Tensile Characteristics of Costal and Septal Cartilages Used as Graft Materials

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Objectives: To determine the biomechanical characteristics of septal cartilage (SC) and costal cartilage (CC) taken from fresh cadavers using tensile testing and to establish CC graft material of a suitable thickness (ie, with tensile characteristics closest to those of SC).

Methods: Grafts of varying thickness were harvested from the central part of the seventh-rib CC and SC of 18 fresh cadavers. Tensile testing was performed with a 0.5-kilonewton load calibrated at 7 mm/min. The results were shown as a force-elongation curve.

Results: No significant difference according to tensile force was observed between the SC group and the 1.0-mm and 1.5-mm CC groups (P = .09 and P = .32, respectively). However, a significant difference was observed between the SC group and the 2.0-mm CC group (P = .04). Although the strength value of the CC group was 5.03 MPa, the modulus of elasticity was 1.33 MPa. In the SC group, the strength value was 12.42, but the modulus of elasticity was 1.39 MPa. The strength value of the SC group was higher than that of the CC group (P = .001), but the modulus of elasticity value of the CC group was higher than that of the SC group (P = .001).

Conclusions: From the standpoint of tensile testing for preparing columellar struts, 1.0-mm and 1.5-mm CC have similar characteristics to SC and thus can be used instead of it. However, it is important to determine the thickness of CC by considering the expected characteristics of the established material and the forces that affect the area in the nose where the graft will be placed.

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ARTILAGINOUS GRAFT MATERIALS are frequently required in revision and augmentation surgery after rhinoplasty and septal reconstruction, as well as in septal elongation.1 If obtainable, septal cartilage (SC) is the first choice for graft material.2 Septal cartilage may not be obtainable for revision surgery when trauma or infection has caused cartilage dissolution.3 Depending on the size of the defect, auricular cartilage or costal cartilage (CC) (in bigger defects) can be used autologously.2,4,5 Both SC and CC are biphasic materials that consist of a solid phase and a fluid phase. The solid phase (ie, solid matrix) is elastic and permeable to fluid.6

One of the factors that should be considered when performing autologous grafting is the similarity of the graft material to SC in terms of durability and rigidity.1 Emerging technologies in cartilage tissue engineering may address some of the biomedical need for chondral grafts, but tools and techniques are needed to create cartilage constructs of desired shapes.2 No sufficient information exists in the medical literature with regard to which mechanical characteristics, shapes, and sizes of cartilage produce the best result. In this study, we researched the similarity of the tensile characteristics of CC and the dimensional characteristics that would provide tensile characteristics similar to those of SC.

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Methods
Study approval was obtained from the Training and Work Council of the Ministry of Justice of Turkey. The seventh rib in each of the 18 fresh cadavers (ie, dead for 6-8 h) was reached through the existing incisions (Figure 1). Leaving a 5-mm support between the septum and the dorsum, the remaining SC was excised. The grafts were wrapped in gauze dampened with normal saline, placed into a transport pack containing ice, and brought to the laboratory. Grafts 1.0 mm to 1.5 mm and 2.0 mm thick were harvested from the central parts of the CC with a low-speed saw designed to separate cartilage from bone (model No. 11-1280-250; Buehler Ltd, Lake Bluff, Il-
A dog bone–shaped cutting mold (Figure 2) was placed longitudinally into the center of each of the study specimens; however, only the middle part of the mold was used to cut cartilage. The thickness of each SC graft was determined with a digital caliper (Mitutoyo Corporation, Kanagawa, Japan). The CC and SC were fixed as having a length of 15 mm and a width of 3 mm.

Tensile testing was performed using a desktop-type, single-column testing system with a 0.5-kilonewton (kN) load capacity (Instron 3340; Instron, Norwood, Massachusetts). The longitudinally harvested specimens were attached between tensile grips with 2-component adhesive (333 Activator 5000; Elkim Elektro Kimya San. Tic. A.S., Istanbul, Turkey) (Figure 3). The tensile rate was determined to be 7 mm/min; the maximum force value at the point when samples ruptured was noted.

Test results were presented as a force-elongation curve, based on the force applied by crossheads and the elongation difference of the sample on the vertical and the horizontal axes. The curves for SC and CC are shown in Figure 4; tests on both were performed under the same conditions. The maximum force and elongation values, which later would determine the results of the test, were detected by determining point coordinates over the curves and reading the test output on the digital display of the tensile device.

Strength could be defined as the ability of a material to withstand an applied stress without failure. When a material undergoes a mechanical deformation, the force per unit area is defined as stress. Therefore, the strength of the cartilage samples was calculated by dividing the maximum force by the cross-sectional area. The elongation value was divided by the original length of the specimen to calculate the strain, which is the deformation in response to an applied force. Thus, the force-elongation curve was converted to the stress-strain curve.

The modulus of elasticity, also known as the Young modulus, was calculated from the slope of the linear portion, which is the elastic region of this curve. The stiffer a material is, the higher the modulus of elasticity value and the more difficult it is to deform.

Various models exist for viscoelastic materials such as different types of cartilage. The most popular and widely accepted among the viscoelastic behavior models is the Kelvin-Voigt model. In accordance with this model, the modulus of elasticity was established for the partial values of the curve by opening a partial window where the curve drawn by the tensile device showed linearity. In these experiments, rather than using the modulus of elasticity, the tensile forces affecting the cartilage or tensile strength (measured as force per unit area) should be used for testing cartilage samples in the same conditions. Comparison can be done by expressing the force in N and the strength in megapascals (MPas).
Table. Force Applied to Septal and Costal Cartilage Grafts

<table>
<thead>
<tr>
<th>Cartilage Graft Type</th>
<th>Samples, No.</th>
<th>Force, N</th>
<th>Mean (SD)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Septal</td>
<td>16</td>
<td>0.018-0.006</td>
<td>0.009-0.030</td>
<td></td>
</tr>
<tr>
<td>1-mm costal</td>
<td>16</td>
<td>0.016-0.008</td>
<td>0.007-0.033</td>
<td></td>
</tr>
<tr>
<td>1.5-mm costal</td>
<td>13</td>
<td>0.024-0.010</td>
<td>0.011-0.041</td>
<td></td>
</tr>
<tr>
<td>2.0-mm costal</td>
<td>17</td>
<td>0.029-0.009</td>
<td>0.012-0.042</td>
<td></td>
</tr>
<tr>
<td>1-mm septal</td>
<td>16</td>
<td>0.018-0.006</td>
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<td></td>
</tr>
<tr>
<td>2.0-mm septal</td>
<td>17</td>
<td>0.029-0.009</td>
<td>0.012-0.042</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5. Mean values of strength (σ) and modulus of elasticity (E) obtained from tensile tests.

Statistical analyses were performed with SPSS statistical software, version 16 (SPSS, Inc, Chicago, Illinois). One-way analysis of variance was used for comparing independent multiple groups. The Tukey post hoc test was used for comparing subgroups. P < .05 was considered statistically significant.

RESULTS

Eighteen male cadavers were used in the study; the mean age at death was 37.2 years (age range, 35.2-40.9 years). Grafts that were perforated by vessel transition and those that had not been kept in an appropriately cool environment during graft preparation were discarded. Thus, 16 grafts of 1.0 mm thickness, 13 grafts of 0.5 mm thickness, and 17 grafts of 2.0 mm thickness were included in the study. The mean thickness of the SC grafts was 1.38 mm (range, 1.10-1.67 mm). The mean tensile force was 0.018 N in the septum group (range, 0.009-0.030 N), 0.016 N in the 1-mm graft group (range, 0.007-0.033 N), 0.024 N in the 1.5-mm graft group (range, 0.011-0.041 N), and 0.029 N in the 2.0-mm graft group (range, 0.012-0.042 N). No significant difference was found between SC grafts and 1.0- and 1.5-mm CC grafts in terms of tensile forces (P = .09 and P = .32, respectively) (Table). A significant difference was found between the SC grafts and the 2.0-mm CC grafts (P = .04).

These variables were checked in the CC and SC groups, keeping in mind that results obtained from all CC should be the same because strength and the modulus of elasticity are specific characteristics that are independent of the cross-section of the material. The strength value of the CC grafts in the study was 5.03 MPa, and the modulus of elasticity was 1.33 MPa; the strength value of the SC grafts was 12.42 MPa, and its modulus of elasticity was 1.39 MPa (Figure 5). The strength value of the SC grafts was found to be higher than that of the CC grafts (P = .001), and the modulus of elasticity of the CC grafts was higher than that of the SC grafts (P = .001). The force values of the SC and CC grafts are shown in Figure 6, in which an SC control group is chosen and cross-sectional areas of the CC grafts are changed (Table).

Elongation differences also were observed during the test for the 1.0-mm, 1.5-mm, and 2.0-mm CC grafts compared with the SC control sample. The mean values for elongation were 1.98 mm for the SC grafts, 1.94 mm for the 1.0-mm CC grafts, 2.01 mm for the 1.5-mm CC grafts, and 2.34 mm for the 2.0-mm CC grafts. From these data, it could be said that the elasticity characteristics closest to the septum were exhibited by 1.0-mm and 1.5-mm CC grafts.

The purpose of rhinoplasty and septal reconstruction is to provide septal structuring and dorsal stabilization to ensure nasal tip projection and support and to maintain optimum respiratory function. Choosing appropriate graft material is important in achieving this goal. To be able to provide the desired aesthetic result, strength, and durability, CC is the preferred autologous graft material for traumatic saddle nose deformity; for congenital nasal deformities, after neoplastic resection, in noses with low forward projection; for rhinoplasties in patients with Asian ethnicity; and for rhinoplasty revisions. Despite issues such as requirement of surgical experience, donor morbidity, and the extended duration of surgery, sufficient cartilage still is used to provide graft material.3

The safety of rhinoplasty and septal operations still is being debated today because of the dynamic structure of the nose and because the effects of internal and external mechanical loads that the nose may experience have not fully been determined yet. Although a number of publications since that of Anderson11 explained the tripod theory, few experimental studies have been published that focus on the durability and the response of nasal graft to external factors.1,12,13

The nose is exposed to the external forces of compression, tension, bending, and the combination of these. Lu and Mow6 suggest that in biomechanical articular cartilage undergoing compressive loading, interstitial fluid...
would begin to flow through the tissue. The fluid passing through the solid matrix generates high frictional resistance and therefore is the primary mechanism giving rise to the frictional dissipation responsible for the viscoelastic behavior of the cartilage undergoing compression. However, we did not use articular cartilage or compression force. Because the SC and CC do not contain much fluid, no possibility exists of high frictional resistance occurring.

Our study specifically presents the tensile characteristics of SC and CC, which are widely used as autologous graft material. One of the common problems in using CC is the distortion of cartilage appearing in long-term follow-up. To prevent distortion, the central portion of the cartilage should be used.9,10 Also, the sixth-, seventh-, and eighth-rib CC should be used. Results of a computed tomographic examination of the thorax in a study by Windfuhr et al14 shows that the seventh-rib CC has the most material suitable for grafting and is ideally located. In our study, grafts were harvested from the central parts of the seventh-rib CC of the cadavers.

The CC should be prepared in a specific way to ensure an aesthetic appearance and durability appropriate for the nasal type in question. No previous studies, to our knowledge, have specified any appropriate criteria for such preparation. However, some studies1,13,16 have examined which physical and elastic characteristics would be helpful in preparing suitable grafts. Cardenas-Camarena et al17 studied cellular content, intercellular characteristics, matrix context, and fiber distribution and compared the physical–elastic characteristics of autologous cartilage grafts. In that study, CC samples and alar cartilage were observed to be similar and to contain fewer cells and more intercellular materials. Also, the intercellular material was shown to be formed of collagen, displaying homogeneous distribution. In addition, the auricular cartilage was shown to be formed of intracellular material consisting of more cells and less irregularly distributed elastic fibers.

Westreich et al18 evaluated the modulus of elasticity of inferior and superior lateral cartilage samples, SC, and auricular cartilage samples in the first biomechanical study in the medical literature, to our knowledge. This work showed that SC had the highest modulus of elasticity, followed by superior and inferior lateral cartilage. Also, it was shown in vivo that the hardness of the graft would decrease significantly after it was taken from the septum and thinned to make a columellar strut.

Tensile strength was observed to increase with the increase in modulus of elasticity. Increase in modulus of elasticity and strength caused the decrease of elongation in breakage. These values are presented as a force-elongation curve in Figure 4. Here, the septum, which showed a rapid upward slope (ie, had a higher slope angle), showed lower elongation. In contrast, CC had a lower elasticity modulus but higher elongation compared with SC.

As a result, problems may arise concerning long-term durability when thinning SC to make columellar struts. For this reason, using CC in the nasal tip area can be appropriate when a thinner cartilage graft is required for cosmetic purposes and long-term stabilization. Our study shows that SC with a mean thickness of 1.37 mm can withstand force similar to that which can be withstood by the 1.0-mm and 1.5-mm CCs. The closest elongation to the septum is shown by 1.5-mm CC.

Age is an important factor for biomechanical behavior. As the patient ages, his or her cartilage will become more brittle; however, in our study, the cadavers were close in age, so this effect varied little.

Consequently, we conclude that SC instead of CC should be used as graft material. However, determining the thickness of the CC is a necessary prerequisite. The aspects to be evaluated are the force values obtained during tests, depending on the cross-sections of cartilage. The important data obtained from the results demonstrate that it is possible to use CC instead of SC if the CC samples are 1.0 mm and 1.5 mm thick, respectively. We also conclude that for columellar strut preparation, CC is similar to 1.0 mm and 1.5 mm SC from the standpoint of biomechanics and thus, CC can be used instead of SC. However, it is important to determine the thickness of the CC to be used by considering the expected characteristics of the established material and the forces that affect the nasal area where the graft will be placed.

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Author Contributions: Drs Alkan and Unal and Ms Bekem had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Alkan, Yigit, Acioğlu, Bekem, Kocak, and Unal. Acquisition of data: Alkan, Bekem, Azizli, Unal, and Buyuk. Analysis and interpretation of data: Alkan, Bekem, and Unal. Drafting of the manuscript: Alkan, Acioğlu, Bekem, Azizli, Unal, and Buyuk. Critical revision of the manuscript for important intellectual content: Alkan, Yigit, Bekem, Kocak, and Unal. Statistical analysis: Alkan and Acioğlu. Obtained funding: Alkan, Acioğlu, Bekem, Kocak, Unal, and Buyuk. Administrative, technical, and material support: Alkan, Bekem, Azizli, and Unal. Study supervision: Alkan, Yigit, Bekem, and Unal.

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