Dynamic 3D MRI of upper airway collapse during inspiratory loading

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Introduction   Three-dimensional (3D) imaging of the upper airway can give new insights into the mechanisms of airway obstruction and provide data for its modeling [1,2]. Conventional MRI is not fast enough to capture the dynamics of the entire airway volume. Hence, several groups have resorted to using single slice approaches [3] (e.g., axial, midsagittal), which lack spatial coverage. Some recent studies adopted respiratory gating to acquire 3D dynamic imaging data [4]. In this work, we propose ungated dynamic 3D imaging using undersampled Cartesian golden-angle sampling [5] and compressed sensing and parallel imaging [6], and show that it is now possible to visualize airway collapse in three dimensions with excellent image quality.

Methods   Experiments were performed on a GE Signa Excite HDxt 3.0T scanner with a 6-channel carotid receive coil. Two healthy volunteers without any indications of obstructive sleep apnea were scanned and underwent an airway occlusion test during MRI scanning. The subject lay supine and wore a mask that covered their nose and mouth. Our balloon occlusion setup is based on prior work by Colrain et al. [7]. Occlusions of this type lead to substantial narrowing of the upper airway during inspiration.

Imaging parameters were: FOV = $16.0 \times 12.8 \times 6.4$ cm^3, slab thickness = 6 cm, 3DFT gradient echo sequence, matrix size = $100 \times 80 \times 40$, 1.6 mm isotropic resolution, TR = 3.86 ms, prospective 3D Cartesian golden-angle sampling [5]. Scan time was 1 minute 45 seconds. The operator blocked the airway prior to inspiration and sustained the airway occlusion until the subject made three attempted breaths (pressure monitored using WinDAQ software, DATAQ Instruments). The pressure recording during inspiration was approximately -10 to -16 cm H$_2$O.

Images were reconstructed with L1-SPIRiT [6]. L1-norm regularization promoted wavelet and finite difference sparsity along all spatial and temporal dimensions. We retrospectively chose a temporal resolution of 965-msec, which amounts to an acceleration factor of 12.8. Sliding window reconstruction was used to interpolate to 2.1 frames per second.

Results   The cross-sectional areas of the upper airway in respiratory cycles varied more significantly during inspiratory load than during tidal breathing (see Fig 1). Figure 2 compares the airway shapes captured when the airway was maximally open (time frame 36) and maximally closed (time frame 90). The airway obstruction site was observed in the velopharyngeal region (see red arrow).

Discussion   We used inspiratory loading to induce dynamic changes of the upper airway in healthy volunteers. The proposed acquisition/reconstruction scheme provided complete airway coverage and sufficient spatio-temporal resolution to resolve the dynamics of airway volume change during inspiratory loading. As future work, we will apply the proposed technique to the visualization of the airway collapse during natural sleep in patients with obstructive sleep apnea.

References   [1] Schwab et al., *Am J Respir Crit Care Med* 168:522-530 (2003). [2] Mylavarapu et al., *J Biomechanics* 42: 1553-1559 (2009). [3] Donnelly, *Radiology* 236:768-778 (2005). [4] Arens et al., *ISMRM* p2502 (2011). [5] Doneva et al., *ISMRM* p641 (2011). [6] Lustig et al., *MRM* 64:457-471 (2010). [7] Colrain et al., *ISMRM* p2417 (2006).
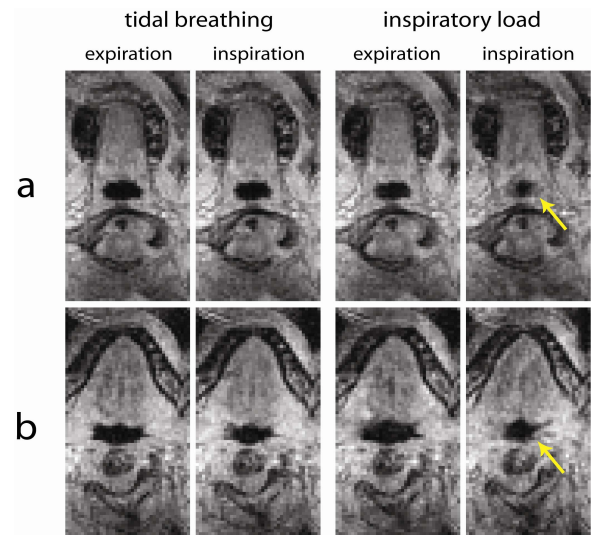
Figure 1. Images captured in expiratory and inspiratory phases during tidal breathing and the movement with inspiratory load from (a) velopharyngeal axial slice and (b) oropharyngeal axial slice. Significant narrowing of the airway is observed in the inspiratory phase during occlusion (see arrows).
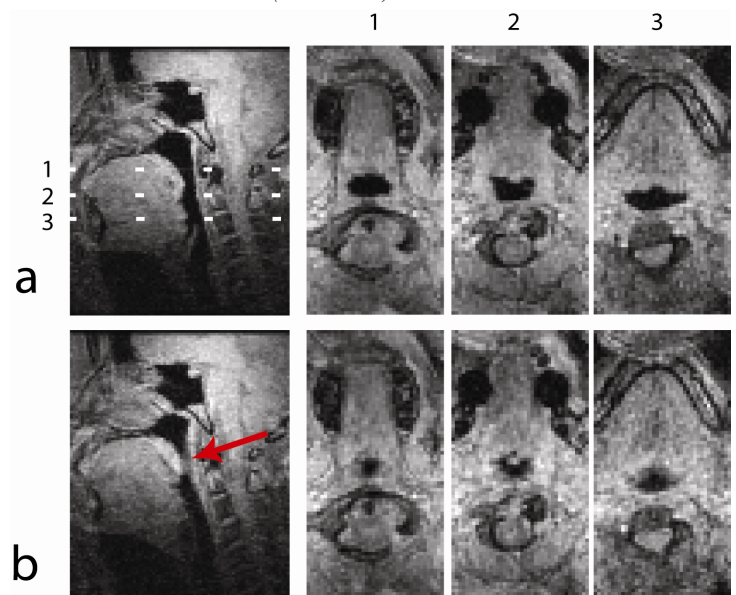

Figure 2. Midsagittal and axial views of the 3D airway shape when the airway is a) maximally open and b) maximally closed. The airway collapse is observed in the velopharyngeal region (see arrow).