Evaluation of Tracheobronchomalacia by Dynamic Flexible Bronchoscopy

A Pilot Study

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Abstract

Objectives: Dynamic flexible bronchoscopy is the "gold standard" for assessing changes in airway luminal size associated with tracheobronchomalacia, but the procedure has not been adequately validated. The present study was designed to test the validity of diagnosing tracheobronchomalacia by dynamic flexible bronchoscopy through assessing inter- and intraobserver agreements in estimating degree of central airway collapse associated with tracheobronchomalacia.

Methods: This prospective observational pilot study enrolled consecutive patients with suspected tracheobronchomalacia scheduled for dynamic flexible bronchoscopy. Images of the airway lumen were obtained at five different sites in the tracheobronchial tree during forced inspiration and expiration and were evaluated by 23 pulmonologists (not involved in the care of study patients) with different levels of training and experience at baseline (interobserver agreement) and 8 days later (intraobserver agreement). The degree of airway collapse was visually estimated by each examiner and expressed as a percentage of narrowing. A multirater generalized kappa-type statistical method was used to calculate the correlation coefficients and to assess reliability of the measurements obtained during dynamic flexible bronchoscopy.

Measurements and Main Results: Between September 1 and 30, 2009, 10 patients (median age, 65 yr) underwent dynamic flexible bronchoscopy. The correlation coefficients for inter- and intraobserver agreement were favorable and ranged for the five airway sites from 0.68 to 0.92 and from 0.80 to 0.96, respectively.

Conclusions: The favorable inter- and intraobserver agreements among 23 pulmonologists using dynamic flexible bronchoscopy to estimate the degree of dynamic central airway collapse provide additional evidence that dynamic flexible bronchoscopy is a reliable diagnostic tool for tracheobronchomalacia.

Keywords: tracheomalacia; bronchomalacia; excessive dynamic airway collapse; bronchoscopy; airway obstruction

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The tracheobronchial tree is a dynamic tubular structure that changes lumen size on exposure to varying pressures experienced during different phases of respiration. The intrathoracic airways narrow during expiration and expand during inspiration. With tracheobronchomalacia airway cartilage rings soften, leading to exaggerated collapse of the airways during exhalation. Atrophy of the longitudinal muscle fibers in the posterior membranous portion of major airway walls with structurally intact airway cartilage also results in excessive dynamic airway collapse during exhalation (1–4).

Although the pathophysiology is different for each entity, the clinical features of and therapeutic goals for tracheobronchomalacia and excessive dynamic airway collapse are similar (3, 4). Patients with severe airway collapse refractory to medical management are candidates for surgical stiffening of central airways to prevent excessive narrowing during exhalation. No distinction between tracheobronchomalacia and excessive dynamic airway collapse is made in this communication.

The decrease in lumen size during exhalation associated with tracheobronchomalacia is most commonly diagnosed by dynamic flexible bronchoscopy, but it can also be accomplished noninvasively by dynamic airway computerized tomography (5). Airway dimension is estimated by dynamic flexible bronchoscopy as the anteroposterior distance between mid-points of the posterior membrane and anterior luminal aspects of the airway, whereas dynamic airway computerized tomography measures the cross-sectional area of the lumen. A decrease in lumen size by 50% or less during exhalation is regarded as nonpathologic, between 51 and 75% as mild obstruction, between 76 and 90% as moderate obstruction, and between 91 and 100% as severe obstruction (2). The diagnosis of tracheobronchomalacia or excessive dynamic airway collapse requires obstruction greater than 50% during exhalation combined with respiratory symptoms (3,4). We chose to measure lumen size by anteroposterior diameter rather than the cross-sectional area as the former is easy to measure, does not require additional software commonly employed in clinical practice, and does not involve radiation exposure.

Dynamic flexible bronchoscopy, unlike dynamic airway computerized tomography, allows real-time visualization and characterization of airway walls when used in conjunction either with radial endobronchial ultrasound (6, 7) or optical coherent tomography (8). Dynamic flexible bronchoscopy also facilitates the detection of coexisting pathology such as vocal cord abnormalities or bronchitis and facilitates biopsy of the mucosa as well as sputum sampling for histological and bacterial analysis. However, dynamic flexible bronchoscopy has not been adequately validated. The purpose of this pilot study was to test inter- and intra-observer agreement of dynamic flexible bronchoscopy data estimating the degree of central airway collapse during exhalation among patients suspected of having tracheobronchomalacia or excessive dynamic airway collapse. Some of the results of this study were previously reported in an abstract (9).

Methods

We performed a prospective observational study of consecutive patients referred to the Complex Airway Center at Beth Israel Deaconess Medical Center (Boston, MA) between September 1 and 30, 2009 for suspected tracheobronchomalacia. The study was approved by the Beth Israel Deaconess Medical Center Institutional Review Board and was performed in compliance with Health Insurance Portability and Accountability Act guidelines (Protocol 2005P-000112). Written informed consent was obtained from the patients before enrollment into the study.

Demographic information, age, sex, body mass index, comorbidity, respiratory symptoms, and procedure-related complications including hypoxemia (oxygen saturation $<$ 90%), hypotension (systolic blood pressure $<$ 100 mm Hg or diastolic blood pressure $<$ 60 mm Hg), hemoptysis (need for topical epinephrine, electrocautery, or argon photocoagulation), need for noninvasive or invasive mechanical ventilation, vocal cord hematoma, airway laceration, and requirement for increase in level of medical care, were recorded. Of the 10 patients who underwent dynamic flexible bronchoscopy, 6 were female.

Procedure

Blood pressure, heart and respiratory rates, as well as arterial oxygen saturation, were monitored throughout the procedure. Arterial oxygen saturation was maintained above 90% with supplemental oxygen. Minimal sedation allowing spontaneous respiration was used. Lidocaine (1%, 20 ml), was delivered by atomizer to the posterior oropharynx until the gag reflex was suppressed. The larynx, vocal cords, and aryepiglottic folds were irrigated with 1% lidocaine in 2-ml aliquots. Intravenous midazolam and fentanyl were administered for minimal sedation, as defined by the American Society of Anesthesiologist Task Force on Sedation and Analgesia by Non-Anesthesiologists, throughout the procedure (10). Ketamine (11) was not used because of its relaxing influence on smooth muscle and potential enhancement of airway collapse.

An Olympus BF P180 video bronchoscope (Olympus America, Melville, NY) with a 4.9-mm outer diameter and 2.0-mm working channel was used to minimize any possible stenting effect. The patients were placed in a supine position. The bronchoscope was inserted through the larynx, and then advanced into the trachea while 1% lidocaine delivered in 2-ml aliquots to the entire tracheobronchial tree. Patients were instructed to take a deep breath, hold it, and then blow it out. Still images were taken through the dynamic flexible bronchoscope at the end of inhalation and exhalation after forced inspiration and expiration at the following five sites: proximal trachea at the level of the cricoid; mid-trachea 5 cm proximal to the carina; distal trachea 2 cm proximal to the carina; right main stem bronchus at the right tracheobronchial angle; and left main bronchus at the left tracheobronchial angle (Figure 1). The maneuver was repeated three times to ensure maximal airway narrowing during exhalation. The image with the greatest reduction in anteroposterior diameter was selected for analysis. The images were processed with ImageJ (12) for assessing airway lumen size.

Each processed image was examined for anteroposterior airway lumen dimensions at the baseline point in time and 8 days later by 23 pulmonary

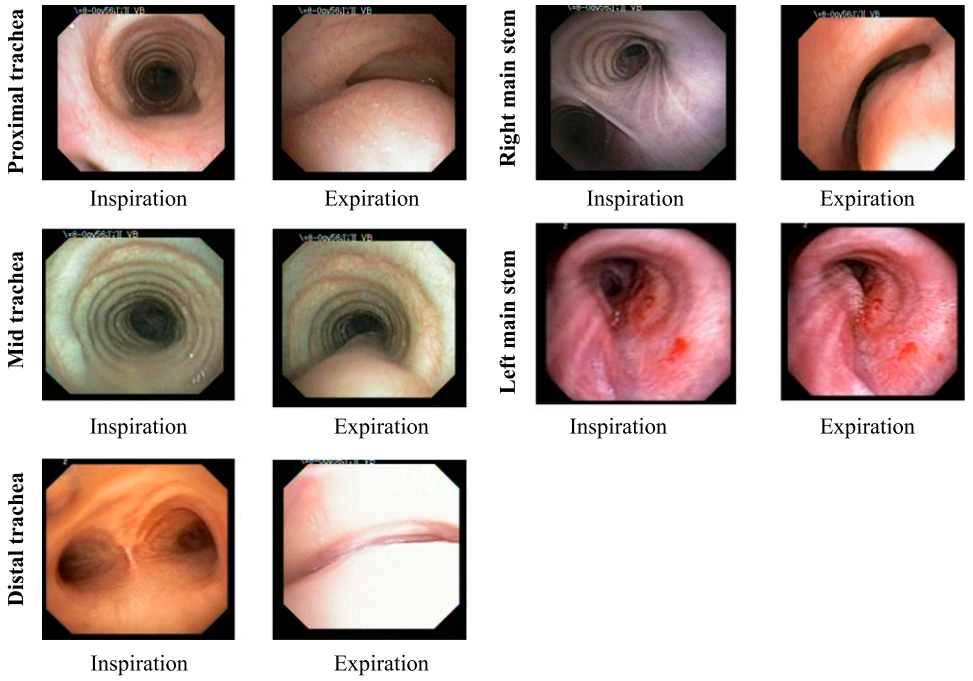

Figure 1. Samples of images obtained by dynamic flexible bronchoscopy during inhalation and exhalation at five different sites in the tracheobronchial tree (proximal trachea, mid-trachea, distal trachea, right main stem bronchus, and left main stem bronchus) were evaluated for degree of luminal narrowing.

physicians consisting of 8 interventional pulmonologists, 8 general pulmonologists, and 7 senior pulmonary fellows with more than 100 bronchoscopy experiences. The latter number was considered sufficient for acquisition of basic competence. The participating examiners were not involved in the care of the subjects and were blinded to clinical or radiological data. Results on the percentage of airway narrowing were scored and recorded. For interobserver agreement, 5 anteroposterior data points per patient and 50 data points for the 10 study subjects were available for each of the 23 interpreters, resulting in a total of 1150 data points. An identical number of data points was available for intraobserver agreement between baseline and 8 days, thereafter for a total of 2300 data points to be used for inter- and intraobserver agreement. Scores obtained from the baseline examination were used to determine interobserver agreement and the assessments 8 days later for intraobserver agreement.

Statistical Analysis

Interclass correlation coefficients were used to assess the reliability/validity of images obtained during dynamic flexible bronchoscopy, due to small sample size. A value of 1.0 represents perfect agreement and value of 0.0 represents no agreement. Values between 0 and 0.3 indicate weak agreement, between 0.3 and 0.7 moderate agreement, and between 0.7 and 1.0 strong agreement. The correlation coefficient was tested against a null hypothesis that the coefficient was zero (i.e., no correlation). A P value less than 0.05 was considered significant (evidence against the null of no correlation). Statistical analysis was performed with Statistical Analysis System software (SAS Institute, Cary, NC).

Results

The median age was 65 years with dyspnea and/or cough as the presenting respiratory symptoms in 9 of the 10 patients. The most common comorbid disease was chronic obstructive pulmonary disease (Table 1). Mean doses of intravenous midazolam and fentanyl were 1.5 ± 0.5 mg and 37.5 ± 12.5 μg, respectively. Average lidocaine (1%) usage was 420 ± 40 mg (200 mg at the pharynx, 80 mg at the vocal cords, 60 mg in the trachea, 20 mg in right main stem bronchus, 20 mg in the bronchus intermedius, and 40 mg in the left main stem bronchus). Mean total duration of the dynamic flexible bronchoscopy procedure was 20 ± 5 minutes. All 10 patients completed the study. There were no procedure-related complications. Airway images were obtained at all five designated sites during dynamic flexible bronchoscopy and graded by all 23 physicians for the degree of collapse during exhalation. Inter- and intraobserver correlation coefficients showed strong agreement in estimates of dynamic central airway narrowing (Table 2). The findings were consistent with tracheobronchomalacia of varying extent and severity in seven patients. Three patients had no pathological airway collapse on exhalation. Medical treatment was recommended to six patients, and four underwent operative tracheobronchoplasty.

Discussion

In spite of advances in radiologic imaging technology, dynamic flexible bronchoscopy remains the "gold standard" for estimating airway size for diagnosing

Table 1. Demographics, findings, and treatment of study population

Patient	Sex	Age (*yr*)	Symptoms	Degree of Malacia by DFB	Comorbidities	Treatment
1	Female	43	Dyspnea, cough	Mild TBM	Relapsing polychondritis	Medical
2	Female	60	Dyspnea	Severe TBM	COPD, lung cancer	Medical
3	Male	74	Cough	None	Mild tracheal stenosis, GERD	Medical
4	Female	56	Dyspnea, cough	Severe TM	COPD, GERD	TBP
5	Male	49	Cough	None	GERD, history of skin melanoma	Medical
6	Female	65	Dyspnea	Severe TBM	COPD, OSA	TBP
7	Male	71	Dyspnea	Severe TBM	OSA	TBP
8	Female	59	Dyspnea	Moderate bilateral BM	COPD, pulmonary	Medical
9	Male	62	Recurrent respiratory infections	Severe TBM	DM, post-renal transplant	TBP
10	Female	74	Dyspnea	None	COPD, CHF	Medical

Definition of abbreviations: BM = bronchomalacia; CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; DFB = dynamic flexible bronchoscopy; DM = diabetes mellitus; GERD = gastroesophageal reflux disease; OSA = obstructive sleep apnea; TBM = tracheobronchomalacia; TBP = tracheobronchoplasty; TM = tracheomalacia.

tracheobronchomalacia and guiding treatment. Dynamic flexible bronchoscopy permits real-time examination of the airways and provides information on morphology, degree, extent, and location of pathology. Dynamic flexible bronchoscopy also provides access to bronchial secretions and to airway wall biopsy for microbiologic and histologic examinations. Moreover, with the aid of a radial probe endobronchial ultrasound or optical coherence tomography, further characterization of the airway wall can be obtained during dynamic flexible bronchoscopy (6–8). In spite of widespread use, dynamic flexible bronchoscopy has been inadequately validated, especially in terms of inter- and intraobserver agreement on airway luminal dimensions by pulmonologists with various levels of training and experience. To our knowledge, the present communication represents the first report on this important aspect of dynamic flexible bronchoscopy in tracheobronchomalacia. The results show "moderate to strong" inter- and intraobserver agreement among physicians at various levels of training and experience in dynamic flexible bronchoscopy in assessing the degree of airway collapse during exhalation.

Shortcomings of our study include reliance on still rather than video images that are less susceptible to distortions and have the potential for greater accuracy because changes with tracheobronchomalacia are dynamic. However, we made every effort to take the images at maximal inspiration and expiration and to obtain satisfactory resolution with high-quality reproduction. The high levels of inter- and intraobserver agreements lend further support to the accuracy of the information we obtained. In clinical practice, if the images are not captured at maximal exhalation the degree of airway narrowing is underestimated. Moreover, if images are captured during coughing the degree of airway obstruction during exhalation tends to be overestimated. Another limitation of our study is that the lumen size was subjectively estimated by anteroposterior diameter and not quantitatively measured by cross-sectional area. It is relevant, however, that in another pilot study, we found that the two approaches produced similar results (13).

Additional studies are needed to confirm the findings in this communication. Ellingsen and Holmedahl (14) demonstrated that during simulation of posterior tracheal wall bulging to various lengths in an excessive dynamic airway collapse model, there was a strong correlation between the reduction in cross-sectional area of the trachea and anteroposterior diameter.

Alternative approaches to evaluating airway collapse are through objective quantification, using the color histogram mode technique (15) or optical coherence tomography during dynamic flexible bronchoscopy (13). However, application of the technology may be limited by availability of software and familiarity with the technique.

The ability to safely and accurately capture dynamic airway properties, with reproducible results, are the basic requirements of an acceptable method for assessing tracheobronchial luminal dimensions (15). Dynamic flexible bronchoscopy meets most of these criteria. We believe that dynamic flexible bronchoscopy is also user-friendly as it resembles flexible bronchoscopy and is easier to perform than *in vivo*

Table 2. Inter- and intraobserver agreements

Airway Site	Correlation Coefficient (*P* Value)*	
	Interobserver	Intraobserver
Proximal trachea	0.85 (0.002)	0.92 (<0.001)
Mid-trachea	0.68 (0.03)	0.82 (0.004)
Distal trachea	0.89 (<0.001)	0.95 (<0.001)
Right main stem bronchus	0.72 (0.02)	0.80 (0.02)
Left main stem bronchus	0.92 (<0.001)	0.96 (<0.001)

*$P < 0.05$ = statistically significant.

morphometric bronchoscopy methods employing calibration markers not readily available in many bronchoscopy suites. In our experience with training interventional pulmonary fellows, the learning curve for dynamic flexible bronchoscopy is very short.

The high inter- and intraobserver agreement among pulmonary physicians with varying training and experience lends support to the value of dynamic flexible bronchoscopy in diagnosing tracheobronchomalacia. Familiarity with flexible bronchoscopy by a large group of specialists represents a distinct advantage for the approach.

Conclusions

This study demonstrates close intra- and interobserver agreement among pulmonologists and trainees with various levels of experience in the evaluation of the degree of airway collapse by dynamic flexible bronchoscopy for diagnosing tracheobronchomalacia. The procedure is safe, user-friendly, and can be performed without extensive training or need for additional software. ■

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