Real-time MRI of Upper Airway Collapse during Inspiratory Loading

I. M. Colrain[1,2], K. S. Nayak[3], J. F. Nielsen[3]

[1]Center for Health Sciences, SRI International, Menlo Park, CA, United States, [2]Psychology, University of Melbourne, Melbourne, Victoria, Australia, [3]Department of Electrical Engineering, University of Southern California, Los Angeles, CA, United States

Introduction: Obstructive sleep apnea syndrome (OSAS) is a disease in which the upper airway collapses during sleep, leading to reduction in breathing volume (hypopnea) or total cessation of airflow (apnea), and a subsequent reduction in arterial oxygen saturation. Symptomatic relief is provided by continuous positive nasal airway pressure (CPAP) that maintains an open airway during sleep [1]. Accurate knowledge of the site and nature of the airway collapse has been shown to improve outcome [2], but to date has been challenging to obtain. This study set out to test the hypothesis that single and multi-slice echo-planar imaging schemes can be used for real-time imaging of airway collapse, and potential assessment of airway compliance.

Methods and Results: The subject was one man, aged 41 with a body mass index (BMI) of 35.1 m/kg^2. He was studied at our sleep laboratory and found to have no apneas or hypopneas associated with oxygen desaturation but snored throughout most of the night and in all body positions. MR imaging was performed on a GE Signa 1.5T system with gradients supporting 40 mT/m amplitude and 150 T/m/s slew rate, using a transmit/receive head coil. All sequences were implemented within a custom real-time imaging framework [3]. Circular EPI with sixteen interleaves was used to achieve an in-plane resolution of 1.56 mm over a 20 cm FOV every 160 ms. In images where the airway was viewed in cross-section, the airway was manually segmented using Matlab.

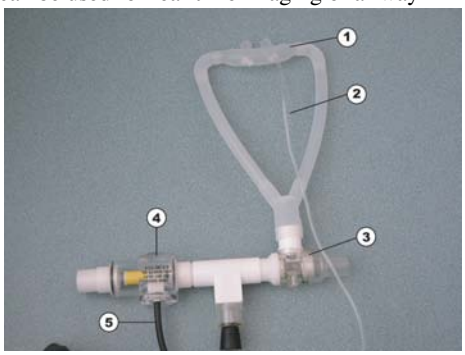

Figure 1: *The Airway Loading Apparatus consisted of: 1) Spiritus™ respiratory system CPAP interface, 2) 1 mm internal diameter tubing from nose to a pressure transducer in the control room, 3) Hans Rudolf Inc. #1410 small two-way non-rebreathing valve, 4) Hans Rudolf Inc. #9340 one-way balloon occlusion valve, and 5) pressurized oxygen hose coming from the valve controller in the control room. All parts are non-magnetic, non-conductive, and fit within the head-coil.*

Loading provides a physiologically valid stimulus to the upper airway, that simulates the increased negative pressures experienced with apneas and hypopneas. The subject breathed through his nose, to which the loading apparatus (Figure 1) was attached. Inspiratory occlusion was presented by manually activating the occlusion valve via a solenoid control causing an interruption of inspiration. Pressures were monitored and recorded in real-time. The average change in pressure with occlusion was –5cm H_2O at the nose. This provides a load typically seen during sleep, even in symptom-free individuals.

Scan planes were localized using a sagittal slice, with sample images shown in Figure 2. Based on six repetitions, during normal inspiration before loading, the UA 2D cross-sectional area was 1.31 ± 0.224 cm^2 (mean ± SD), with a lateral opening of 1.61 ± 0.127 cm and anterior/posterior opening of 0.65 ± .064 cm. The 2D minimum cross-sectional area during each period of loading was 0.63 ± 0.12 cm^2, with a lateral opening of 0.94 ± 0.14 cm, and anterior/posterior opening of 0.62 ± 0.10 cm. Measurement error was dominated by quantization due to limited spatial resolution (0.156 cm). In this subject, the anterior/posterior direction narrowed by 3.33 ± 17.8 %, while lateral narrowing of 41.3 ± 12.5% was the dominant factor.

Discussion: We have demonstrated that EPI gradient echo imaging with short readout duration can effectively mitigate susceptibility artifacts, while providing rapid acquisition of upper airway images. Our current experiments involved rudimentary synchronization of MRI acquisition with pressure recordings, which had a delay of up to 0.5 sec. Accurate synchronization with pressure recordings and with load application would permit the accurate assessment of temporal dynamics and the movement of UA structures in response to applied load. It would also enable the production of respiratory phase vs. UA area curves, to identify phases of the respiration cycle maximally susceptible to UA collapse.

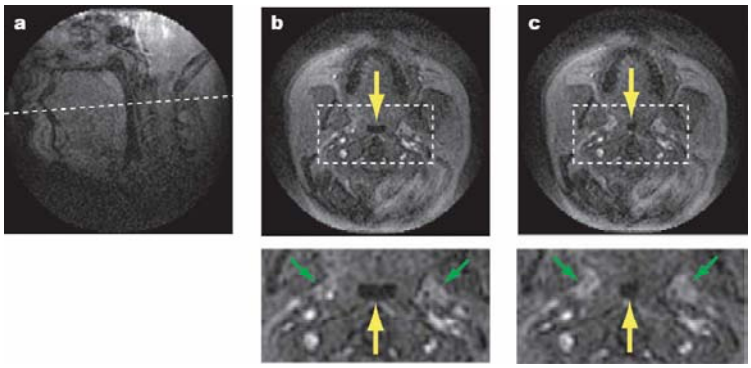

Figure 2: *In-vivo Results. (a) sagittal localization frame with the slice prescription shown with a dotted line. (b) 2D image with airway open (taken during peak of inspiration on an un-occluded breath. (c) 2D image at same location on the next breath immediately following closure of the occlusion valve. Zoomed in regions are shown below b and c. Yellow arrows indicates the location of the airway. Green arrows indicate locations of lateral fat pads.*

References:

[1] Means MK, et al., Sleep Breath 2004; 8(1):7-14.
[2] Launois SH, et al., Am Rev Respir Dis 1993; 147(1):182-189.
[3] Santos JM, et al., Proc. IEEE EMBS meeting 2004.