# Outcomes of slide tracheoplasty in 101 children: A 17-year single-center experience

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**Objective:** Our study describes the results from surgical slide tracheoplasty (STP) in children with long segment tracheal stenosis.

**Methods:** Demographic and preoperative conditions, operative details, and outcome measures, including the need for endoscopic airway intervention and mortality, were collected for children undergoing STP between February 1995 and December 2012.

**Results:** One hundred one patients (median age, 5.8 months; range, 5 days-15 years) underwent STP. Seventy-two patients (71.3%) had associated cardiovascular anomalies. Preoperative ventilation was necessary in 56 patients (55.4%), whereas extracorporeal membrane oxygenation was required in 10 patients (9.9%). Abnormal bronchial arborization was present in 39 children (38.6%), which included 13 patients (12.8%) with an anomalous right upper lobe bronchus and 17 patients (16.8%) with tracheal trifurcation. Airway stenosis extended into 1 or both bronchi in 24 patients (23.7%) and preoperative malacia was present in 24 patients (23.7%). STP was extended into the bronchus in 47 patients (46.5%). Overall survival was 88.2% (mortality in 12 patients). Post-STP balloon dilation was necessary in 45 patients (44.6%) and stenting was required in 22 patients (21.8%). Multivariate analysis revealed preoperative extracorporeal membrane oxygenation ($P < .05$), preoperative malacia ($P < .001$), and bronchial stenosis ($P < .05$) to be adverse predictors of survival. Preoperative malacia was a significant risk factor for stenting ($P < .05$).

**Conclusions:** STP is a versatile and reliable technique associated with low morbidity and mortality when compared with previous strategies for children with long segment tracheal stenosis. The presence of preoperative bronchomalacia is a significant risk factor for death and postoperative stenting. (J Thorac Cardiovasc Surg 2014;147:1783-90)

Long segment congenital tracheal stenosis (LSCTS) is a severe and often life-threatening anatomical anomaly constricting the trachea for >50% of its length. Whereas a defining feature is the presence of complete tracheal rings, many patients have other congenital anomalies. Cardiovascular malformations such as pulmonary artery sling and ventricular septal defects are common; however, both pulmonary and gastrointestinal defects may also be present, highlighting the heterogeneity found in these groups of children.[1,2]

Historically, LSCTS has often been associated with significant morbidity and mortality with the various surgical approaches advocated.[3-8] These have included simple resection, augmentation with cartilage or pericardial patch graft, replacement with homograft, or slide tracheoplasty (STP).[9,10] Following initial reports from centers where STP was shown to have a favorable outcome, we became early adopters of this technique.[7,11-13] Despite its increasing use, most reported studies have been small and long-term outcomes are rarely reported.

As the nationally funded quaternary referral unit for complex pediatric airway disease, our unit receives nearly all new cases of LSCTS in the United Kingdom. Our approach to management involves a dedicated multidisciplinary team,[13] and we now have gained >17 years of experience in managing a diverse group of children with very complex tracheal disease. This study reviews our results and endeavors to determine predictors of adverse outcome for children with LSCTS undergoing STP.

## MATERIALS AND METHODS

Our study was a retrospective, consecutive case series of children undergoing STP for LSCTS at Great Ormond Street Hospital for Children, London, between February 1995 and December 2012. Institutional review board approval was granted for this study. Data were recorded in a registered database and subsequently analyzed for demographic and specific pre- and perioperative characteristics. These included the presence of cardiac and noncardiac anomalies, minimal tracheal diameter, airway

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**Abbreviations and Acronyms**

CPB = cardiopulmonary bypass
ECMO = extracorporeal membrane oxygenation
ICU = intensive care unit
LSCTS = long segment congenital tracheal stenosis
OCT = optical coherence tomography
STP = slide tracheoplasty

arborization patterns, extent of tracheal stenosis, presence of bronchial stenosis, the need for mechanical ventilation before surgery, and the need for either pre- or postoperative extracorporeal membrane oxygenation (ECMO). Preoperative bronchomalacia was defined as dynamic collapse of the main bronchus by >50% (by diameter) on biplane bronchography. Postoperative airway malacia was defined as dynamic collapse of the airway (either tracheal or bronchial) of >50% diameter on biplane bronchography. Operative details and postoperative management, including complications and length of intensive care unit (ICU) stay and postoperative ventilation were recorded. The need for airway reintervention was defined as ≥3 endoscopic dilations.

Tracheobronchial arborization patterns and extent of stenoses were defined as previously described.[14] Arborization patterns were normal bifurcation, anomalous right upper lobe or porcine bronchus (bronchus suis), bronchial trifurcation, and single lung. Congenital bronchial stenosis was defined as the presence of complete tracheal rings in at least 1 bronchus (beyond carina or into a right upper lobe bronchus), with >50% narrowing.[14] Follow-up data, including the need for endoscopic interventional radiology procedures (eg, tracheal and/or bronchial dilation and/or stenting), were also collected.

## Patient Management

All children referred to Great Ormond Street Hospital with LSCTS are channeled through a dedicated multidisciplinary tracheal team. Management follows a defined protocol and includes the following mandatory investigations: bronchoscopy and bronchography, echocardiography, and thoracic imaging with computed tomography and/or magnetic resonance imaging. Other investigations include lung volume-flow loops, optical coherence tomography (OCT), and cardiac catheterization when required.

STP is performed as previously described.[1] Briefly, the surgery is performed through a median sternotomy with cardiopulmonary bypass (CPB). Where necessary, congenital cardiovascular anomalies are corrected at the same time. Before commencing CPB, the anterior trachea is exposed and the entire length of stenosis identified by external inspection, or by needling the airway and identifying limits of the stenosis with flexible bronchoscopy. The trachea is completely mobilized to just beyond the limits of the complete rings, or until normal trachea and/or bronchi are seen. Further mobilization may occasionally be required, and can be achieved by releasing either Hilar lymph nodes below the carina or the posterior pericardial reflection inferiorly. Superior mobilization is routinely via division of the thyroid isthmus or very rarely by a hyoid release. If no cardiovascular repairs are required, normothermic CPB is established and the mobilized trachea divided at the midpoint of the stenosis. Longitudinal incisions are made on opposite sides of proximal (posteriorly) and distal (anteriorly) segments and the ends are spatulated. An oblique sliding anastomosis is performed with interrupted mattress polydioxanone (PDS) sutures. If a tracheostomy is present, and the stoma is adjacent to the stenosis we advocate it be incorporated into the repair, otherwise it is left for conventional de-cannulation once the patient needs only minimal ventilation. Assessment of the effectiveness of repair is judged by immediate postprocedural bronchoscopy and a leak test with gradual insufflation of the lungs with the repair submerged in warm saline. A mediastinal catheter is left in situ together with chest drains as required. Mediastinal irrigation with 1% povidone-iodine solution (reconstituted from 10% aqueous povidone iodine) in 0.9% saline is commenced at 2 mL/kg/h for 48 hours. Reservoir bags are changed every 24 hours and before catheter withdrawal samples are tested for microbial colonization (mediastinal contamination is assumed).

Postoperative management includes bedside fiberoptic bronchoscopy at 24 hours to plan extubation. Further evaluation of the airway is performed at 1 week with bronchoscopy and bronchography. Subsequent evaluations (with or without balloon dilations) are performed according to clinical need. Stent placement is only indicated in cases in which severe postoperative malacia prevents withdrawal of ventilatory support or in patients who fail to progress on noninvasive ventilation.[1,13] In these children, a made-to-order biodegradable PDS stent (Ella-CS, Hradec Kralove, Czech Republic) is sometimes considered, because it resorbs over an 8- to 12-week period.[15] Other stents previously inserted were balloon-expandable metal stents (Palmaz; Cordis, Warren, NJ), and self-expanding nitinol stents (Niti-S; Pyramed, Escher, UK).

Bronchoscopy and bronchography delineate the full anatomical configuration of the airway and provide dynamic information not easily achievable with other forms of imaging. As previously described, these procedures are performed simultaneously in an interventional radiology suite.[16] The child is anesthetized with either a laryngeal mask airway or intubated, and without paralysis where possible. If intubated, the endotracheal tube is withdrawn so that the upper trachea may be examined. Small volumes (<1 mL) of iohexol (Omnipaque 240 mg/mL; Nycomed Inc, Asker, Norway) are injected either via a catheter introduced through the endotracheal tube or through the working channel of the bronchoscope into the proximal trachea. Dynamic images are acquired in both posteroanterior and lateral projections. OCT is performed in select patients to clarify the status of airway cartilage formation. OCT is specifically used to determine if cartilage rings are complete, fragmented, or absent. Patients undergo OCT at the time of bronchoscopy and/or bronchography. A floppy-tipped 0.36-mm diameter OCT wire (ImageWire 200; St Jude Medical, St Paul, Minn) is passed through the side arm of the bronchoscope or the bronchographic catheter and advanced to the region of interest. Confirmation of positioning is obtained by direct visualization and/or bronchography.[17,18] If balloon dilation is required; for example, for recurrent granulation tissue, an angioplasty catheter is selected (with a balloon approximately the same size as the normal airway) and inflated under fluoroscopic guidance until the stenosis is obliterated. Intervals between ballooning are determined by clinical symptoms and the appearance of the airway at bronchoscopy.

## Data Analysis

Patient demographics and the nature of treatments were obtained from hospital records. Data are presented as mean values ± standard deviation, medians and ranges, and/or binomial percentages, where appropriate. Kaplan-Meier survival curves were plotted for outcome measures and log-rank tests were performed to analyze differences between specific subgroups. Risk factors for mortality and stent insertion were analyzed with a Cox proportional-hazards regression model with the forward (likelihood ratio) method applied. Data were analyzed and displayed with SPSS software version 21.0 (IBM-SPSS, Inc, Armonk, NY) and Prism 6.0 (GraphPad Software Inc, La Jolla, Calif).

# RESULTS

One hundred one children (median age, 5.8 months; range, 5 days-15 years) underwent STP. Patient demographics and general characteristics are shown in Table 1. All children had stenosis >50% of the length of the trachea and 89%