

Automated Airway Lumen Segmentation and Characterization in Patients with Tracheomalacia: a Feasibility Study

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Introduction: Tracheomalacia (TM) is an excessive luminal narrowing of the intrathoracic part of the trachea such that the airway is softer and more susceptible to collapse. This narrowing is most prominent when intrathoracic pressure increases and exceeds the intraluminal pressure, as during forced expiration, cough, or the Valsalva manoeuvre. TM is a common congenital central airway anomaly, but it is often not recognized due to their unspecific clinical presentation. Endoscopy is the essential and invaluable tool and remains the gold standard method for evaluating the airways, but it requires general anaesthesia and cannot supply information during standardized breathing manoeuvres. Recent advances in computed tomography (CT) technology allow using Cine-CT in adults as a non-invasive alternative technique to diagnose TM. Although CT scanning provides excellent anatomic detail of the trachea and adjacent structures, this technique exposes patients to ionizing radiation and requires iodinated contrast material administration in case the mediastinal vascular structures need to be assessed as well. For children magnetic resonance imaging (MRI) is an attractive alternative for CT because it does not require ionizing radiation and is able to evaluate vascular structures without contrast material. Recent advances in MRI technology make it possible to image large airways and its surroundings structures even in smaller children.

Purpose: To demonstrate a suitable acquisition scenario using static and dynamic 3D MRI sequences with sufficient temporal and spatial resolution to provide good morphological information and visualization of dynamic events in the central airways. Secondly, to evaluate an automatic segmentation and dynamic analysis tool to compute the cross-sectional areas of the central airways down to the 2nd generation branching and detect airway narrowing during respiratory manoeuvres.

Materials and Methods: To date 10 subjects (8 males, 2 adults, mean age 15, range 6 to 30 yrs) have been enrolled in the pilot study. Patients were trained to perform spirometry controlled breathing manoeuvres (peak flow and coughing) using a MRI compatible spirometer. "Static" 13-second breath-hold scans covering the entire thoracic region were acquired at end-inspiration and end-expiration using a 3D rf-spoiled gradient echo sequence with TR/TE=1.2/0.5 ms, flip angle 2°, sagittal volume acquisition with isotropic (2.8)³ mm³ voxels (Figure 1). "Dynamic" scans were performed with the same scan parameters but covering only the central thorax (1/3 volume) with a temporal resolution of 500 ms per volume using the TRICKS (time resolved imaging of contrast kinetics) platform and accelerated imaging options (Figure 2). In-house developed software for segmentation and analysis was used. To initiate the time-domain analysis 3 seeds were placed corresponding to the beginning of the trachea and ends of the left and right main bronchi to produce a centerline. The lumen is then segmented and a surface created to produce a unique reference frame to ease the time-analysis (Figure 1). A cross-sectional analysis can then be performed to determine stenosis and distensibility parameters. Likewise, longitudinal and geometrical analyses (e.g., bifurcation angles and planarity) are generated (Figure 3).

Results and Discussion: All but one subject managed to follow the required breathing manoeuvres. Images of central airways during static and dynamic conditions were acquired and could be analyzed. The software tracked the level of the branching automatically and provided a uniquely defined origin per data set thus enabling time comparisons in the same individual and across healthy and patients with TM. The analysis was completely automated (except for three seed points for lumen), providing as output any lumen based parameters that are desired and/or are clinical relevant. With optimized parameter settings the method successfully tracked the central airway paths in all subjects enrolled. Three out of eight children had TM (confirmed by bronchoscopy in 2 cases) and in 1 case by CT. Figure 2 illustrates one of the patients with TM, showing complete collapse during the dynamic scan with the forced expiration maneuver. Figure 3 depicts the lumen analysis of another young patient with TM above the carina, shown clearly in the end-expiration static volume.

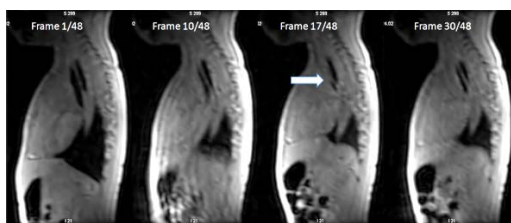


Figure 2: 4 frames from the 48 frame 3D acquisition (total acquisition time of 19 seconds). Complete collapse is seen during forced expiration (arrow, frame 17 of 48).

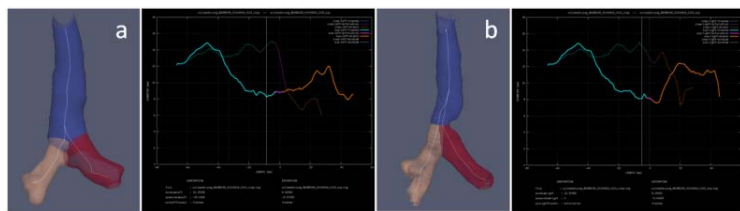


Figure 3: Lumen analysis of a patient with tracheomalacia 1cm above the carina (reduction of 62%). The graphs demonstrate the computed lumen diameter for the trachea and a single bronchus during end-inspiration and end-expiration on the static 13s volume acquisitions.

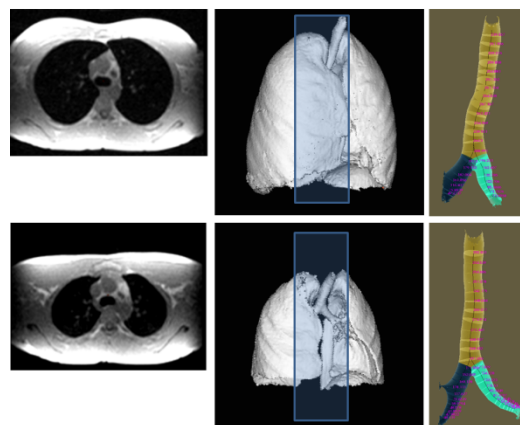


Figure 1: Volume reconstructions of the static whole-thorax volume scans to show the lung and air spaces at end-inspiration and end-expiration, respectively.

The analysis volume is depicted with the rectangular area, which is the same as the scan range during the dynamic acquisition. Axial multi-planar reformats from the sagittally acquired data set and surface/lumen diameter extracted.

Conclusions: This pilot study shows that Cine-MRI is a feasible non-invasive radiation free alternative for bronchoscopy to acquire static and dynamic images of the central airways of sufficient quality to allow analysis of central airway dimensions. Although further data analysis and a bigger casistic are deemed for validating our procedure, we think that this work is highly relevant for clinical research and practice: automated lumen segmentation in patients with TM.