Automated Airway Lumen Segmentation and characterization for use in Patients with Traqueomalacya: a Feasibility study

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Introduction

Tracheomalacia (TM) refers to a weakness of the trachea, frequently due to reduction and/or atrophy of the longitudinal elastic fibers of the pars membranacea, or impaired cartilage integrity, such that the airway is softer and more susceptible to collapse. various degrees of tracheal collapse, and therefore airway obstruction, can result from this narrowing. Diagnosis of TM includes history and physical examination, e.g. expiratory manoeuvre and cough. Pulmonary function tests include the determination of flow limitations during expiration. However, endoscopy is the essential and invaluable tool and remains the gold standard method for evaluating the airways. From the imaging perspective, conventional radiographs have had a lower sensitivity (62%), and are used in conjunction with endoscopy. A CT-scan is the initial radiologic test in cases of suspect TM. MRI is another imaging possibility for evaluating central airway abnormalities, however, not often used because of severe drawbacks in an area with large magnetic susceptibility gradients, poor signal homogeneity and prone to low spatial resolution and motion artifacts.

The majority of papers diagnosis of TM considers imaging during end-inspiration and end-expiration Nonetheless, more recently, some authors have demonstrated the importance of dynamic CINE acquisitions, indicating that dynamic-MRI studies during coughing may facilitate the evaluation of the collapsibility of the trachea in patients with TM.
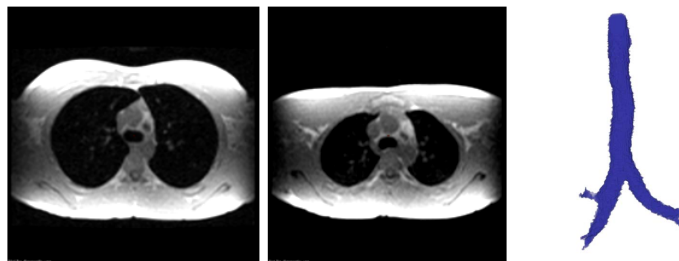
Purpose

The purpose of this work was to provide: first, a suitable acquisition scenario including 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 and, secondly, to provide the means for an automatic analysis program suitable to segment the airway lumen and a dynamic evaluation of cross-sectional areas of the central airways down to the 2nd generation branching.

Materials and Methods

10 healthy adult volunteers between 18 and 50 years of age were recruited as pilot group to optimize image acquisition for the static and dynamic portions of the MRI examination at 1.5T. Volunteers were trained to perform spirometry controlled breathing manoeuvres using a MRI compatible spirometer. Each subject was instructed additionally to perform forced expiration and cough maneuvers. "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 $(2.8)^3$ mm^3 voxels. "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. 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 primary 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.

Results and Discussion

The software tracks the level of the branching automatically and provides a uniquely defined origin per data set thus enabling time comparisons in the same individual and across healthy and patients with TM. The analysis is 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 volunteers.

Figure 1: An axial multi-planar reformat of the static volume in end-inspiration and end-expiration, respectively. Surface/lumen extracted from the inspiration set.

Conclusions

The results show that robust and accurate segmentation of the airways is feasible with the acquired MRI datasets. This work is highly relevant for clinical research and practice: automated lumen segmentation in patients with TM (or other related disease of the airways) is the first step for automatic grading of airway malignancy.