Anterior and Posterior Cartilage Graft Dimensions in Successful Laryngotraheal Reconstruction

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Objective: To describe the dimensions of cartilage grafts used for successful laryngotraheal reconstruction, with the goal of establishing appropriate sizes for “off-the-shelf” tissue-engineered cartilage grafts.

Design: A retrospective review of prospectively maintained operative illustrations of a single surgeon’s experience.

Setting: Two tertiary children’s hospitals.

Patients: A consecutive sample of 54 patients (tracheotomized or intubated) with a diagnosis of subglottic stenosis.

Interventions: Each patient underwent anterior (n=30), posterior (n=3), or anterior and posterior (n=22) laryngotraheal reconstruction. Rib cartilage was used in 51 patients and thyroid cartilage was used in 3 patients.

Main Outcome Measure: Successful or failed extubation.

Results: Of the 54 patients, 48 (89%) were successfully decannulated. The mean ± SEM length of the anterior graft was 20.7±10.3 mm, and the mean width of the anterior graft was 7.7±2.5 mm. The mean length of the posterior graft was 13.9±2.9 mm, and the mean width of the posterior graft was 4.2±0.9 mm.

Conclusions: With the prospect of tissue-engineered cartilage implants becoming available for laryngotraheal reconstruction, the most appropriate templates for designing these implants should be based on the geometric dimensions of grafts carved from native tissues in cases that have been successfully decannulated. Based on our analysis, the use of 2-mm increments for the posterior grafts suggests a set of molds that are 2, 4, and 6 mm wide and 22 mm long. Using 2×2-mm increments for the anterior grafts indicates that 36 mold sizes will be sufficient for 90% of predicted cases.

LARYNGOTRAHEAL RECONSTRUCTION (LTR) with autologous cartilage grafts (anterior only, anterior and posterior, or posterior only) has been demonstrated to be an effective and reliable technique for the surgical management of severe subglottic stenosis. Its consistent utility has been well described for the past 27 years from many different institutions around the world. The ribs are the most commonly used source of cartilage for LTR, although thyroid cartilage is a readily available alternative in special cases. The 3 primary disadvantages of native rib cartilage are donor site morbidity, the operative time needed for harvest, and the time required for carving the cartilage into the appropriate configuration.

In an effort to overcome these limitations, several alternative materials to cartilage have been proposed; however, they remain for the most part experimental and clinically unproved. The prospective availability of tissue-engineered cartilage holds the promise of “off-the-shelf” grafts that may be implanted directly for airway reconstruction, bypassing the need for autologous harvest and carving. In working toward this goal, the most appropriate templates for engineering these implants should be based on the geometric dimensions of grafts in children who have undergone decannulation after surgery for subglottic stenosis. The objective of this report is to describe the dimensions of cartilage grafts used for successful LTR as the means for establishing the appropriate sizes for tissue-engineered cartilage grafts.

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METHODS

During a period of 15 years (1989-2004), at 2 different tertiary care medical centers (Albany Medical College, Albany, NY, and The Cleveland Clinic, Cleveland, Ohio), 54 consecutive pediatric patients underwent LTR with autologous cartilage grafts (anterior, anterior...
and posterior, and posterior) performed by the same surgeon (P.J.K.). Graft sizes were prospectively recorded at the time of the procedure in an operative journal maintained by the surgeon, as was the success or failure of the subsequent extubation of the patients. These records were retrospectively reviewed and subjected to statistical analysis (S-Plus 6; Insightful Corp, Seattle, Wash). The intent of our calculations was to determine the spectrum of graft sizes used successfully in LTR. Tissue-engineered cartilage grafts could then be constructed with the appropriate dimensions, with the goal of developing prostheses that could be used off-the-shelf.

RESULTS

Among the 54 patients, the median age was 3 years and the mean ± SEM age was 6.3±6.6 years. Thirty of the 54 patients had anterior grafts only; 4 had posterior grafts only; and 20 had both anterior and posterior grafts. Rib cartilage was used in 51 patients for the LTR, and thyroid cartilage was used in 3 patients for the LTR. Forty-eight (89%) of the patients were successfully decannulated. Among the 48 patients, the median length of the anterior graft size (n=44) was 18 mm (range, 7-70 mm); the mean ± SEM length of the anterior graft size was 20.7 mm ±10.3 mm; the median width of the anterior graft size was 7 mm (range, 3-12 mm); the mean width of the anterior graft size was 7.7 mm ±2.5 mm; the median length of the posterior graft size (n=20) was 15 mm (range, 7-19 mm); the mean length of the posterior graft size was 13.9±2.9 mm; the median width of the posterior graft size was 4 mm (range, 3-6 mm); and the mean width of the posterior graft size was 4.2 mm ±0.9 mm.

COMMENT

Several research groups have developed cartilage tissue engineering models for LTR using in vivo animal models, with varying amounts of success.16-18 As techniques for bioengineering cartilage improve, there will be increasing interest in the use of tissue-engineered cartilage in LTR. To design appropriate templates for LTR grafts, the geometric dimensions of grafts carved from native cartilage tissue need to be determined in cases that have been successfully decannulated. Ideally, it would be desirable to have the fewest number of engineered grafts but enough selection to satisfy the reconstructive needs of each patient. Applying a suitable statistical model appears to be the most logical means of achieving this goal.

There are 2 dimensions to each graft: length and width; therefore, it is necessary to select an appropriate set of lengths for the widths of the grafts. With posterior grafts, the geometric shape of the grafts is such (a rectangle) that the length can be trimmed at the time of insertion so that the set of molds is reduced to a single length that will cover most of the potential sizes. Assuming that the length dimension follows the traditional bell curve distribution, it would be expected that 95% of patients would require a posterior graft length between 8.3 and 20 mm, suggesting that a length of 22 mm would be satisfactory for nearly all patients. Similarly, the widths of the grafts fall into the region between 2 and 6 mm, which would be satisfactory for 95% of patients. Using 2-mm increments in the mold sizes would result in a set of molds that are 2, 4, and 6 mm wide and 22 mm long.

Selecting the mold sizes of the anterior grafts is more complex, because the elliptical shape of the grafts is less amenable to trimming, and the range of lengths and widths is much larger. To select the anterior graft mold sizes, we restricted our attention to the 48 patients whose anterior grafts were successful. Two of the 48 patients had grafts with abnormally large vertical dimensions because of concurrent distal tracheal grafting, and 3 had thyroid cartilage grafts that did not pose the same difficulties that were previously mentioned with rib grafts. We have excluded these 5 patients from our analysis, as they are likely to have a considerable effect on any model we choose to fit, without being representative of an “average” patient. This leaves 43 patients whose anterior grafts were successful and whose anterior grafts were successful.

Figure 1. Diagnostic plots for the regression. A, Residuals vs fitted values. B, Distribution of the residuals relative to a bell-shaped distribution.
patients, with a range of 10 to 35 mm in graft length and a range of 3 to 13 mm in graft width. Figure 1 demonstrates the relationship between graft length and width.

When this relationship was being modeled, an assumption was made that the sizes would probably never be less than 3 mm. To estimate the geometric dimensions of the grafts, a log-normal model was chosen, which can be used to describe a wide range of physical phenomena from species abundance to medical expenses.\(^\text{19}\) In this model, it is assumed that the length of the anterior graft (Y) is related to its width (X), as illustrated in the following equation:

\[
Y_i = e^{\alpha + \beta \log(X_i) + \epsilon_i},
\]

an expression equivalent to simple linear regression after a log transformation of both the X and Y variables. Results from this regression are shown in the Table.

To estimate the sizes for our molds, we calculated various prediction bands. For example, a 95% prediction band will contain a new observation with a probability of 0.95, while a 90% prediction band will contain a new observation with a probability of 0.90, and so on. Figure 2 shows prediction bands for the 95%, 90%, 80% and 70% regions. Rounding up the odd width values (eg, 7 mm to 8 mm) to help with the estimates serves to reduce the potential number of molds by half.

To calculate the number of molds, we divide the predictive bands into \(2 \times 2\)-mm blocks, rounding to the nearest millimeter. This method requires 73 molds for 90% of predicted cases, which yields too many mold sizes. Using \(2 \times 2\)-mm increments for the grafts reduces the number of molds to 36, which covers 90% of predicted cases (Figure 3).

In summary, we have reviewed our experience with cartilage grafts for LTR and used the measurements of our grafts from successful cases to calculate a range of sizes for the prospective creation of off-the-shelf tissue-engineered cartilage implants. The primary weakness of this study is the modest number of graft sizes on which our model is based. Nevertheless, with the ongoing advances in tissue engineering, the prospect of synthetically manufactured cartilage implants for LTR is highly plausible. We hope that our contribution will be a positive step toward that future.

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### REFERENCES


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Table. Regression Coefficients for Anterior Graft Length vs Width*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>SEM</th>
<th>P Value</th>
</tr>
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<tbody>
<tr>
<td>(\alpha)</td>
<td>1.966</td>
<td>0.231</td>
<td>≤.001</td>
</tr>
<tr>
<td>(\beta)</td>
<td>0.484</td>
<td>0.113</td>
<td>≤.001</td>
</tr>
</tbody>
</table>

\(^*\text{Adjusted } R^2_{\text{adj}} = 0.29.\)

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![Figure 2. Prediction bands for the 95%, 90%, 80%, and 70% regions.](image)

![Figure 3. Anterior graft molds using 2 × 2-mm increments.](image)


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**Announcement**

New Address for Editorial Office

The ARCHIVES editorial office has moved. Effective October 1, 2005, the editorial office address is as follows: Paul A. Levine, MD, Archives of Otolaryngology—Head and Neck Surgery, 183 Tuckahoe Farm Ln, Charlottesville, VA 22901; telephone, 434-960-9202 or 434-960-9203; fax, 434-973-3454. Manuscripts should continue to be submitted electronically through eJournalPress via the journal Web site (http://manuscripts.archoto.com).