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ORIGINAL RESEARCH—PEDIATRIC OTOLARYNGOLOGY

Laryngotracheal reconstruction with posterior costal cartilage grafts: Outcomes at a single institution

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OBJECTIVE: To describe our outcomes after laryngotracheal reconstruction that required posterior costal cartilage grafting focused on decannulation rates and complications.

STUDY DESIGN: Case series with chart review.

SUBJECTS AND METHODS: Charts were reviewed on 58 patients. Operation specific and overall decannulation rates were determined. Complications were reviewed and correlated with technique of graft placement. Available voice outcomes were reviewed.

RESULTS: Forty-eight patients were included. There was no statistically significant correlation between degree of stenosis and rate of decannulation. The overall decannulation rate, regardless of number of surgeries performed, was 96 percent. The relative risk for complications was higher among children who had a sutured versus a sutureless flanged posterior graft (RR = 2.5, $P < 0.01$). The most common voice anomaly was supraglottic compression.

CONCLUSIONS: Operation-specific decannulation rates are not significantly different with increasing disease severity, although the power to detect small differences in this study is low. Sutureless graft placement is associated with a lower complication rate. Supraglottic compression is a common postoperative compensatory vocal behavior and may correlate with disease severity.

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Laryngotracheal stenosis (LTS) represents a complex spectrum of life-threatening disease states that result in narrowing of the glottis, subglottis, or trachea, or a combination of these subsites. This condition may be acquired or congenital, and the acquired form most commonly results from trauma that relates to endotracheal intubation.[1] Accordingly, the incidence of LTS increased significantly in the late 1960s when prolonged mechanical ventilation became an accepted treatment in the management of chronically ill children. Since that time, preventive measures such as the development of endotracheal tubes constructed of polyvinyl chloride and the use of high volume, low pressure cuffed or cuffless tubes have decreased the incidence of airway stenosis. The current incidence of postintubation stenosis is estimated to range from 0.9 percent to 8.3 percent[2] although the true incidence in the pediatric population is unknown. Given the increasing incidence of premature births, which often lead to long-term mechanical ventilation, it is likely that LTS will persist as a significant problem in the pediatric population.

The subglottis is often the site of significant obstruction in LTS. At this level, obstruction is commonly circumferential and requires both anterior and posterior grafts to reestablish adequate luminal patency of the airway. Given that the most common cause of subglottic stenosis (SGS) is trauma related to intubation, involvement of the posterior subglottis is common and scarring often extends superiorly to involve the posterior glottic region. This tendency is likely due to the fact that an indwelling endotracheal tube selectively exerts pressure posteriorly.[3]

The initial description of open laryngotracheoplasty (LTP) with posterior cricoidotomy was first provided by Rethi[4] and was subsequently modified and popularized by Fearon and Cotton.[5] Cotton[6] demonstrated excellent free costal cartilage graft survival in the divided posterior lamina with the use of both a rabbit and human model. Placement of a posterior graft is indicated when placement of an anterior graft alone does not adequately expand the airway to allow for an age-appropriate endotracheal tube and is therefore useful in the treatment of advanced cases of subglottic stenosis or isolated posterior glottic stenosis. The most common source of cartilage is from the fifth or sixth rib although alternative sources are the thyroid ala, auricular cartilage, or nasal septal cartilage. The method of securing the posterior graft within the divided cricoid lamina has evolved at our institution from the initial use of interrupted sutures to the current technique of sutureless placement of a flanged costal cartilage graft as described by Hof[7] and Ward.[8]

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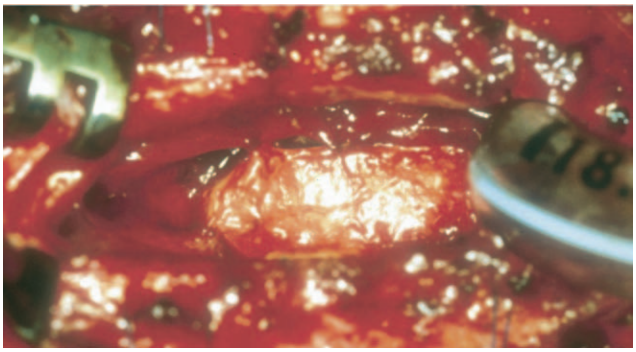

Figure 1 Intraoperative photo shows a posterior cartilage graft sewn into position.

The goal of such surgery is to create an airway that is adequate for survival in the absence of a tracheotomy, which has led to considerable focus on decannulation as an outcome. Recently, this method of analysis has been further refined with the use of operation-specific decannulation rates to evaluate disease-specific outcomes. Operation-specific decannulation was first described by Hartnick et al[9] and is defined as the rate at which an open surgical procedure is associated with subsequent decannulation or extubation without the need for further open surgical reconstructive procedures.

Focus on postreconstruction voice outcomes after laryngotracheal reconstruction (LTR) has become increasingly common in recent years. Phonation with supraglottic structures, abnormal vocal fold mobility, and destabilization with prolapse of the arytenoid cartilage have been among the more commonly noted consequences of LTR in the literature.[10] This interest has led to the development and adaptation of methods of voice analysis that are suited to the post LTR pediatric population.[10-12] Given the significant impact of impaired voice on the quality of life and education of a child,[13] evaluation and management of voice outcome is likely to become a necessity in the complete treatment of these patients.

This study describes the experience with posterior costal cartilage graft (PCCG) LTR at a single tertiary care children's hospital by focusing on operation-specific decannulation rates and disease-specific outcomes. Furthermore, the rate of complications associated with the method of securing the posterior graft (sutured versus sutureless) is reported. Finally, a preliminary assessment of postoperative voice outcomes is provided.

MATERIALS AND METHODS

Following full Institutional Review Board approval, a case series with chart review was performed that analyzed all patients who underwent LTR with a posterior graft either alone or in conjunction with an anterior graft at The Children's Hospital of Philadelphia from the years January 1998 to January 2008. Patients were included if their initial surgery was performed by either of the senior authors (INJ or KBZ) and if their medical records contained the preoperative Cotton-Myer grade of stenosis. Patients who had subglottic stenosis or posterior glottic stenosis as their initial diagnosis were included. All patients were under 18 years of age at the time of initial surgery. Patients were excluded if their initial open airway reconstructive procedure did not involve placement of a posterior graft, if insufficient preoperative or follow-up data were available, or if their primary site of airway obstruction at the time of initial diagnosis was supraglottic or tracheal. Patients who underwent planned double-staged procedures sooner than four months before this writing were also excluded. Minimum allowable follow-up was six months.

Patients are initially evaluated in our multidisciplinary Center for Airway Disorders. Initial diagnosis is confirmed by microlaryngoscopy and bronchoscopy (MLB). Management of concomitant gastroesophageal reflux and pulmonary disease is optimized before any attempt at open reconstructive surgery. After adequate open exposure of the laryngotracheal complex is obtained, LTR is performed via vertical anterior cricoidotomy. Rarely, a complete laryngofissure is performed to adequately expose the superior aspect of the stenotic region posteriorly. The posterior lamina of the cricoid cartilage is completely divided to the level of the tracheoesophageal party wall. The necessary width of the anterior and posterior splits that will allow for the placement of an age appropriate endotracheal tube is measured followed by harvest of costal cartilage grafts. Initially, the posterior graft was secured by multiple interrupted sutures (Fig 1). Since 2003, grafts are carved to allow for sutureless placement via flanged edges that are secured deep to the cut edges of the cricoid cartilage (Fig 2). For double-staged procedures, a stent is left in place for one to three weeks. Currently, a cut Montgomery T tube is our most commonly used stent. For single staged procedures, patients are maintained intubated for an individualized duration of time, between 3 to 7 days. A repeat bronchoscopy is performed one week postextubation or stent removal, and subsequent endoscopies then depend on the clinical course of each patient.

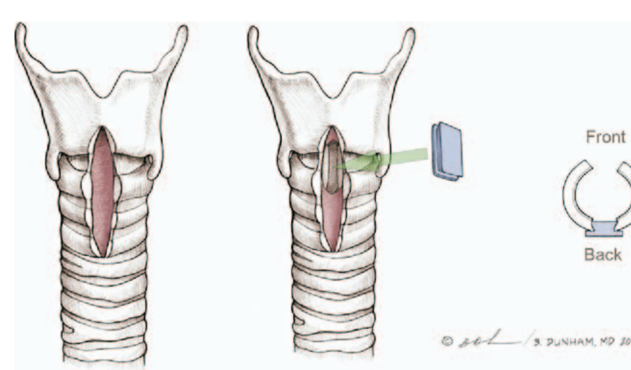

Figure 2 Illustration shows our sutureless technique of posterior graft placement.

The primary outcome measures were the operation-specific decannulation or extubation rates based on the patients' preoperative Cotton-Myer grade of stenosis. The operation-specific decannulation rate was calculated as has been described by Hartnick et al.[9] In addition, overall decannulation or extubation rates based on initial pathosis are reported, regardless of the number of procedures required. Secondary outcome measures included presence or absence of complications, including supraglottic dysphonia for those patients who have undergone a formal voice evaluation.

Statistical testing was performed with the statistical software package Stata (StataCorp College Station, TX). The alpha level was set at 0.5 for all statistical tests. Comparison of binary outcome measures was performed with either a χ^2 test or Fisher's exact test when required due to small cell sizes. Comparison of continuous measures was performed using two-sample *t* tests.

RESULTS

A total of 58 patients underwent placement of a posterior graft during the study period. Four patients were excluded because their surgeries were performed by surgeons other than the senior authors. Three patients were excluded due to inadequate data available with respect to their preoperative degree of stenosis or follow-up. One patient was excluded because he had a tracheal resection before PCCG LTR. Two further patients were excluded because their most recent reconstructive surgery was performed within four months of this writing. Therefore, 48 patients who met the inclusion criteria were identified for chart review. Forty-one of these patients were dependent on tracheotomy before the procedure. The mean patient age at the time of initial surgery was 45 months. The male to female ratio was 1.1:1. A total of 64 open reconstructive procedures were performed on the study group resulting in an average of 1.33 procedures per patient. Thirty-three patients had double-staged LTP with anterior and posterior grafts as their initial procedure. The remaining 15 received an isolated posterior graft. Three of these patients underwent single-staged posterior graft placement as their initial procedure. Twenty patients underwent initial posterior graft placement via the sutured technique, and the remaining 28 were placed in a sutureless fashion. The overall decannulation or extubation rate for all patients, including those who underwent concomitant anterior graft placement, is 96 percent (46 of 48).

Thirty-one of the 46 successfully decannulated or extubated patients required one open reconstructive procedure while the remaining 15 required multiple surgeries. Of these 15, 4 patients required an additional open reconstruction with anterior and posterior grafts due to restenosis, and 2 patients needed placement of a posterior graft only. In one of these patients, revision was indicated due to migration of the initially placed posterior graft (Fig 2) and in the other, a second procedure was required for restenosis. Of the remainder, 7 patients required an additional anterior graft in isolation, 1 patient needed a cricotracheal resection, and 1 patient required tracheal resection with end to end anastomosis as a third open procedure to accomplish decannulation.

Patients were analyzed based on their initial degree of stenosis in order to facilitate interpretation of the operation-specific and overall decannulation rates. The operation-specific decannulation rate was 100 percent (6 of 6) for Myer-Cotton grade II SGS, 69 percent (25 of 36) for grade III and for grade IV it was 60 percent (3 of 5). For isolated posterior glottic stenosis, it was 71 percent (5 of 7) and for posterior glottic stenosis combined with subglottic stenosis, it was 60 percent (6 of 10). There was no statistically significant difference in decannulation rate among these groups ($P = 0.51$, Fisher's exact test). The overall decannulation rates regardless of the number of open reconstructions procedures are: 100 percent for grade II SGS, 93 percent for grade III, 100 percent for grade IV SGS, and 100 percent for isolated PGS either in isolation or with associated SGS. There was no statistically significant difference among these groups ($P > 0.9$, Fisher's exact test).

The rate and nature of postoperative complications was reviewed. The most common complication was anteromedial prolapse of the arytenoid that occurred in 10 patients (Fig 3). In addition, the rate of complications between patients who had their posterior grafts secured with or without suture was compared. There were nine total complications among 31 surgeries in children who had a sutureless posterior graft placed. There were four instances of significant arytenoid prolapse: one patient had graft migration that required revision surgery, one patient had an air leak that required reexploration; one episode of recurrent stomal bleeding; and two patients who had unanticipated

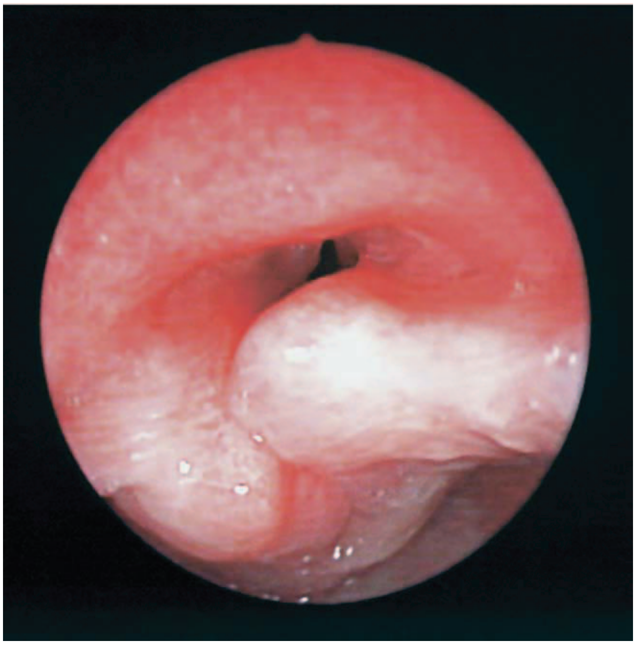

Figure 3 Postoperative image of the supraglottic larynx in a patient with anteromedial prolapse of the arytenoid.

Table 1
Complications of PCCG LTP stratified by sutured versus sutureless graft technique

	Arytenoid prolapse	Graft migration	Restenosis	Other	Total
Sutured graft	7/21	1/21	6/21	1/21	15/21
Sutureless graft	4/31	1/31	2/31	2/31	9/31
	$P = 0.17$	$P > 0.9$	$P = 0.11$	$P > 0.9$	$P < 0.01$

recurrent stenosis that required revision surgery. In children who had their posterior graft sutured in place, there were 15 complications in 21 surgeries. Seven children had anterior prolapse of the arytenoid, six had restenosis that led to an unplanned revision procedure, one has chronic aspiration associated with posterior glottic incompetence and one had graft migration that required revision surgery. The relative risk for postoperative complication was significantly higher among children who had their posterior grafts placed sutured (relative risk, 2.5, $P < 0.01$, see Table 1). The width of the posterior graft was documented in 28 of the patients with a nonsutured graft and 7 of the patients with sutured grafts. The mean width of the posterior graft in the sutured group (7.43 mm) was higher than in the sutureless group (4.27 mm). On average, sutured posterior grafts were just over 3 mm larger than posterior grafts placed via a sutureless technique (95% CI 1.27 to 4.85 mm, $P < 0.001$). This difference in graft size does not appear to fully explain the differences in complication rates, as the mean graft size in patients who experience a complication was not statistically significantly higher than in those without complications (95% CI −0.36 to 3.16 mm, $P = 0.12$).

Thus far, 16 patients have undergone evaluation in our multidisciplinary center for pediatric voice disorders. Detailed voice data are further documented for 14 other patients who were managed before the voice center's inception. The most common aberrant vocal behavior that affected these patients is compensatory supraglottic compression. It preliminarily appears that this phenomenon is much more common in children with higher preexisting degrees of laryngotracheal stenosis and indeed is rarely seen in our patients reconstructed for grade II SGS or PGS alone. Further characterization of this phenomenon is an area of active exploration at our institution.

DISCUSSION

Division of the posterior cricoid lamina was first described by Rethi[4] who used long-term stenting after division and diffraction of the scarred cricoid lamina. Subsequently, the concept of free cartilage grafting was introduced[6] that allowed for a shorter duration of stenting. The ease with which autologous cartilage grafts are harvested and carved, coupled with their ability to survive without concern for vascularity, has allowed for significant progress in the management of LTS. It has been reported that overall rates of decannulation are inversely related to the degree of stenosis.[9,14] Similarly, we report a decrease in decannulation rate with increased LTS severity rates, although a statistically significant correlation between these two variables was not seen. Our overall rate of decannulation was 96 percent, regardless of initial degree or site of stenosis, which is slightly higher than reported rates of decannulation for subglottic stenosis from other centers.[15,16] This discrepancy may be due to the fact that this work focuses on a select group of our patients, ie, those who require posterior graft placement, rather than all patients who have needed open LTR. Furthermore, many patients in this series also underwent placement of an anterior graft in addition to PCCG for reconstruction. This maneuver alone can enhance rates of decannulation but is often necessary given the circumferential nature of many cases of LTS. In our series, the majority of children achieved decannulation with one open procedure and most of the remaining patients are decannulated with a second procedure.

Because of the significant differences in the presentation and natural history of LTS among individuals even with the same Myer-Cotton grade of stenosis, broad calculations of decannulation rates drawn from a disparate study group are difficult to interpret. Accordingly, the concept of assessing disease specific outcomes after LTR was designed by Hartnick et al[9] to provide useful prognostic information with respect to the potential success of reconstructive surgery. Their study included 199 children who received either standard LTR or CTR for subglottic stenosis and found operation-specific decannulation and extubation rates similar to those reported here. We chose to also include patients with either associated or isolated posterior glottic stenosis because these patients often require posterior graft placement and because this method of calculation allows an assessment of decannulation rates in a disease-specific manner. As one might expect, it appears from our data that concomitant posterior glottic and subglottic stenosis is associated with an overall lower likelihood of decannulation per procedure although this disadvantage was not statistically significant.

The most frequent postoperative complication seen in our patient series was anteromedial prolapse of the arytenoid, which has been associated with posterior graft placement in the literature[17,18] and also may occur after CTR.[19] In addition, we noted a higher incidence of this complication for sutured versus sutureless PCCG. The sutureless

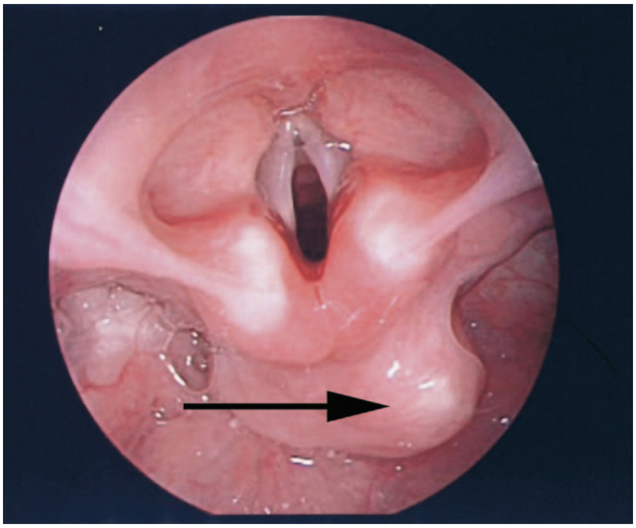

Figure 4 Postoperative image of a patient who had migration of his posterior graft into the post cricoid region (*arrow*). This graft was placed via the sutureless technique and revision surgery was required to reestablish it in proper position.

technique, which has evolved in recent years, seems to enable the surgeon to achieve a more secure graft placement and prevent complications with minimal risk of graft migration. Nevertheless, there was one incidence of PCCG migration that required revision surgery in both the sutured and the sutureless groups (Fig 4). This may have been related to overzealous undermining that is now avoided. The association of sutured graft placement with arytenoid prolapse is not entirely clear. The larger average graft width of patients in the sutured group does not appear to completely account for this difference because there was no statistically significant relationship between graft size and complications in our series when patients with complications were isolated and reviewed.

Compensatory supraglottic compression appears to be the most common aberrant vocal behavior seen in our study group. The use of supraglottic structures to phonate is likely a compensatory mechanism for lack of glottic vibratory surface after LTR. A detailed voice analysis was not performed for every patient in this retrospective study. More definitive voice data are being prospectively compiled in our pediatric voice center and will be reported in a subsequent article. However, in our group of patients, it appears preliminarily as if this type of dysphonia is more commonly seen in patients with a higher grade of SGS before LTR. This concept of preexisting pathosis that affects postoperative voice outcomes has been noted at other centers,[3,20] but never formally studied. In addition, we have seen preliminarily that early voice therapy may minimize supraglottic voicing compensation. Prospective studies on these outcomes as well as the relationship between posterior graft width and postoperative dysphonia are planned in the near future.

This study is limited by a small sample size and consequent inadequate power to detect small differences among our treatment groups. Furthermore, because pre- and postoperative voice outcomes data are not available for each patient, our comments with respect to voice are vulnerable to the selection bias. It is currently our practice that a detailed voice evaluation be performed for each patient to allow for improved study design in the near future as well as superior and timely treatment. Future prospective studies are needed to evaluate the long-term outcome of PCCG in terms of voice and airway. In addition, prospective studies of pre- and postoperative voice outcome and appropriate interventions such as early voice therapy are planned. Furthermore, future refinements in airway and voice results will come with advances in tissue engineering, wound healing, and postoperative care.

CONCLUSION

The Rethi technique continues to evolve and has become a workhorse for both posterior glottic stenosis and laryngeal stenosis. Our study confirms that the use of a posterior graft in laryngeal reconstructive surgery results in reliably high rates of decannulation although multiple procedures are necessary in some patients. The use of sutures to secure a posterior graft is associated with a higher rate of complications in our series that is not totally explained by the larger graft size in these patients. Compensatory supraglottic compression may be associated with a preoperative degree of stenosis.

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AUTHOR CONTRIBUTIONS

Mark D. Rizzi, writer, study design; **Marc C. Thorne,** statistical analysis, study design; **Karen B. Zur,** writer, study design; **Ian N. Jacobs,** writer, study design.

FINANCIAL DISCLOSURE

None.

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