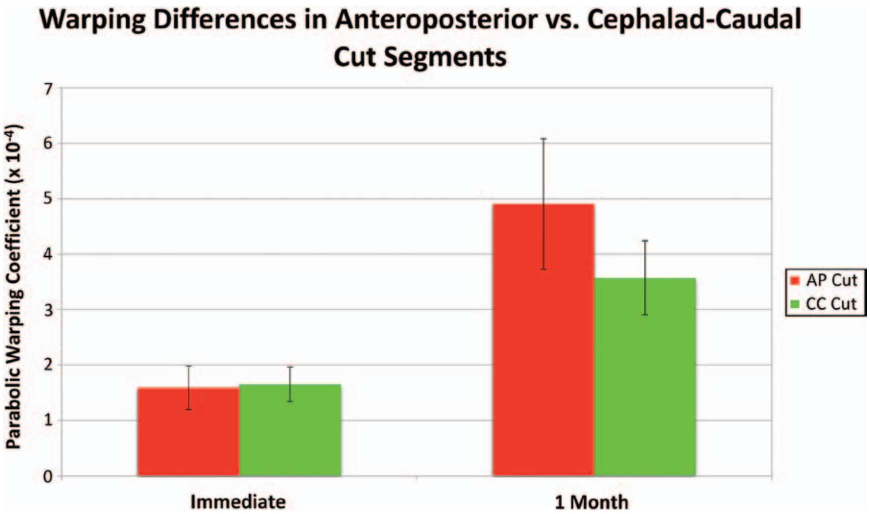

Fig. 4. Graphic representation of warping statistical differences of immediate compared with 1 month of anteroposterior (*AP*) carving versus cephalocaudad (*CC*) carving in costal cartilage specimens, which did not reach statistical significance ($p < 0.05$) (group 1).

RESULTS

Plane of Dissection

Twenty cartilaginous segments were compared in group 1 to determine whether plane of dissection influenced warping. Immediately after dissection, no differences were observed (anteroposterior, 1.59×10^{-4}; cephalocaudad, 1.65×10^{-4}; $p = 0.91$). Data were compared again at 1 month, and although both subgroups had warped in this time, differences were not significant by paired t test analysis (anteroposterior, 4.9×10^{-4}; cephalocaudad, 3.57×10^{-4}; $p = 0.34$) (Fig. 4). Both carving groups were found to significantly warp between the immediate time period and at 1 month (anteroposterior group, $p = 0.018$; cephalocaudad group, $p = 0.005$).

Oppositional Suture Technique

Opposing segments in group 2 displayed significantly less warping in the immediate time period than their matched pair (oppositional, 1.3×10^{-4}; carving alone, 2.7×10^{-4}; $p = 0.019$). At 1 month, however, differences were no longer significant (oppositional, 2.9×10^{-4}; carving alone, 3.8×10^{-4}; $p = 0.41$) (Fig. 5).

Opposing segments in group 3 did not display significant differences in warping relative to their matched controls at either the immediate (oppositional, 2.29×10^{-4}; carving alone, 2.08×10^{-4}; $p = 0.79$) or 1-month time point (oppositional, 3.28×10^{-4}; carving alone, 3.55×10^{-4}; $p = 0.77$) (Fig. 6). Warping was significantly increased in all

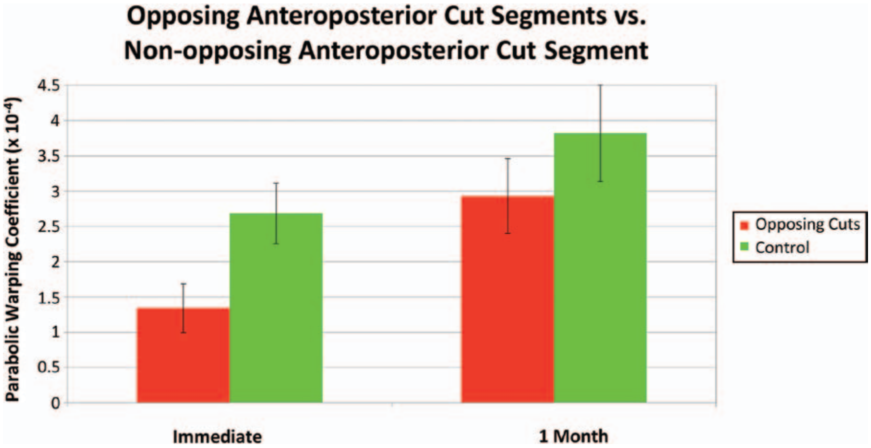

Fig. 5. Graphic representation of warping statistical analysis of opposition suturing versus anteroposterior carving (group 2), without a statistically significant difference ($p < 0.05$).

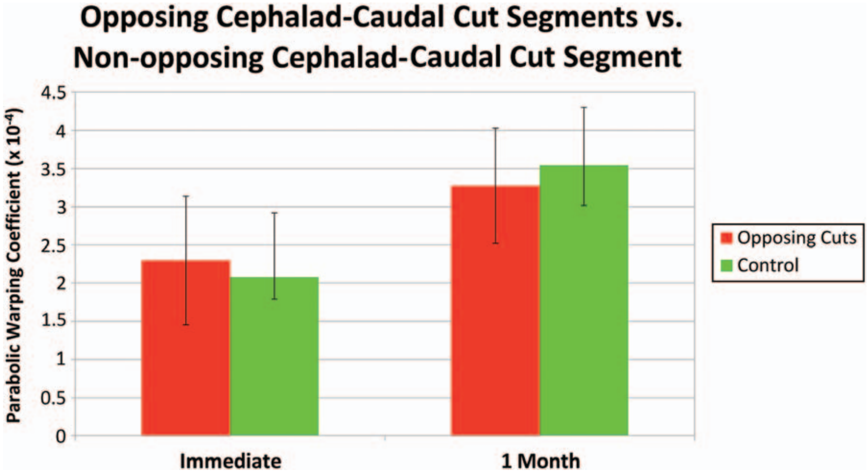

Fig. 6. Graphic representation of warping statistical analysis of opposition suturing versus anteroposterior carving (group 3), showing no significant difference ($p < 0.05$).

groups from time point immediately to 1 month after carving/suturing ($p < 0.05$).

Warping of Individual Rib Segments

Warping of individual rib segments (sixth through tenth) was analyzed using data from all group 1 specimens and the carving-alone specimens (right thoraces) from groups 2 and 3 ($n = 40$). Compared with immediate harvest, at 1 month, the warping increase in the sixth, seventh, eighth, ninth, and tenth ribs was 2.4, 1.9, 0.9, 2.6, and 1.9×10^{-4}, respectively. These differences were not significantly different when compared with one another ($p = 0.765$) (Fig. 7).

DISCUSSION

Costal cartilage continues to be a preferred option in cosmetic and reconstructive rhinoplasty on account of its reliability, volume, and strength. Warping remains a problematic obstacle, and its unpredictability, however small, continues to plague rhinoplasty surgeons. Balanced cross-sectional carving of costal cartilage with central harvest has lasted the test of time and proven to be very helpful in decreasing the amount of warping observed when costal cartilage grafts are used. Various studies have reaffirmed the findings of Gibson and Davis and the importance of perichondrial stripping and central harvest to balance the intrinsic interlocking stresses of the graft.[2,3,26,32,43,44] Techniques such as irradiation and scoring have failed the test of time with regard to warping prevention.[28,33–37,40,43,45–47] This study reaffirms the intrinsic warping characteristics of costal cartilage grafts at multiple levels of the thoracic cage, regardless of orientation of harvest or oppositional suturing techniques. Also contradicting current dogma that the majority of costal cartilage warping will occur within the first 15 to 30 minutes of harvest, our results reconfirmed that cartilage warping can occur outside of this window (up to 1 month) and likely will continue over time.[32,33]

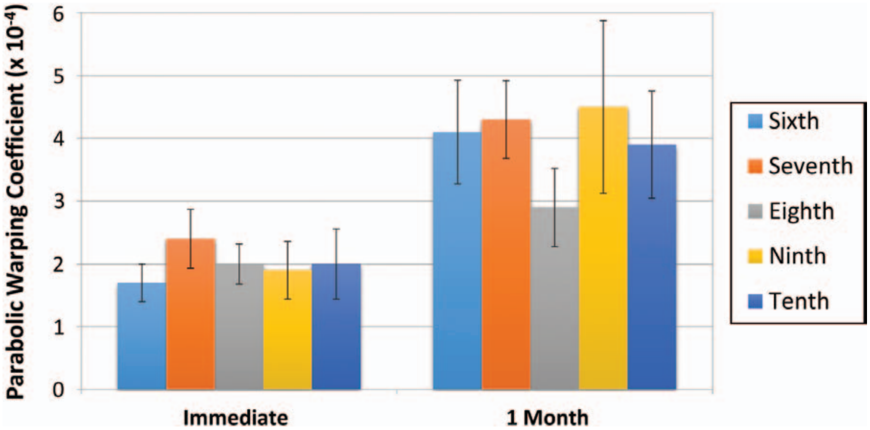

Fig. 7. Comparison of warping of the sixth through tenth segments.

There were obvious limitations to the study. First, our cadaveric costal cartilage is unavoidably more dehydrated, brittle, and calcified than younger autologous cartilage, in part because of chondrocyte viability, which studies have confirmed persists for only approximately 72 hours.[2] Second, variability in freehand specimen carving creates unavoidable interindividual differences between specimens. Third, obvious limitations on account of the small sample size result in an underpowered study, creating clear bias. Future study involving a larger sample size with younger, fresher specimens would assist in supporting the results reported in this study by simulating similar cartilage grafts used in clinical rhinoplasty.

This is a unique study that contributes further evidence regarding the intrinsic properties of costal cartilage warping over time at multiple levels of the rib cage, and continues to provide more information with regard to failure in prevention of warping with extrinsic manipulation including alteration of harvest orientation (anteroposterior versus cephalocaudad) or oppositional suturing techniques. It was hypothesized that these manipulation techniques should counteract the intrinsic warping forces by placing them toward each other; however, this study failed to demonstrate any change in the severity of warping of cartilage when compared with the matched controls. Costal cartilage is an excellent source of autologous graft for revision and reconstructive rhinoplasty on account of ease of harvest, volume, and strength. Warping remains an unpredictable property of cartilage grafting, and future study to prevent this intrinsic property is warranted.

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