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

Jordan P. Farkas, M.D.
Michael R. Lee, M.D.
Chris Lakanhi, B.S.
Rod J. Rohrich, M.D.
Dallas, Texas

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.)

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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. 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.

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. 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. 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).

**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 cephalocaudal carving technique. (Created by MediVisuals, Inc.)](image-url)
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 gauze 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 \(4 \times 2.5 \times 20\)-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 \(2 \times 2.5 \times 20\)-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 gauze 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 \(4 \times 2.5 \times 20\)-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.

**Warping Analysis**

Photographs were examined and analyzed to determine the degree of cartilaginous warping in the manner described by Foulad et al. 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 \(p < 0.05\).
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, $1.59 \times 10^{-4}$; cephalocaudad, $1.65 \times 10^{-4}$; $p = 0.91$). 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, $4.9 \times 10^{-4}$; cephalocaudad, $3.57 \times 10^{-4}$; $p = 0.34$) (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, $1.3 \times 10^{-4}$; carving alone, $2.7 \times 10^{-4}$; $p = 0.019$). At 1 month, however, differences were no longer significant (oppositional, $2.9 \times 10^{-4}$; carving alone, $3.8 \times 10^{-4}$; $p = 0.41$) (Fig. 5).

Opposing segments in group 3 did not display significant differences in warping relative to their matched controls at either the immediate (oppositional, $2.29 \times 10^{-4}$; carving alone, $2.08 \times 10^{-4}$; $p = 0.79$) or 1-month time point (oppositional, $3.28 \times 10^{-4}$; carving alone, $3.55 \times 10^{-4}$; $p = 0.77$) (Fig. 6). Warping was significantly increased in all
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 \(1.9 \times 10^{-4}\), 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.²⁻³,²⁶,³²,³³⁻³⁴ Techniques such as irradiation and scoring have failed the test of time with regard to warping prevention.²⁸⁻³⁷,⁴⁰,⁴³⁻⁴⁷ 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 reaffirmed that cartilage warping can occur outside of this window (up to 1 month) and likely will continue over time.²²,³³
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. Second, variability in freehand specimen carving creates unavoidable interindividually different 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.

**REFERENCES**


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Beginning in July of 2007, *PRS* has required all articles reporting results of clinical trials to be registered in a public trials registry that is in conformity with the International Committee of Medical Journal Editors (ICMJE). All clinical trials, regardless of when they were completed, and secondary analyses of original clinical trials must be registered before submission of a manuscript based on the trial. Phase I trials designed to study pharmacokinetics or major toxicity are exempt.

Manuscripts reporting on clinical trials (as defined above) should indicate that the trial is registered and include the registry information on a separate page, immediately following the authors’ financial disclosure information. Required registry information includes trial registry name, registration identification number, and the URL for the registry.

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