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Lung: Short Report

Clinical Outcomes After Tracheobronchoplasty With Ringed Polytetrafluoroethylene Vascular Graft

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ABSTRACT

BACKGROUND This report describes the surgical technique and outcomes of tracheobronchoplasty (TBP) with ringed polytetrafluoroethylene (PTFE) vascular graft.

METHODS We identified all patients who underwent PTFE-TBP for severe expiratory central airway collapse from January 1, 2018 to August 2021 at Mayo Clinic, Florida. Preoperative and postoperative St George's Respiratory Questionnaire (SGRQ), Cough-Specific Quality of Life Questionnaire (CSQLQ), pulmonary function testing, 6-minute walk test, and blinded dynamic bronchoscopy videos at 3-month follow-up were used to assess outcomes.

RESULTS Fourteen patients (median age, 62.5 years; 64.3% female) underwent PTFE-TBP. The median operative time was 355 minutes, median hospital length of stay was 5 days, and median intensive care unit stay was 1 day. One patient had a Clavien-Dindo grade ≥3 complication. Comparison of preoperative and postoperative questionnaire scores demonstrated improvement in median SGRQ score by 14.79 ($P = .013$) and CSQLQ score by 22 ($P = .005$). Preoperative and postoperative pulmonary function and 6-minute walk test results showed no significant difference. Postoperative bronchoscopy demonstrated improvement in median collapsibility of mid trachea by 39.6% ($P < .001$), distal trachea by 50% ($P < .001$), left main bronchus by 38.2% ($P < .001$), right main bronchus by 37.9% ($P < .001$), and bronchus intermedius by 30.7% ($P < .001$).

CONCLUSIONS PTFE-TBP provides significant improvement in patients' symptoms and expiratory central airway collapse as judged by preoperative and postoperative quality of life questionnaires and bronchoscopy.

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Expiratory central airway collapse (ECAC) is increasingly recognized as the cause of or a contributor to a variety of respiratory complaints. ECAC comprises 2 different subtypes: excessive dynamic airway collapse (EDAC), when the airway narrows by a forward displacement of the posterior membrane; and tracheobronchomalacia (TBM), involving the anterior or lateral collapse of cartilaginous structures. Tracheobronchoplasty (TBP) is currently recommended in patients with an airway collapsibility >90%.[1]

IN SHORT

- PTFE-TBP provides significant improvement in patients' symptoms.
- PTFE-TBP improves ECAC as judged by blinded preoperative and postoperative bronchoscopy.

TBP is performed by suturing a flexible polypropylene hernia mesh to the posterior aspect of the trachea and mainstem bronchi.[2,3] This was the standard TBP technique performed at our institution until 2018.

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Abbreviations and Acronyms

CSQLQ = Cough-Specific Quality of Life Questionnaire
ECAC = expiratory central airway collapse
EDAC = excessive dynamic airway collapse
6MWT = 6-minute walk test
PFT = pulmonary function test
PTFE = polytetrafluoroethylene
SGRQ = St George's Respiratory Questionnaire
TBM = tracheobronchomalacia
TBP = tracheobronchoplasty

Because of less than ideal airway patency, we explored alternative surgical techniques. Extrapolating from the success of polytetrafluoroethylene (PTFE) in patients with congenital tracheal or bronchial anomalies, we adopted this material for use in patients with ECAC.[4] The ringed grafts provide superior structural support to the membranous wall of the airway compared with flexible mesh. We report our series of 14 patients with ringed PTFE grafts.

MATERIAL AND METHODS

We included all patients who underwent PTFE-TBP between January 1, 2018, and August 1, 2021, at our institution. All patients had severe ECAC confirmed by dynamic bronchoscopy and underwent stent trial.

We analyzed patients' demographics and surgical outcomes. Assessment of patients' symptoms was based on preoperative and postoperative St George's Respiratory Questionnaire (SGRQ), Cough-Specific Quality of Life Questionnaire (CSQLQ), and subjective reports at 3-month follow-up. Functional outcomes were measured by comparing preoperative and postoperative pulmonary function test (PFT) and 6-minute walk test (6MWT) results and dynamic bronchoscopy findings at a 3-month follow-up.

Videos from preoperative and postoperative dynamic bronchoscopy were stripped of identifying information and randomized. The videos were then independently assessed by 2 pulmonologists. The degree of collapsibility was recorded to the nearest decile at 5 locations along the airway.

STATISTICAL ANALYSIS. Categorical variables were summarized as counts (percentages), and continuous variables were reported as medians (interquartile range) and compared by Wilcoxon signed rank test. Intraclass correlation coefficient measured the correlation between each pulmonologist's assessment. All tests were 2 sided, with a P value $< .05$ considered significant. The analysis was done using IBM SPPS Statistics.

SURGICAL TECHNIQUE. We use a standard posterior-lateral thoracotomy. The ringed PTFE is cut along the length of the graft and unfurled. It is further cut into strips (2 rings per strip). We use interrupted Prolene sutures, usually 4 per row. Each double-arm suture comes through the PTFE mesh on either side of each ring, using a parachute technique with 6 to 10 sutures per mesh strip. The lateral sutures are placed with a horizontal mattress through the cartilage so that each strip's ends extend over the trachea's edge by a few millimeters and face anteriorly. We use 3 or 4 strips of mesh on the trachea, 1 or 2 strips on the left and right mainstem bronchi, 1 on the bronchus intermedius, and 1 on the right upper lobe bronchus (Figure 1). Using preoperative computed tomography (CT) scans, we measure the width of each strip. We typically oversize each strip by 2 or 3 mm over our intended posterior membrane diameter. We perform cryoablation of the intercostal nerves and use a knot

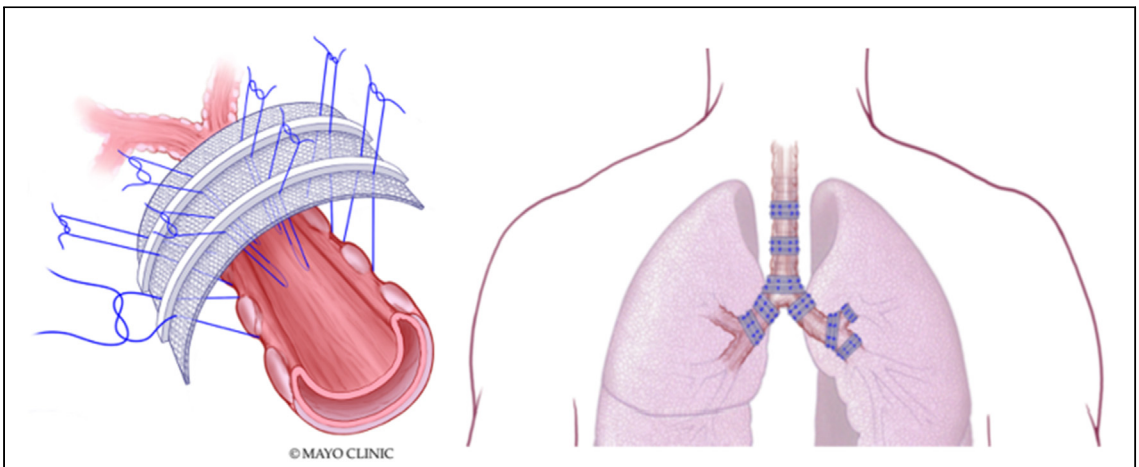

FIGURE 1 Trachea with ringed polytetrafluoroethylene grafts. Used with permission of Mayo Foundation for Medical Education and Research, all rights reserved.

TABLE Clinical Characteristics and Outcomes

ID	Chief Complaint	Type of ECAC	Delta SGRQ	Delta CSQLQ	Delta $FEV_{1\%}$	Delta 6MWT distance, m	Delta Mid Trachea, %	Delta Distal Trachea, %	Delta Left Main, %	Delta Right Main, %	Delta BI, %
1	Cough	EDAC	−42.33	−27	+10	NA	−35	−50	−55	−50	−50
2	Cough	EDAC	−36.52	−8	+1	−26.69	−60	−40	−50	−40	−25
3	Cough and shortness of breath	EDAC	−14.79	−20	0	+19.2	−70	−60	−60	−75	−75
4	Cough and shortness of breath	EDAC	+6.49	0	−12	−100.8	−70	−65	−65	−55	−50
5	Cough and shortness of breath	EDAC	−46.29	−43	+7	NA	−20	−55	−30	−30	−40
6	Shortness of breath	TBM, saber-sheath	−6.79	NA	−7	+138.52	−25	−10	0	−15	−10
7	Shortness of breath	TBM, crescent	−0.79	+5	−17	−217.74	+10	−25	−30	−5	−15
8	Shortness of breath	EDAC	−13.07	−7	−15	+5.2	−35	−30		+30	+30
9	Shortness of breath	EDAC	−72.93	−40	+18	+28.41	−35	−75	−55	−50	−35
10	Shortness of breath	EDAC	−14.41	−42	−9	+22.1	−55	−55	0	−25	−10
11	Cough	EDAC	−3.98	−10	NA	+154.75	−45	−60	−45	−45	−35
12	Cough	EDAC	NA	NA	−2	NA	−55	−50	−45	−55	−35
13	Shortness of breath	EDAC	+28.33	−7	−14	−26.43	−35	−50	−40	−50	−40
14	Cough and shortness of breath	EDAC	−70.35	−41	+8	+53	−20	−30	−10	−20	0

Green corresponds to patients who reported an improvement or results that demonstrated a benefit. Red corresponds to patients who reported no improvement or results that showed no benefit. White is neutral or not available.
BI, bronchus intermedius; CSQLQ, Cough-Specific Quality of Life Questionnaire; ECAC, expiratory central airway collapse; EDAC, excessive dynamic airway collapse; FEV_1, forced expiratory volume in 1 second; ID, identifier; 6MWT, 6-minute walk test; NA, not available; SGRQ, St George's Respiratory Questionnaire; TBM, tracheobronchomalacia.

pusher to increase visualization of knot placement and to reduce surgical time.

RESULTS

Fourteen patients (median age, 62.5 years; 64.3% female) were included. The most common comorbidities were gastroesophageal reflux (85.7%) and hypertension (78.6%). Twelve (85.7%) patients had EDAC and 2 (14.3%) TBM (Table). The most common symptom was shortness of breath (71%; Table). The median operative time was 355 minutes (292-388 minutes), median intensive care unit stay was 1 day (1-2 days), and median total length of hospital stay was 5 days (5-7.75 days).

Both blinded pulmonologists agreed that postoperative dynamic bronchoscopy demonstrated improvement in median collapsibility of mid trachea by 39.6%, distal trachea by 50%, left main bronchus by 38.2%, right main bronchus by 37.9%, and bronchus intermedius by 30.7% (all $P < .001$; Figure 2). The average intraclass correlation coefficient between both blinded physicians was 0.75 ($P < .001$).

Preoperative and postoperative PFT and 6MWT results showed no significant difference (Supplemental Table).

Comparison of preoperative and postoperative SGRQ and CSQLQ scores demonstrated improvement in median SGRQ score by 15.88 ($P = .013$) and CSQLQ score by 22 ($P = .005$). Similarly, 12 patients (85.7%) reported symptom improvement.

There were no perioperative deaths. Only 1 patient (7.2%) had a Clavien-Dindo grade 3 complication <30 days after operation. This patient underwent operative repair of a persistent right middle lobe collapse. Three patients had complications >30 days after operation. In 1 patient, an ulceration developed on the posterior wall of the trachea, which resolved with conservative measures. One patient required revisional TBP, and another had to have 1 of the mesh strips removed a year later for erosion into the airway wall.

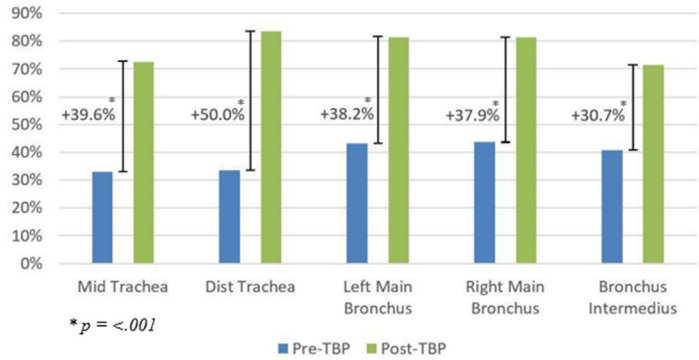

FIGURE 2 Residual airway area during coughing before (pre-) and after (post-) tracheobronchoplasty (TBP) at 3 months. (Dist, distal.)

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COMMENT

As described by Damle and Mitchell,[3] the goal of TBP is to approximate the cartilaginous edges of the trachea, restoring a D shape. This makes mechanical sense with crescent-type TBM, but it does not make structural sense with the TBM subtypes of EDAC, saber-sheath, and circumferential (Figure 3). These subtypes have a D shape at rest but are prone to dynamic collapse of the posterior membrane (EDAC), lateral walls (saber-sheath), or both (circumferential) with coughing.[5] Similar to other reported series,[6] most of our patients had EDAC, so we focus on this subtype.

Polypropylene mesh is flexible and provides only a modicum of stability to the posterior membrane. Collapsibility is hypothesized to improve secondarily as the mesh stiffens the posterior membrane over time.[7] Ringed PTFE is a vascular graft with circular supporting rings. The rings are attached to the PTFE tube with a thin film. Ringed PTFE is more rigid than polypropylene mesh and therefore better at preventing airway collapse.

Gangadharan and colleagues have published the most extensively on TBP.[2,8,9] In 2023, they reported 5-year outcomes of 61 patients who underwent traditional TBP, demonstrating reduced collapsibility as assessed by dynamic CT scan and improvement in 6MWT and quality of life surveys.[8] However, they could not show an improvement in PFTs in their first series and stopped reporting this parameter in subsequent publications.[3] This same group reported an operative time of 373 minutes and a hospital stay of 8 days in another series. On the Clavien-Dindo classification, 23% of patients had grade ≥3 complications, with 17% being due to respiratory failure.[9] They had 2 in-hospital deaths and 7 revisional surgeries.[9]

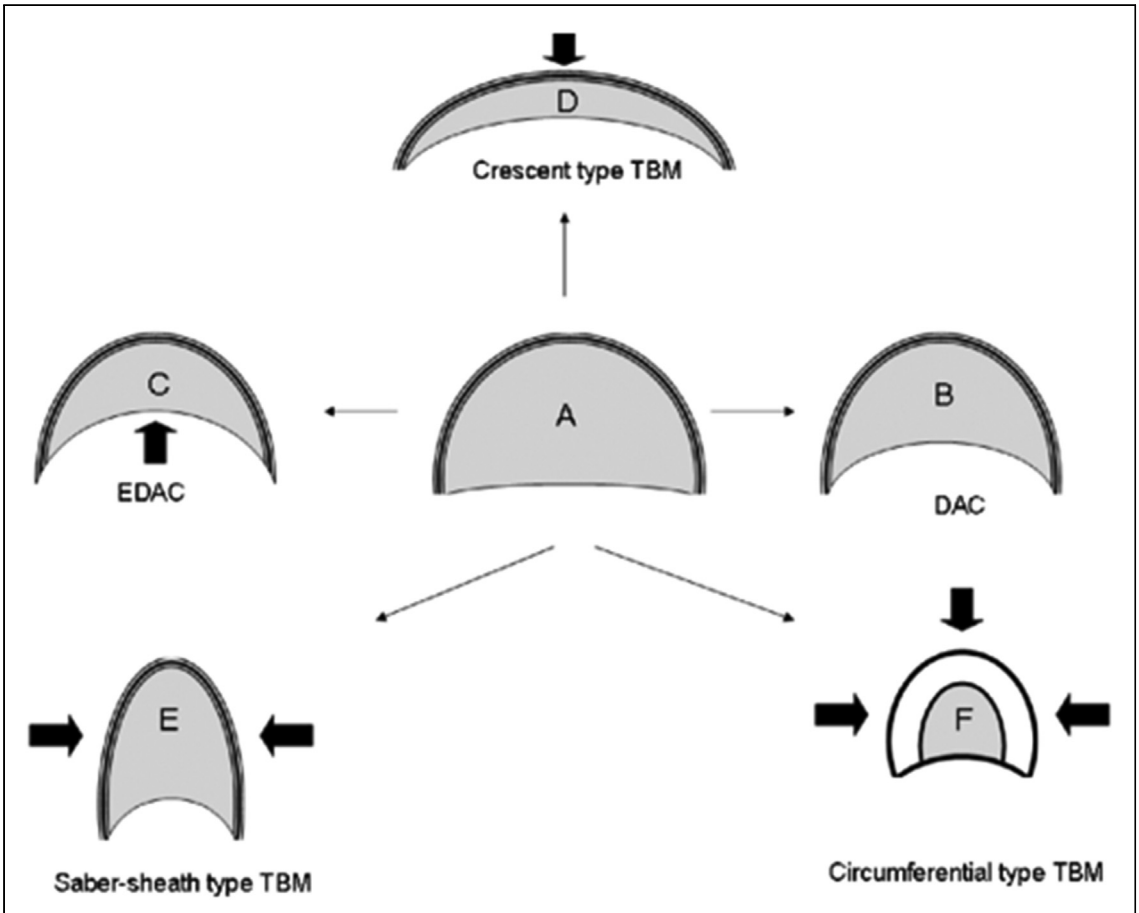

FIGURE 3 Different subtypes of tracheobronchomalacia. (A) Airway lumen during inspiration. (B) During expiration, there is inward bulging of the posterior membrane. This process is physiologic and is called dynamic airway collapse (DAC). (C) The pathologic exaggeration of this process results in a reduction in cross-sectional area of 50% or more and is called excessive dynamic airway collapse (EDAC). The pathologic collapse of the cartilaginous rings represents tracheobronchomalacia (TBM). (D) The crescent type of TBM occurs when the anterior cartilaginous wall is softened and results in excessive narrowing of the sagittal airway diameter. (E) The saber-sheath type of TBM is due to softening of the lateral walls and excessive narrowing of the transverse airway diameter. (F) Circumferential (combined) type of TBM is characterized by anterior and lateral airway wall collapse and is usually associated with significant airway wall inflammation. Reproduced from[5] with permission from John Wiley & Sons, Inc.

Lazzaro and coworkers[1] were the first to describe robotic TBP. They published a series of 42 patients with a median follow-up of 40 months, demonstrating improvements in quality of life surveys (SGRQ) and PFT results. The change in 6MWT distance was not statistically significant. Operative time was 249 minutes, and hospital stay was 3 days. Eight patients (19%) had grade ≥3 complications. One patient had revisional operation, and there were no deaths. In addition, 82% reported satisfaction with the procedure.

Assessing postoperative changes in airway collapsibility is critical for TBP. Dynamic CT has been used to assess changes in collapsibility. Buitrago and colleagues[9] demonstrated a decrease in airway collapsibility from 70% to 36% ($P < .001$) by dynamic CT. However, performance characteristics of dynamic CT can be impaired by inherent difficulties in appropriate timing of image acquisition. We showed significant improvement in dynamic collapse using preoperative and postoperative bronchoscopy. Dynamic bronchoscopy is the "gold standard" for ECAC diagnosis,[3] and we document significant reduction in collapsibility by bronchoscopy.

The lack of improvement in 6MWT distance was surprising as it was incongruent with bronchoscopy and quality of life outcomes. However, only 11 patients had preoperative and postoperative 6MWT data, which limited the power of this observation. We also did not find a significant change in PFT results, which was less surprising because preoperative PFT findings were relatively normal. Our operative time and hospital stay were shorter than those of Buitrago but longer than those of Lazzaro. Overall procedure satisfaction was positive in 86% (12/14) of patients.

This series highlights some of the benefits and potential caveats of PTFE-TBP. The main benefit is an excellent support to the posterior membrane as shown by improved bronchoscopic assessment of collapsibility. Clinically, this meant that every patient was extubated on the day of operation, with no reintubations and no intensive care unit readmissions. On the negative side, ringed PTFE reverts to its cylindrical shape if it comes loose from the lateral edges.

As a solution, we now extend the PTFE past the edge of the tracheal cartilage and secure it to the lateral wall. In 2 patients, the PTFE strips curled into the posterior membrane, causing erosion. One patient had a crescent subtype of TBM, which did not improve, and had a revision TBP at another center. In these situations, a polypropylene mesh or suture technique may be more appropriate. The other patient had a short-term (right middle lobe collapse) complication followed by a long-term (mesh erosion) complication a year later. Despite these setbacks, this patient still reported improved breathing.

Of the 2 patients who reported worsening symptoms after TBP, 1 had crescent TBM (already mentioned), and the other had saber-sheath TBM. For the saber-sheath subtype, we thought the ringed PTFE would provide support and hold open the lateral edges of the anterior cartilage, but this was not the case.

Recognized limitations of our study are the cohort size and median follow-up of 13 months. In addition, although all videos were deidentified and randomized, differentiation of preoperative from postoperative bronchoscopy was often evident.

In conclusion, using ringed PTFE for TBP significantly improved airway collapsibility, as demonstrated by the gold standard technique of dynamic bronchoscopy. This technique appears to work best for patients with the EDAC subtype of TBM. Outcomes compare favorably with other published series.

The Supplemental Table can be viewed in the online version of this article [https://doi.org/10.1016/j.atssr.2023.05.023] on http://www.annalsthoracicsurgery.org.

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DISCLOSURES

The authors have no conflicts of interest to disclose.

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