One slide fits all: The versatility of slide tracheoplasty with cardiopulmonary bypass support for airway reconstruction in children

Peter B. Manning, MD,^a Michael J. Rutter, MD,^b Asher Lisec, BS,^c Resmi Gupta, MS,^c and Bradley S. Marino, MD, MPP, MSCE^c

Objectives: This study describes results of tracheal reconstruction in children with slide tracheoplasty with cardiopulmonary bypass and identifies predictors for adverse outcomes.

Methods: Preoperative characteristics, operative variables, and outcome measures were collected for children undergoing slide tracheoplasty with cardiopulmonary bypass between April 2001 and October 2009. Predictors of worse outcomes were identified by bivariate analysis. Multiple regression analysis was performed for predictors of prolonged hospital stay.

Results: Cohort included 80 patients (median age, 8.7 months; 7 days–21 years). Forty-eight patients had associated cardiac or great vessel anomalies; 24 had simultaneous repair of cardiovascular anomaly at tracheal reconstruction. Fifty (63%) were extubated within 48 hours after operation. Median stay was 18.5 days (range, 7–119 days). Twenty-three patients (29%) required significant airway reintervention during median follow-up of 12 months (range, 4 months–7.8 years). There were 4 deaths, 2 early and 2 late. In bivariate analysis, age ($P = .017$), cardiopulmonary bypass duration ($P = .025$), and duration of mechanical ventilation ($P < .05$) were associated with mortality; duration of postoperative mechanical ventilation was associated with need for significant airway reintervention ($P = .009$). Multiple regression analysis indicated preoperative ventilatory support ($P < .001$), longer cardiopulmonary bypass ($P = .002$), previous airway operation ($P = .01$), and need for significant airway reintervention ($P < .001$) as predictors of longer hospital stay.

Conclusions: Slide tracheoplasty with cardiopulmonary bypass can be performed with low mortality in a diverse pediatric population. This technique minimizes need for early significant airway reintervention in most cases. (J Thorac Cardiovasc Surg 2011;141:155-61)

Earn CME credits at
<http://cme.ctsnetjournals.org>

The management of tracheal stenosis in infants and children has often been associated with significant morbidity and mortality. A number of specific tracheal reconstruction techniques have been described, including simple resection with direct reanastomosis, pericardial patch tracheoplasty, rib cartilage tracheoplasty, tracheal autograft, tracheal homograft, and slide tracheoplasty. The variety of techniques alone suggests the lack of emergence of a single best method, although a number of centers in recent years

have advocated slide tracheoplasty as the preferred technique for most cases of tracheal stenosis in children because of a number of perceived advantages relative to other methods. These include immediate tracheal reconstruction with rigid, vascularized tissue with a normal mucosa; ability to extubate patients early in many cases; less postoperative granulation tissue formation; and growth potential of the reconstructed trachea.¹⁻⁴

Although most cases of tracheal stenosis in children are congenital malformations characterized by complete tracheal rings with the absence of a membranous trachea extending for varying lengths of the airway, other congenital airway malformations may be seen, as well as acquired lesions resulting from endotracheal tube trauma, infections, or previous surgical interventions. In addition to the variety seen in the tracheal anatomy, many children have associated cardiovascular malformations as well, further complicating their management and often contributing significantly to adverse outcomes.

Because of the diversity that may be seen in this population, a variety of approaches have been advocated, even within an individual center. Examples include selective use of certain tracheal reconstruction techniques to specific types or lengths of stenosis,¹ staged versus combined repair of associated cardiovascular anomalies, and the use or

From the Divisions of Cardiothoracic Surgery,^a Otorhinolaryngology,^b and Cardiology,^c Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio.

Disclosures: Authors have nothing to disclose with regard to commercial support.

Read at the 90th Annual Meeting of The American Association for Thoracic Surgery, Toronto, Ontario, Canada, May 1-5, 2010.

Received for publication May 1, 2010; revisions received Aug 7, 2010; accepted for publication Aug 29, 2010; available ahead of print Nov 9, 2010.

Address for reprints: Peter B. Manning, MD, Division of Cardiothoracic Surgery, MLC 2004, Cincinnati Children's Hospital Medical Center, 3333 Burnet Ave, Cincinnati, OH 45229 (E-mail: peter.manning@cchmc.org).

0022-5223/\$36.00

Copyright © 2011 by The American Association for Thoracic Surgery

doi:10.1016/j.jtcvs.2010.08.060

Abbreviation and Acronym

CPB = cardiopulmonary bypass

avoidance of cardiopulmonary bypass (CPB) support, including the extension of such support to the postoperative period with extracorporeal membrane oxygenation.^{5,6}

On the basis of our center's early favorable experience with slide tracheoplasty, we adopted a "one size fits all" management approach to all cases of tracheal stenosis in children. This approach relies on the extreme versatility inherent in the slide tracheoplasty technique. The key components of our approach, in addition to universal application of the slide technique for tracheal reconstruction, include sternotomy with CPB support for all repairs, simultaneous reconstruction of any associated cardiovascular anomalies, management by an integrated multidisciplinary team codirected by cardiothoracic surgery and otorhinolaryngology, and a postoperative management strategy focusing on early extubation. The purpose of this study was to review the results of this approach applied to a large and varied population of children with tracheal stenosis and to identify risk factors for mortality, airway reinterventions, and longer hospital stay.

MATERIALS AND METHODS

This study is a retrospective case series. Patients who underwent slide tracheoplasty with CPB at Cincinnati Children's Hospital Medical Center between April 2001 and October 2009 were included in the study. Demographic characteristics, preoperative characteristics, operative variables, and outcome measures were compiled in a registry. Institutional review board approval with waiver of consent was granted for this study. Tracheal stenoses were categorized as congenital or acquired, with restenosis after previous repair coded as acquired. Length of stenosis was categorized as less than 50%, 50% to 80%, or more than 80% of the total tracheal length (cricoid to carina). As an outcome variable, significant airway reintervention was defined as the need for more than a single endoscopic dilation, placement of an endotracheal stent, or tracheal reoperation.

Patient Management

Preoperative bronchoscopy was universally relied on for definition of airway anatomy. Contrast chest computed tomographic scans with 3-dimensional reconstruction and echocardiography were performed in all cases to aid in defining airway and great vessel anatomy and also to define cardiac malformations.

All operations were performed through a median sternotomy with CPB support. Associated cardiovascular anomalies were repaired at the same time, typically before the tracheoplasty. In the absence of the need for intracardiac repair, single venous cannulation with normothermic bypass was used. Moderate hypothermia, bicaval cannulation, and cold blood cardioplegic arrest were used as dictated by the need to repair specific cardiac anomalies. The anterior trachea was exposed before initiation of CPB support. Once the patient was supported by CPB, flexible bronchoscopy was performed to visualize the proximal extent of the stenosis while a fine needle was passed through the trachea from the mediastinal side to confirm the precise level of upper end of the repair. Distal extent of the stenosis was commonly near the level of the carina. The midpoint of the stenosis was defined, and circumferential dissection of the trachea limited to this region was per-

formed before dividing the trachea at this level. Posterior mobilization of the tracheal segments, typically extending 1 or 2 cm down each bronchus and below the carina, was performed. Lateral dissection was avoided to preserve blood supply and prevent injury to the recurrent laryngeal nerves. Anterior or posterior dissection alone virtually always afforded enough mobility of segments to perform a tension-free anastomosis. Longitudinal incisions were next made on opposite sides of the proximal and distal tracheal segments, and a sliding oblique anastomosis was performed with running polydioxanone suture. All repairs were leak tested with gradual insufflation of the lungs to 35 cm H₂O pressure while the chest was filled with saline solution. In the absence of associated cardiac repair, patients were weaned from CPB support without inotropic infusions. Modified ultrafiltration was used in all cases.

Postoperative management focused on weaning from mechanical ventilatory support within the first 24 to 48 hours. While the patient was intubated, the head was maintained in forward flexion on a pillow. No chin sutures or other immobilization methods were used. Follow-up endoscopy to examine the repair was performed routinely 1 and 2 weeks after the operation. Gentle balloon dilation was sometimes useful during the recovery phase if the figure-8 tracheal deformity at the repair was significant. This intervention was found to help prevent left and right lateral suture lines from coming into contact and adhering. This was usually a transient problem, and for this reason a single dilation was not defined as a significant reintervention in our outcome analysis. Stent placement was reserved for patients with weak cartilage and some tracheal collapse with very negative intrathoracic pressures (patient retracting). Virtually all these cases were revisions with previously damaged cartilage. Transient stenting allowed the patients to be weaned from sedation and supported the trachea while fibrosis stabilized the repair. In most cases, the stent was removed within 3 weeks and did not need to be reinserted.

Statistical Analysis

Data analysis proceeded in 2 distinct phases: a descriptive phase and an inferential phase. Descriptive statistics were computed for each variable to describe the basic features of the data. Descriptive statistics for continuous variable are presented as means and ranges, and skewed continuous data are summarized by medians and interquartile ranges. Categorical variables are presented as frequencies and percentages. Bivariate analyses with χ^2 testing was performed to measure the degree of nonrandom association between categorical variables. In case of frequency having expected cell count of less than 5, Fisher's Exact test was used for association studies. Wilcoxon rank sum test was used to determine group differences in case of violation of normality assumption. A quantile-quantile plot was used to determine whether hospital stay was normally distributed and amenable to analysis with traditional parametric techniques. On the basis of the observed plot, log transformations were used to normalize the hospital stay distribution for subsequent modeling. A multiple regression analysis was used to predict the variables associated with hospital stay. All analyses were conducted with SAS statistical software version 9.2 (SAS Institute Inc, Cary, NC).

RESULTS

Eighty children (median age, 8.7 months; range, 7 days–21 years) underwent tracheal reconstruction with CPB support. Descriptive data for the patients in this series are presented in Table 1. Although the median age of the population was 8.7 months, with a median patient weight of 7.4 kg, Figure 1 demonstrates the predominance of younger patients, because most children with congenital tracheal stenosis demonstrated symptoms in the first months of life. The length of stenosis ranged from only a few complete tracheal rings to full-length stenosis from cricoid to carina. Rarely, important stenosis extended into a main stem bronchus. The stenosis

TABLE 1. Descriptive variables used in analysis

Age (median and range)	8.7 mo (7 d–21 y)
Weight (kg, median and range)	7.4 (1.9–59.4)
Cardiopulmonary bypass time (min, median and range)	94 (49–318)
Crossclamp time (n = 12, min, median and range)	43 (6–132)
Hospital stay (d, median and range)	18.5 (7–119)
Postop ventilation < 48 h (no.)	50 (62.5%)
Any airway reintervention (no.)	34 (42.5%)
Significant airway reintervention (no.)	23 (28.7%)
Preoperative ventilation (no.)	22 (27.5%)
Sex (male/female ratio)	41:39
Congenital stenosis (no.)	65 (81%)

comprised more than 80% of the tracheal length in 20 patients (25%), between 50 and 80% of the total tracheal length in 37 patients (46%), and less than 50% of the tracheal length in 23 patients (29%). Of the 15 cases categorized as acquired stenosis, 13 were related to previous tracheoplasty procedures performed at other institutions. Most of these procedures were originally performed for congenital complete rings. Trauma from prolonged intubation or severe tracheal infection with associated cartilage loss or fibrosis accounted for the remainder of the acquired lesions.

Forty-eight patients had additional cardiac or great vessel anomalies. Twenty-four patients underwent simultaneous repair of cardiac or great vessel anomalies at the time of slide tracheoplasty at our center (Table 2). Thirty-five patients had undergone previous operations at outside institutions (Table 3). A number of these patients had undergone repair of a cardiac or vascular anomaly without preoperative recognition of the tracheal stenosis. Interestingly, 21 patients had bilateral superior venae cavae with absence of a crossing innominate vein. In only 2 cases, in which the left superior vena cava was unroofed, was an operation related to the left superior vena cava itself performed (bidirectional Glenn shunt in 1, intra-atrial baffling in 1). The absence of an innominate vein crossing the midline, in fact, often simplified exposure of the trachea, and the left superior vena cava did not require separate venous cannula-

FIGURE 1. Age distribution of patients undergoing slide tracheoplasty.

TABLE 2. Cardiac/vascular operations performed in combination with slide tracheoplasty

Procedure	No.
Left pulmonary artery sling repair (reimplantation)	17
Ventricular septal defect closure	5
Atrial septal defect closure	5
Tetralogy of Fallot	2
Pulmonary vein stenosis	1

Some patients underwent repair of more than 1 anomaly.

tion in the absence of the need for any intracardiac repair. CPB support was used in all cases, with a median CPB time for the entire group of 94 minutes (49–318 minutes). For patients undergoing tracheoplasty alone (n = 56), median CPB time was 85 minutes (range, 49–165 minutes). For patients undergoing additional procedures (n = 24), median CPB time was significantly longer ($P < .01$) at 152 minutes (range, 85–318 minutes). Twelve of the patients requiring additional cardiac or vascular procedures required cardioplegic arrest for a median duration of 43 minutes (range, 6–132 minutes).

Extubation within 48 hours of operation was achieved in 50 cases (62.5%), with median postoperative mechanical ventilation duration of 30 hours and a range of 0 hours (extubation in the operating room) to 67 days. A significantly higher percentage of patients undergoing airway reconstruction alone were able to achieve early extubation (within 48 hours) than of those patients undergoing airway reconstruction and cardiac and vascular procedures (71% vs 42%, $P < .03$).

Outcome variables for analysis included mortality, the need for any airway reintervention, the need for significant airway reintervention (defined as the need for more than a single endoscopic dilation, stent placement, or surgical revision), and hospital stay. Follow-up information was available for a median duration of 12 months (4 months–7.8 years). There were two early deaths (2.5%) and two late deaths (2.5%). There have been no early deaths in the last 50 consecutive patients managed at our center. Bivariate analyses revealed younger age ($P = .02$), longer duration of postoperative mechanical ventilation ($P = .05$), and

TABLE 3. Operations performed before slide tracheoplasty

Procedure	No.
Tracheal reconstruction	13
Tracheostomy	9
Left pulmonary artery sling	7
Tetralogy of Fallot	4
Double-outlet right ventricle	2
Ventricular septal defect	1
Coarctation	1
Bidirectional Glenn shunt	1
Esophageal atresia or tracheoesophageal fistula	2
Diaphragmatic hernia	1
Other nonthoracic operation	6

Some patients underwent more than 1 procedure.

FIGURE 2. Distribution of hospital stays.

longer CPB time ($P = .03$) as predictors of mortality at any time. Because of the small number of deaths observed, multivariable analysis was not performed.

Thirty-four patients underwent a procedure coded as an airway reintervention, with 23 cases characterized as significant according to the previously stated definition. All 23 of these patients underwent more than a single balloon dilation or endoscopic resection of granulation tissue. In addition, 9 patients underwent temporary stent placements (none of these currently have intratracheal stents in place), 3 underwent tracheostomy, and 2 underwent repetition of slide tracheoplasty for short-segment restenosis. In addition to the airway reinterventions, 1 patient required stenting of a left pulmonary arterial stenosis, and 1 required surgical revision of a left pulmonary arterial stenosis. Only the duration of postoperative mechanical ventilation ($P = .008$) was associated with significant airway reintervention. Importantly, neither age, length of stenosis, nor acquired (versus congenital) disease predicted a higher rate of airway reintervention.

Median hospital stay for the entire series was 18.5 days, but the distribution of values was significantly skewed, as demonstrated in Figure 2. Younger age, lower weight, longer CPB time, postoperative mechanical ventilation longer than 48 hours, preoperative use of ventilation, and the need for significant airway reintervention were associated with longer hospital stay ($P < .01$). Multiple regression analysis showed only previous airway operation, preoperative use of mechanical ventilation, the need for significant airway reintervention, and longer CPB duration to be predictors of a longer hospital stay (Table 4). As previously reported, CPB time was longer in cases where additional cardiac or vascular procedures were performed. Further analysis was performed to attempt to define additional factors associated with longer CPB times. Length of tracheal stenosis was found to be associated with longer CPB time for the entire

population ($P = .02$) and also when only the patients undergoing slide tracheoplasty alone were examined ($P = .005$). To assess whether there was a learning curve effect resulting in shorter CPB times with increasing experience, patients undergoing slide tracheoplasty alone were divided into groups representing the first and second halves of our experience. Age, length of stenosis, frequency of acquired stenosis, and previous airway operations were similar between these groups. In the more recent experience, CPB times were observed to be shorter by a median of 10 minutes (90 minutes vs 80.5 minutes), a difference that only trended toward statistical significance ($P = .09$).

DISCUSSION

Our experience has demonstrated that the slide tracheoplasty technique with CPB support can be performed with very low mortality despite the complexity of this patient population. The slide technique requires airway reintervention less frequently than is reported for other techniques.

TABLE 4. Multiple regression results with hospital stay as outcome variable

Variable	Estimate (transformed scale)	P value
Age		NS
Weight		NS
Acquired stenosis		NS
Length of stenosis		NS
Previous airway operation	0.36	.01
Preoperative ventilation	0.79	<.01
Cardiopulmonary bypass time	0.004	<.01
Simultaneous cardiac operation		NS
Duration of postoperative ventilation		NS
Significant airway reintervention	0.55	<.01
R^2 value for model		.57

NS, Not significant.

Longer hospital stay is influenced primarily by the complexity of the airway disease and longer duration of CPB support (which is significantly affected by the need for simultaneous cardiac operation) but not by patient age, patient weight, or length of tracheal stenosis.

Children with tracheal stenosis are an extremely heterogeneous and often complex population of patients whose care has historically been quite difficult to manage. A number of different surgical techniques for tracheal reconstruction have been used, and different management strategies have been advocated. Our recent results have demonstrated excellent survivals relative to those reported previously in the literature. Reports from individual centers with small to moderate series, as well as reviews summarizing multiple reports, have demonstrated mortalities typically in the 10% to 30% range.^{2,4,7-12}

Experience with the slide tracheoplasty technique has been considered by many not only to yield lower mortality but also to result in fewer postoperative complications, particularly airway restenosis.^{5,9,12} In one of the largest reported series of airway reconstruction in children, representing a very diverse group of lesions and with a variety of management strategies, Wright and colleagues⁵ reported a rate of significant complications of 35%. Age younger than 7 years, reoperative procedures, and stenoses greater than 30% of the tracheal length predicted a higher risk of complication. Our experience contrasts with these findings. Although we did find the need for reintervention to be far from trivial, most reinterventions after slide tracheoplasty were found to be related to transient airway instability or deformity (figure-8 deformity) and rarely involved more than endoscopic management.

No specific preoperative characteristic predicted a greater need for postoperative reintervention. Hospital stay was, however, prolonged by a number of factors. It was not surprising that children requiring postoperative interventions had longer mechanical ventilation and remained longer in the hospital, because these procedures often prolonged the need for further inpatient observation. Longer stays for patients having undergone previous airway operations, or in those with preoperative mechanical ventilation emphasize that these groups may be slower to wean from the ventilator or overcome nonairway issues. Because neither of these factors predicted a higher rate of airway reintervention, however, the additional time in the hospital does not appear to be specifically related to the airway reconstruction itself.

CPB time was one of the strongest independent predictors of longer hospital stay. A number of factors, however, contribute to prolonged CPB times. As expected, we found that performing additional cardiac or vascular procedures in combination with the airway reconstruction significantly prolonged CPB time, and although the recovery related to postoperative cardiac issues contributed to length of stay, it did not appear to adversely influence survival. Repair of

longer stenoses was seen to prolong CPB time, although this feature was not associated with either mortality or a more frequent need for reintervention. We were able to demonstrate a trend suggesting that as our experience managing these patients increased, CPB times diminished.

We believe that one of the most important factors underlying our favorable results with this very complex population is the assembly of a management group that focuses on a team approach to the care of these patients, beginning with diagnostic evaluation, proceeding through surgical repair, and continuing throughout the postoperative hospitalization. The key members of this team include cardiothoracic surgeons, otorhinolaryngologists, critical care specialists, and cardiologists. Such a strategy of team management was reported by Kocyildirim and associates¹¹ from Great Ormond Street in London to significantly reduce duration of mechanical ventilation, intensive care unit stay, hospital stay, and cost of hospitalization.

It is noteworthy in the London experience that at the time of creation of a multidisciplinary tracheal team this group also switched their preferred method of tracheal reconstruction from pericardial patch to the slide technique. We firmly believe that this technique itself is largely responsible for our excellent results. Although some centers have advocated selective use of slide tracheoplasty, recommending resection and direct reanastomosis for shorter stenoses¹ and a variety of methods for full-length stenosis, we have found the slide technique to have enough versatility to be used for all cases, regardless of length. We feel that performing a short slide for a limited length stenosis has the advantage of distributing the suture line over a greater length of trachea, likely reducing the risk of restenosis. We have found that even in cases of full-length stenosis enough mobilization can be obtained for a tension-free reconstruction with the slide technique, without the need for specific procedures such as hyoid or hilar releases. Mobilization of the tracheal segments with only anterior and posterior dissection is typically satisfactory, particularly in younger patients who have not previously undergone tracheal dissection, which represents the majority of our experience. Even in cases in which previous tracheoplasty has been performed with an anterior patch technique (pericardial or cartilage), we have found that mobilization is often readily achieved, probably because of the lack of previous posterior dissection.

The slide technique can easily be modified to apply to a variety of unusual anatomic variations, such as the presence of a bronchus suis or extension of stenosis into a bronchus.¹³⁻¹⁵ The resultant reconstruction is structurally more stable than other techniques, particularly pericardial patch, allowing a strategy of early postoperative extubation. Although postoperative extracorporeal membrane oxygenation support has been advocated in some complex cases,⁶ we consider this to be completely unnecessary in most cases. Reduction in the time during which the reconstructed airway

may be further traumatized by an indwelling endotracheal tube or colonized by bacteria probably contributes to a lower incidence of postoperative anastomotic problems. Finally, and particularly important in this generally very young population, the slide technique affords better growth potential because of the avoidance of nonnative tissue in the reconstruction. Tracheal growth after slide reconstruction has been demonstrated in a newborn piglet model¹⁶ as well as in clinical series.^{1,17}

Although much of the information about this cohort was accumulated prospectively in a registry, some of the data were collected retrospectively. A high percentage of the patients were referred from centers beyond our immediate region, which may have increased the percentage of more complex cases in this experience. Most patients have continued to receive periodic examinations at our center, but some follow-up information was obtained from referral physicians or from families. Although it is difficult from this experience to draw definite conclusions about long-term outcomes because of our median follow-up duration of 12 months, we have generally found that if the airway is doing well at 3 months after reconstruction, it remains so without the need for further reintervention with follow-up data extending to nearly 8 years.

In conclusion, the slide tracheoplasty for reconstruction of the pediatric airway is an extremely versatile method, with specific advantages relative to other techniques. Incorporating this method into a management strategy that includes simultaneous repair of associated cardiac and vascular anomalies and management with a multidisciplinary team approach results in excellent survival and minimizes the need for future tracheal reinterventions in this very complex patient population.

References

- Grillo HC, Wright CD, Vlahakes GJ, MacGillivray TE. Management of congenital tracheal stenosis by means of slide tracheoplasty or resection and reconstruction, with long-term follow-up of growth after slide tracheoplasty. *J Thorac Cardiovasc Surg.* 2002;123:145-52.
- Matúte JA, Romero R, Garcia-Casillas MA, de Agustín JC, Marhuenda C, Berchi FJ, et al. Surgical approach to funnel-shaped congenital tracheal stenosis. *J Pediatr Surg.* 2001;36:320-3.
- Manning PB, Rutter MJ, Border WL. Slide tracheoplasty in infants and children: risk factors for prolonged postoperative ventilatory support. *Ann Thorac Surg.* 2008;85:1187-92.
- Elliott M, Roebuck D, Noctor C, McLaren C, Hartley B, Mok Q, et al. The management of congenital tracheal stenosis. *Int J Pediatr Otorhinolaryngol.* 2003;67 (Suppl. 1):S183-92.
- Wright CD, Graham BB, Grillo HC, Wain JC, Mathisen DJ. Pediatric tracheal surgery. *Ann Thorac Surg.* 2002;74:308-14.
- Hines MH, Hansell DR. Elective Extracorporeal Support for Complex Tracheal Reconstruction in Neonates. *Ann Thorac Surg.* 2003;76:175-9.
- Chiu PL, Kim PC. Prognostic factors in the surgical treatment of congenital tracheal stenosis: a multicenter analysis of the literature. *J Pediatr Surg.* 2006;41:221-5.
- Fanous N, Husain SA, Ruzmetov M, Rodefeld MD, Turrentine MW, Brown JW. Anterior pericardial tracheoplasty for long-segment tracheal stenosis: long-term outcomes. *J Thorac Cardiovasc Surg.* 2010;139:18-25.
- Forsen JW Jr, Lusk RP, Huddleston CB. Costal cartilage tracheoplasty for congenital long-segment tracheal stenosis. *Arch Otolaryngol Head Neck Surg.* 2002;128:1165-71.
- Herrera P, Caldarone C, Forte V, Campisi P, Holtby H, Chait P, et al. The current state of congenital tracheal stenosis. *Pediatr Surg Int.* 2007;23:1033-44.
- Kocylidirim E, Kanani M, Roebuck D, Wallis C, McLaren C, Noctor C, et al. Long-segment tracheal stenosis: slide tracheoplasty and a multidisciplinary approach improve outcomes and reduce costs. *J Thorac Cardiovasc Surg.* 2004;128:876-82.
- Tsugawa C, Nishijima E, Muraji T, Satoh S, Takamizawa S, Yamaguchi M, et al. Tracheoplasty for long segment congenital tracheal stenosis: analysis of 29 patients over two decades. *J Pediatr Surg.* 2003;38:1703-6.
- Kutlu CA, Yeginsu A, Ozalp T, Baran R. Modified slide tracheoplasty for the management of tracheobronchopatia osteochondroplastica. *Eur J Cardiothorac Surg.* 2002;21:140-2.
- Beierlein W, Elliott MJ. Variations in the technique of slide tracheoplasty to repair complex forms of long-segment congenital tracheal stenoses. *Ann Thorac Surg.* 2006;82:1540-2.
- Le Bret E, Roubertie F, Roger G, Sigal-Cinqualbre A, Coblenz M, Belli E, et al. Slide tracheoplasty in infant with congenital tracheal stenosis and tracheomalacia after esophageal atresia with tracheoesophageal fistula repair. *J Pediatr Surg.* 2009;44:e15-7.
- Macchiarini P, Dulmet E, de Montpreville V, Mazmanian GM, Chapelier A, Darteville P. Tracheal growth after slide tracheoplasty. *J Thorac Cardiovasc Surg.* 1997;113:558-66.
- Kutlu CA, Goldstraw P. Slide tracheoplasty for congenital funnelshaped tracheal stenosis (a 9-year follow-up of the first case). *Eur J Cardiothorac Surg.* 1999;16:98-9.

Discussion

Dr Charles Huddleston (St Louis, Mo). When I was given the manuscript to review, I had to do a double take to review the numbers. I was surprised to see the large number of patients in this series. This has to be the largest series of patients with congenital tracheal stenosis reported in the United States for sure, and it is a testament to the interest of the Cincinnati group in dealing with this particular phenomenon and to your ability to treat successfully these very complex and sick patients. One thing that was conspicuously absent from your manuscript and from the presentation this morning is a control group, or at least a group against which to compare these results. With few exceptions, I think that centers interested in this disease have switched to the slide tracheoplasty, although I don't think anybody has actually done a careful comparison of their results with that technique versus other airway reconstruction techniques. Do you in fact have any information to compare your series at least with a historical control group?

Dr Manning. You are exactly right, it is mostly historical controls. As I briefly stated, in some of our early experience with other techniques, such as cartilage patch or a tracheal autograft, we just ran into problems. I think other centers have reported similar experiences, specifically Elliott Martin's group from Great Ormond Street in London, and when you find something that seems to work well, I think you stick with it. It is really tough to go back to some of those other techniques. And I think other centers that have used them for a longer time have certainly reported higher rates of complications, again in historical controls. So it is a little hard to compare.

I emphasize that there were other things that changed at the same time. Specifically, our multidisciplinary care group was formed around the time we started using the slide tracheoplasty. I know that in London they had a similar experience. So that there are obviously a lot of things that create problems when you use historical comparisons.

Dr Huddleston. I have a technical question. Occasionally, these patients have an anomalous origin of the right upper lobe from the

trachea. How, specifically, would you deal with that entity with this diagnosis?

Dr Manning. Actually, we saw that in about a quarter of our patients. In some cases, it was a true bronchus that was arising essentially from the midtracheal level; in some cases, it was a blind stump. It really didn't require significant modification of the technique. In many cases, the hypoplastic segment of trachea began at that pig bronchus and extended down to the carina, although sometimes it might be more superior. Typically, we have just followed the same principles. Occasionally we may have moved the direction of our split off from a true anteroposterior direction to a little bit angulated, to stay away from that pig bronchus to make it lie better, but it really didn't require significant modification of the technique.

Dr Huddleston. Finally, these are terrific results and a quite phenomenal series; however, the really interesting patients are the ones who had problems. Is there anything that you could have done in retrospect to avoid some of the airway interventions, particularly placement of stents?

Dr Manning. Obviously, this is a series that relied heavily on distant referrals, and we would always cringe a little bit when we would hear about a child with whom others had gotten into trouble. Even though it is a congenital lesion, these kids surprisingly often don't have symptoms in the first weeks of life. It is typical at 1 or 2 months of age that even patients with some of these long-segment tracheal stenoses can get sick. It is compounded when they get intubated, and somebody maybe performs an ill-advised balloon dilatation of a stenosis, and then we have added injury on top of a congenital anomaly, or a tracheostomy has been done. Those are patients that have gotten the ball rolling downhill, leading to more problems with scarring and stenosis. Or they may be ventilated for a long time preoperatively, so they take longer to be weaned from the ventilator.

The kids in whom the disease has presented essentially *de novo*, without history of any previous significant airway manipulation or trauma, generally have had relatively smooth postoperative courses. Again, this assumes there are not a lot of other complexities, such as unilateral lung agenesis or a complex cardiac anomaly, on top of that.

Dr Robert J. Cerfolio (*Birmingham, Ala*). This is an outstanding series; congratulations. I have a quick question. If the patient doesn't have congenital heart disease, why not do this off bypass?

Dr Manning. That is certainly the approach that the group from Massachusetts General has advocated through the years. I think our practice was predominantly driven by the fact that this is a relatively young population. Doing the surgery off bypass can be done, and has been done in some centers, but then you have got to work around an endotracheal tube. And some of these kids who are 4 months old have an airway lumen that is a couple of millimeters in diameter. It is just very difficult. I won't argue if you can do it; that is fine, but the added morbidity of normothermic bypass with a single venous cannula to allow you to do the tracheoplasty in 30 or 40 minutes with really exact technique is, I think, worth the risks.

Dr Cerfolio. I think it is easier to do it off bypass, and simpler actually, but thank you.

Dr Igor E. Konstantinov (*Victoria, Australia*). I have a question. Some patients, particularly with pulmonary artery sling, have severe tracheomalacia, and the carina collapses. It is very soft. How do you deal with this problem to stabilize the airway?

Dr Manning. That is a good question, and that is a true in a lot of the young kids, not just the ones with left pulmonary artery slings. There is some associated tracheomalacia. Again, and advantage of the slide is that when you are doing your slide, you are bringing a segment of trachea from proximal down. In our case, we come behind the lower segment down to the carina. So the part that you are using to augment has cartilage and has some structural stability. Among the children who did require stenting, it was not typically for stenoses but for tracheomalacia. Some of these small kids still have some floppiness and angulation of their airways, and a temporary stent, typically left in for only 2 or 3 weeks and then removed endoscopically, was often enough to overcome that problem and get them off the ventilator and out of the hospital.

Dr Carl L. Backer (*Chicago, Ill*). That was a terrific presentation, probably the best series of results in patients with congenital tracheal stenosis ever reported. Through the years, it has been interesting for me to watch the progression from the pericardial tracheoplasty, the cartilage tracheoplasty that was done in St Louis, the autograft that we tried for a while, but I would say that the slide tracheoplasty has clearly won the battle. None of us are probably going back to some of those other techniques, and I think that this really is the procedure of choice.

I was interested in your title slide, and we talked a little bit about this yesterday. There are 2 options for the slide operation: you can either incise the anterior portion of the inferior segment or the anterior portion of the superior segment. I noticed in your title slide that it appeared that you incise the way Grillo recommended it. When we talked yesterday, however, you talked about the reverse orientation, which to my mind is a very facile solution to the patient with a previous tracheostomy, which many of these complex patients have. In what percentages of the patients did you use the 2 different techniques, and what is your current recommendation for where to make those 2 critical incisions? Again, really a terrific presentation.

Dr Manning. Thank you. I agree, the reason that we stuck with the single technique is because of its versatility. And I don't think it makes a lot of difference whether you bring the lower part in front or behind the upper segment. We started incising the front of the lower segment and beginning our anastomosis superiorly on the back and changed it sort of by chance in the case of a patient with a tracheostomy that we wanted to incorporate into the repair. We had a hole in the front of the upper segment already, so we divided the front of the upper segment and then down the back of the lower segment and found that actually to be easier and switched over to that, which is now our preferred technique. We just think that it is a little bit easier. But you can certainly offset the cuts a little bit on an angle if you need to slide down a bronchus a little bit, which honestly we haven't needed to do very often, because the bronchi typically are not hypoplastic. I think the technique offers enough versatility, however, that you can do it a lot of different ways.