Functional tracheal narrowing: what does it mean on CT?

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Learning Objectives

To review different types of expiratory functional tracheal narrowing and demonstrates the utility of 4-dimensional CT (4D-CT) in diagnosis, quantification, and treatment of these important conditions.

Background

Functional tracheal narrowing occurs in 23% of unselected adults during bronchoscopy and is frequently encountered on routine CT of chest particularly when the patient is not able to breath-hold properly\(^1\). This condition has been poorly understood by many radiologists and clinicians. These disorders are often under-diagnosed clinically and may cause severe symptomatic airflow limitation with dypnoea, wheeze, and exercise intolerance\(^1\)\(^-\)\(^3\). They can be misconstrued and mistreated as 'difficult-to-treat' asthma or chronic obstructive pulmonary disease\(^4\)\(^-\)\(^9\).

Terminology

Often terms, such as tracheomalacia, tracheobronchomalacia (TBM), dynamic airway collapse (DAC) and excessive dynamic airway collapse (EDAC), have been used indiscriminately. The first two describe luminal reduction from cartilage softening and the latter refers to luminal reduction from exaggerated posterior tracheal membrane movement\(^10\)\(^-\)\(^12\). In this exhibit, we use the term functional tracheal narrowing to describe all causes of expiratory tracheal narrowing. Murgu and Colt have stratifies expiratory airway collapse as follows: normal, mild (50-75% collapse), moderate (75-100% collapse) and severe (100%)\(^10\).

Physiology and Pathophysiology

In healthy individuals, the degree of anterior prolapse of the posterior tracheal wall is limited by the resistive tension of the pars membranacea with less than 50% tracheal luminal reduction\(^8\). This physiological state is termed dynamic airway collapse (DAC)\(^9\). If tracheal narrowing exceeds 50% as a result of posterior wall laxity, the condition is termed as EDAC\(^3\)\(^,\)\(^10\). In TBM, the tracheal cartilage is weakened and it is the anterior and lateral walls that deform excessively on expiration, resulting in tracheal narrowing\(^6\). TBM and EDAC may coexist.
Pathology and Associations

Acquired TBM and EDAC tend to occur in the middle-aged and elderly, and can be progressive.

TBM may be associated with previous intubation, tracheostomy, trauma, malignancy, extrinsic compression from thyroid or vascular rings. Relapsing polychondritis, Mounier-Kuhn syndrome and Ehler-Danlos syndrome can be associated with TBM. EDAC is associated with obstructive lung disease, eg asthma or COPD, perhaps as a result of chronic inflammation leading to weakness from elastic fiber atrophy of the posterior membrane.

Bronchoscopy: Problems with Diagnosis

The gold standard for diagnosis of expiratory tracheal narrowing is bronchoscopy, but this technique is limited by the effect of instrumentation upon the airway, sedation, optical distortion and magnification, and the relative inability to perform these investigations whilst the patient is dyspnoeic. The procedure itself is semi-invasive, operator dependent and may not be readily available. Quantification of airway narrowing is entirely subjective, and characterization of structures external to the tracheal lumen is not possible.

Advantages of 4-dimensional Dynamic Volume CT (4D-CT)

The recent advent of 4D-CT allows fast and noninvasive 4D evaluation of the trachea, surrounding structures and their movement throughout respiration. It allows objective quantification of functional tracheal disorders.

This exhibit reviews expiratory tracheal narrowing and demonstrates the utility of 4D-CT in diagnosis, quantification, and treatment of these important tracheal conditions.

Imaging Findings OR Procedure Details

In our institution, patients with suspected tracheal functional disorders have undergone imaging with a 320-Multi-Detector Computed Tomography (320-MDCT) scanner. This allows the acquisition of 16 cm z-axis CT volumes without table movement over 1 breathing cycle, and renders views of three-dimensional (3D) airway structures in real time (4D). Scanning parameters
were 80kVp, 300-350mA, and 0.35 second interval time. Effective patient radiation doses were in the range of 0.51mSv to 1.32mSv.

Imaging Findings and Types of Functional Expiratory Tracheal Narrowing

Dynamic Airway Collapse (DAC)

DAC is a physiological process and tends to occur throughout the trachea (Figure 1). The expiratory appearance of DAC is characterized by a lack of tracheal cartilage deformation and less than 50% luminal narrowing.

Excessive Dynamic Airway Collapse (EDAC)

EDAC occurs when tracheal area is reduced by greater than 50% on expiration as a result of exaggerated posterior membrane movement with intact tracheal cartilage (Figures 2, 3 & 4). It produces a characteristic ‘frown’ appearance\textsuperscript{24,25}. This may be difficult to judge without dynamic sequences because images may be captured at arbitrary points in the respiratory cycle as seen with conventional CT.

Acute EDAC may also be ameliorated by application of positive pressure ventilation, eg. continuous positive airway pressure or bilevel positive airway pressure. Acute EDAC may also resolve on convalescent re-imaging.

Tracheo-broncho-malacia (TBM)

TBM indicates abnormality of the cartilage rings of the trachea, which are C-shaped in normal individuals. TBM is recognized by an abnormal cartilage configuration, which may be detected on inspiratory or expiratory sequences, or both.

TBM can be focal (Figure 5), segmental or diffuse (Figure 6).

Three axial configurations have been described:

1. ‘Saber-shape’ TBM is characterized by distortion of the normal C-shape cartilage into an anteriorly elongated configuration with concomitant transverse narrowing (Figures 7 and 8) and is often associated with COPD\textsuperscript{13}. Saber-shape TBM is dynamic, occurring on expiration\textsuperscript{10}, and differs from the fixed ‘saber-shaped trachea of COPD’\textsuperscript{26}. 

2. Crescentic TBM has the appearance of laterally splayed tracheal cartilage and excessive sagittal narrowing, resulting from intact but wide cartilage rings and a lax posterior membrane\textsuperscript{27} (Figure 9). Crescentic TBM said to have a 'lunate' configuration\textsuperscript{27}.

3. Circumferential narrowing, in which the airway concentrically narrows on expiration, is usually accompanied by severe inflammation such as relapsing polychondritis\textsuperscript{28,29} (Figure 10).

Images for this section:
**Fig. 1:** Non-contrast dynamic 4D-CT of the larynx and trachea in a 61 year old female showed normal caliber trachea during inspiration on sagittal volume rendering image with air density displayed in blue colour (a) and axial image (b), and less than 50% narrowing during expiration on sagittal rendering technique (c) and axial image (d) consistent with dynamic airway collapse (DAC). There is little change in cartilage configuration between inspiration and expiration.
**Fig. 2:** Non-contrast dynamic 4D-CT of the larynx and trachea in a 75 year old male with acute exacerbation of COPD (AECOPD) demonstrated normal caliber trachea during inspiration on sagittal volume rendering image with air density displayed in blue colour (a) and axial image (b), and greater than 50% narrowing of tracheal lumen during expiration due to posterior tracheal membrane in-drawing on sagittal rendering technique (c) and axial image (d) consistent with excessive dynamic airway collapse (EDAC). There was immediate improvement in tracheal narrowing during expiration with application of 12cm H2O of continuous positive airway pressure (CPAP) as shown on sagittal volume rendering image (d) and axial image (e). The expiratory tracheal narrowing improved at 6 weeks post treatment of AECOPD without the need of CPAP, as observed on sagittal volume rendering image (g) and axial CT (h). No deformation of tracheal cartilage was seen.
**Fig. 3:** Non contrast 4D-CT sagittal volume rendering cine view of the trachea in the 65 year old male with excessive dynamic airway collapse, with posterior tracheal membrane protruding into the tracheal lumen causing greater than 50% narrowing on expiration.

**Fig. 4:** Non contrast axial CT images of the same 65 year old male with excessive dynamic airway collapse, with posterior tracheal membrane protruding into the tracheal lumen causing greater than 50% narrowing on expiration.
**Fig. 5:** Non contrast 4D-CT sagittal volume rendering cine view of the trachea in the 10 year old male with focal TBM affecting the upper trachea.
**Fig. 6:** Non contrast 4D-CT coronal volume rendering cine view of the trachea and bronchial trees in the 8 year old female demonstrates diffuse TBM affecting numerous segments of the airway.
Fig. 7: Non-contrast dynamic 4D-CT of a 78 year old male with AECOPD showed narrowing of the transverse dimension of trachea during inspiration which was worse at the lower trachea on sagittal volume rendering image (a) with the transverse dimension being smaller than the AP dimension on axial image (b) giving rise to a 'sabre' appearance. During expiration, there was further reduction of both AP and transverse dimensions (c) and (d) causing 70% narrowing of the tracheal lumen in keeping with sabre-shaped tracheobrochomalacia (TBM). Significant transverse narrowing occurred during expiration would suggest underlying tracheal cartilaginous deformation. Emphysematous bullae are noted in the adjacent right upper lobe.
Fig. 8: Non contrast 4D-CT coronal volume rendering cine view of the trachea in the 78 year old male with severe saber-shape tracheobronchomalacia.
**Fig. 9:** Non-contrast dynamic 4D-CT of a 71 year old male with crescentic TBM with normal tracheal appearance during inspiration as shown on coronal volume rendering image (a) and axial image (b), and marked reduction of AP dimension and mild reduction in transverse dimension (c) and (d) giving rise to a crescentic appearance.
Fig. 10: Non-contrast dynamic 4D-CT of a 48 year old female with circumferential TBM, with normal tracheal appearances on coronal volume rendering image (a), lateral volume rendering image (b) and axial image (c), with mild to moderate symmetric reduction in both AP and transverse dimensions of trachea during expiration (d), (e) and (f). Apart from the reduction of luminal area during expiration, the overall configuration of trachea is similar between inspiratory and expiratory phases.
Conclusion

Functional tracheal narrowing is common, but often goes unsuspected in the evaluation of dyspnea. 4D-CT is an emerging imaging modality that offers significant advantages over bronchoscopy and permits rapid and noninvasive diagnosis and quantification of these disorders.

Although the terminology applied to the description of expiratory tracheal narrowing has been heterogeneous, the use of accurate and precise terminology is important for diagnosis as well as future investigation of prevalence, pathogenesis and therapies. Four dimensional dynamic volume CT permits differentiation between DAC, EDAC and the various forms of TBM, whilst allowing simultaneous appraisal of structures external to the airway lumen.

Prior investigators have used different imaging techniques including paired inspiratory and end-expiratory CT and cine-MRI in order to detect expiratory tracheal narrowing, but images have been suboptimal.

Non-invasive positive pressure ventilation can help ameliorate the airway narrowing seen in TBM or EDAC and forms the basis of therapy for the majority of patients. 4D-CT allows appraisal of the response to ventilation or other therapy, and for planning of potential airway interventions, eg. stenting.

Conclusion

Expiratory tracheal narrowing is commonly encountered clinically and radiologically, but has been under-appreciated as a potential cause of airway obstruction. The diagnosis and quantification of expiratory tracheal narrowing has crucial aetiological, therapeutic and prognostic implications. This is the first time in literature that 4D-CT has been used for accurate non-invasive diagnosis, assessment and quantification of functional tracheal disorders, as well as assessment of treatment response, with significant advantages over bronchoscopy.

Personal Information
References


