Advanced Technologies for Imaging and Visualization of the Tracheobronchial Tree

From Computed Tomography and MRI to Virtual Endoscopy

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KEYWORDS

• Trachea • Computed tomography • MRI • Virtual endoscopy • Dynamic CT • Tracheal stenosis

KEY POINTS

- Virtual endoscopy plays a complementary role to flexible bronchoscopy and has a role to play in overcoming some inherent limitations of flexible bronchoscopy.
- Because of the significant advances in imaging, computed tomography can now provide accurate 3-dimensional reconstructions of the trachea.
- Imaging of the trachea assists in planning for bronchoscopy and surgical intervention.
- Dynamic expiratory imaging of the trachea is accurate in the diagnosis of tracheomalacia and superior to end-expiratory imaging.
- MRI is useful for imaging of vascular rings and may see increasing use in the pediatric patient population.

HISTORY

Imaging of the trachea has undergone a revolution over the course of Dr Pearson's career. Before computed tomography (CT), imaging of the trachea involved assessment by plain radiograph and tomography. Used over decades, these limited techniques did identify a few classic signs of disease, such as the saber-sheath trachea or steeple sign.[1,2] Given the early limitations of imaging, bronchoscopy has been long considered the gold standard for evaluation of the airway and is clearly superior to plain radiographic techniques. Other advances followed, such as bronchography, providing further insight into the radiographic appearance of the airways but remained of limited use until the advent of CT. Since then, there has been a continuous evolution with advances in

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computing power facilitating virtual endoscopy (VE) and entirely new methods, such as MRI of the airways. Although bronchoscopy is still regarded as the gold standard, advanced technologies for imaging of the airways have an important role to play where bronchoscopy meets limitations and in this way plays a complementary role. Some limitations of bronchoscopy overcome by imaging include the risks related to the invasiveness of the procedure, its inability to visualize structures external to the airway, as in the case with extrinsic compression, adjacent vasculature, or invasive tumors, as well as the inability to visualize distal to an obstruction.

COMPUTED TOMOGRAPHY

Technical Factors and Protocol

Multi-detector CT (MDCT) imaging of the trachea is preferably performed with 64 slices or greater. State-of-the-art CT tracheal imaging optimally uses up to 320 slices that span over a length of 16 cm. Generally, this would cover the length of the trachea and the scan could be completed in the time it takes for the CT gantry to make one complete rotation. This rapid rotation time reduces motion artifact inherent in imaging of the airways.

Detector collimation is narrow (1 mm or less) for high resolution and facilitating reformat reconstruction. The authors' standard protocol uses a tube current of 50 mA and tube voltage of 120 kV. The gantry rotation time is 0.5 seconds. Because a 320-slice CT can cover the length of the trachea in one rotation, the scan time will be equal to the gantry rotation time, thus, achieving very short scan times. Because the scan time is so short, the technique can be applied to patients with limited ability to breath-hold, including children and infants. The total radiation dose depends on patient factors and technical parameters but is less than a full chest CT. Low-dose techniques can be applied to adults when warranted and when imaging children.

Patients are instructed to cough before the procedure to clear secretions and positioned supine on the gantry table. Adequate patient instruction is critical for high-quality imaging with breathing instructions provided in the patients' preferred language. The scan is performed under breath-hold at full inspiration. Imaging of the trachea alone includes a narrow field of view of around 10 cm for optimal spatial resolution beginning from above the vocal cords to below the carina. This view excludes most of the lung. The entire chest may be scanned separately following the tracheal CT with a wide field of view to visualize the lungs and small airways. Studies are generally performed without contrast. Indications for intravenous contrast commonly include evaluation of tumors or vascular anatomy adjacent the trachea.

The authors routinely reconstruct their images in 3-mm-thick axial (transverse plane) slices with 1-mm or thinner slices available for review when needed. Images are reconstructed in a soft tissue kernel and an edge-enhanced (lung) kernel. Images are interpreted in lung windows to evaluate the lumen (window level, −600 Hounsfield units [HU]; window width, 1500 HU). Soft tissue windows (window level, 40 HU; window width, 350 HU) may be helpful for evaluating the tracheal wall and adjacent fat and identifying calcification.

Multi-planar Reformats

With the advent of helical CT and isotropic imaging, it is possible to reconstruct images in any desired plane, in 2 dimensions. Standard reconstructions for the trachea include axial, sagittal, and coronal planes; these are routinely performed on all scans. However, multi-planar reformats (MPRs) in oblique planes may be obtained particularly to display findings to the best advantage in a single image along the course of the entire trachea. Interpretation is routinely performed using the axial images, correlating with MPRs when necessary.

Three-Dimensional Volume-Rendered Images

Volume rendering provides bronchogramlike images of the tracheobronchial tree using postprocessing techniques.[3] The use of volume-rendered images, even on 16-slice CT scanners, has been shown to improve interpreter confidence, provide additional diagnostic information, and improve confidence in the interpretation of congenital airway abnormalities when compared with axial slices alone.[4] Volume rendering includes shaded surface display (SSD) as well as minimum intensity projection (MinIP) and maximum intensity projection (MIP) reconstructions. MinIP accentuates the air spaces and may be useful for demonstrating the tracheal air column. MIP has limited value in routine imaging of the trachea but does accentuate nodularity and filling defects.

SSD requires more operator manipulation but ultimately provides visually pleasing 3-dimensional (3D) reconstructions of the trachea that are of particular interest to the consulting physicians, as the presentation more closely mimics surgical anatomy than axial images alone.

Normal Computed Tomography Appearance

Although the detailed tracheal anatomy is familiar to the thoracic surgeon, there are key points to