

Novel upper airway compliance measurement using dynamic golden-angle radial FLASH

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Introduction: Obstructive sleep apnea (OSA) is a disorder characterized by repetitive upper airway (UA) narrowing or collapse during sleep, it causes reduction or cessation of airflow and increased ventilatory drive leading to frequent arousals. UA compliance, defined as the ratio of UA cross-sectional area and pressure, has been used to measure airway collapsibility. Invasive fiberoptic endoscopy was used before to measure UA compliance^{1,2}, while recently, MRI has been proposed as a non-invasive alternative approach^{3,4,5}. However, one major drawback of current MRI protocol is inadequate spatial and temporal resolution (1.6mm/560ms⁴ and 1.6mm/300ms⁵ with partial k-space Cartesian sampling, or 1.56mm/160ms⁵ using EPI with worse artifacts), which is not always sufficient to resolve the dynamic change of airway collapse. Here we present an MRI protocol based on golden-angle radial FLASH reconstructed with parallel imaging and temporal sparsity constraint. In experiments, we simultaneously record relevant physiological signals, and generate external airway occlusions. All together, this enables novel non-invasive UA compliance measurement during awake and sleep states in humans.

Methods:

Data acquisition: Experiments were performed on a clinical 3T scanner (EXCITE HDxt, GE Healthcare) using a 6-channel carotid receive coil. Velopharyngeal and oropharyngeal axial slices were acquired in two healthy volunteers and in two patients with hypopnea/apnea. Physiological signals including mask pressure, abdomen bellow displacement, O₂ saturation and heart rate were simultaneously recorded to determine awake/sleep states. Imaging parameters: 2D golden-angle radial FLASH, 5° flip angle, 25.6 x 25.6 cm² FOV, 5mm slice thickness, TR = 4.3 ms, 1mm in plane resolution.

Reconstruction: 21 spokes were used to reconstruct each temporal frame without view-sharing, which led to 90ms temporal resolution. Gridding reconstruction⁶, CG-SENSE⁷, CG-SENSE with compressed sensing⁸ using temporal total variation constraint (with empirical regularization weighting) were performed separately for comparison.

Post-processing: The airway was segmented in each temporal frame using a semi-automated region-growing algorithm⁵. Airway area was then normalized by the maximum cross-sectional area during tidal breathing for inter-subject and inter-slice comparison. The normalized area vs pressure for each time frame was used to perform a linear regression, and the slope was defined as the airway compliance.

Results: Figs. 1 & 2 contain some representative results from one slice in one subject using three different reconstruction methods. The temporal frames shown in Fig. 2 correspond to the dots on the mask pressure waveform in Fig. 1. Linear regression plots were shown in Fig. 3, a) compares the airway compliance between different subjects and b) compares the compliance measurement for the same subject during wakefulness and sleep.

Discussion: The proposed methods provide 1mm/90ms resolution, which we believe is needed to fully resolve airway collapse and expansion. This is especially useful when some patients breathe as fast as 0.5s/breath during inspiratory load, as we have observed before. Radial sampling is known to provide benign motion artifacts compared to Cartesian sampling⁹ while golden-angle view ordering enables arbitrary and retrospective selection of temporal resolution¹⁰. It can be seen from fig. 2 that with only 21 spokes, simple gridding reconstruction suffers from severe streaking artifacts. After applying CG-SENSE, they are partly removed but the residual artifacts would still make the airway segmentation very difficult. It is partly because our 6-channel receive coil geometry is not optimized for this application to fully resolve the radial aliasing. After applying temporal total variation as an L1-norm constraint, no visible artifacts are left and the segmentation can be easily performed.

Comparing to healthy volunteers, hypopnea/apnea patients have narrower airways and less negative projected airway closing pressure (airway area = 0), which suggests that their airways are more likely to collapse. Fig 3.b indicates that airways are more easily to collapse during sleep, which was consistent with results using fiberoptic endoscopy².

References: [1] Ryan et al., J Appl Physiol 99:2440-50. [2] Isono et al., J Appl Physiol 82:1319-26. [3] Colrain et al., Proc. 14th ISMRM p2417. [4] Kim et al., Proc. 20th ISMRM p3688. [5] Kim et al., Proc. 21st ISMRM p251. [6] Jackson et al., IEEE Trans Med Imag 10:473-78. [7] Pruessmann et al., MRM 46:638-51. [8] Lustig et al., MRM 58(6):1182-95. [9] Glover et al., MRM 28:275-89. [10] Winkelman et al., IEEE Trans Med Imag 26(1):68-76 2007.

Grant Sponsor: This work was supported by NIH R01-HL105210.

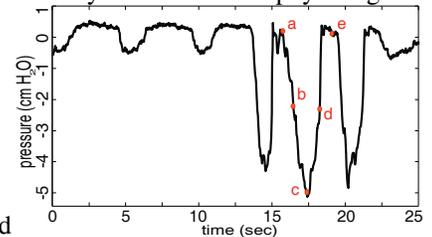


Fig 1. Mask pressure waveforms during inspiratory load (external airway occlusion).

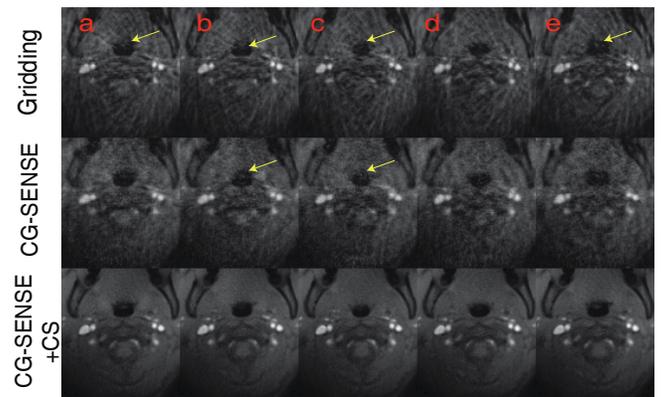


Fig 2. Representative reconstructed frames corresponding to different mask pressures as shown in Fig. 1. Arrows point to artifacts that corrupt airway.

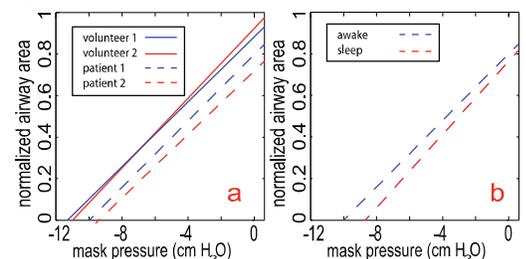


Fig 3. Linear regression plots. a) shows results from two volunteers and two patients (all awake), b) shows results from one patient during wakefulness and sleep respectively.