Assessment of velopharyngeal function with multi-planar high-resolution real-time spiral dynamic MRI

Xue Feng[1], Josh Inouye[2], Silvia Blemker[1], Kant Lin[3], Kathleen Borowitz[3], Talissa Altes[4], Tracy Kovach[3], Walid El-Nahal[3], Katie Pelland[2], and Craig H Meyer[1,4]
[1]*Biomedical Engineering, University of Virginia, Charlottesville, Virginia, United States,* [2]*Mechanical and Aerospace Engineering, University of Virginia, Charlottesville, Virginia, United States,* [3]*Medicine, University of Virginia, Charlottesville, Virginia, United States,* [4]*Radiology, University of Virginia, Charlottesville, Virginia, United States*

Introduction: Velopharyngeal insufficiency (VPI) is commonly seen in children who have had a cleft palate repair. Current clinical methods for visualizing VPI include nasal endoscopy and multi-planar video fluoroscopy, which suffer from poor patient tolerance and/or radiation exposure. Static MRI of the velum before and after surgery has been performed for the evaluation of occult submucous cleft palate and velum muscle modeling. Dynamic MRI during speech has also been developed with a relatively high temporal resolution to capture the movements of the tongue and velum. In our study, we focus on the velum movements and aim to simultaneously acquire two slices of the velum with sagittal and oblique coronal views with high spatial (1.2x1.2 mm^2) and temporal (21 fps) resolution to get sufficient dynamic information for VPI evaluation and modeling using a real-time spiral SSFP sequence and a combined spatial and temporal parallel reconstruction method with off-resonance correction.

Methods: As the contrast mechanism is not the focus in this problem, we use a spiral SSFP sequence to achieve higher SNR than a spoiled GRE sequence. We use a non-balanced SSFP sequence to avoid the banding artifact associated with the balanced SSFP, because the air-tissue boundary may induce severe local off-resonance. A fully sampled spiral trajectory with 18 interleaves and 3.6 ms readout per interleaf is used and the corresponding minimum TR and TE are 6.96 ms and 0.78 ms. 6x k-space undersampling is used, so each frame is reconstructed with the spiral k-space data of 3 interleaves. The 3 interleaves are 120º apart from each other to maximize the k-space coverage; between neighboring frames, the 3 interleaves are rotated with an angle calculated using the bit-reversed table of the undersampling ratio to reduce temporal blurring. Each spiral interleaf is acquired twice at two prescribed slice locations before acquiring the next interleaf so that each frame of these two slices only differs by one TR. Two spatial saturation bands are applied every frame to reduce the FOV and are shared by the two slices. Low-resolution field maps of both slices are acquired at the beginning of the scan.

For the experiment, two healthy subjects were asked to pronounce the /n/, /a/, and /s/ sounds both in a static and dynamic manner. In addition, three sentences were spoken, each containing mostly plosive, nasal, or fricative sounds. The study was performed on a Siemens Avanto 1.5 T scanner equipped with head and neck coil arrays. One mid-sagittal plane and one oblique coronal plane along the major velum movement direction with 150 mm FOV and 8 mm slice thickness were scouted.

To reconstruct the image series of each slice, a non-linear conjugate gradient method is used to minimize the object function given as:

$$\| Dx(\vec{r},t) - y \|_2^2 + \beta \| (G-I)x(\vec{r},t) \|_2^2 + \lambda(\vec{r}) \| \nabla_t x(\vec{r},t) \|_1 + \gamma \| \nabla_r x(\vec{r},t) \|_1$$

in which the first term is a data fidelity term with spiral encoding matrix D; the second term is the SPIRiT constraint [1] with self-consistency matrix G estimated from a low-resolution training image achieved during field map acquisition; the third term is the temporal difference constraint with a spatially-variant coefficient λ(r) to take into account the fact that some regions may experience rapid changes while others may stay the same, so that a smaller coefficient can be applied in faster changing regions to lessen the constraint; and the fourth term is the spatial smoothness constraint [2]. Oversampling is used in the second term so that the reconstructed FOV of the SPIRiT images x(r,t) is enlarged to avoid the effects of the signal outside the original FOV, which can accumulate during the iterative process. The spatially-variant λ(r) can be estimated from the variance of the pixel intensity along time using the image series achieved from a previous iteration and updated for the next iteration. Since air-tissue boundaries may induce severe local off-resonance, the reconstructed image series are then de-blurred using the Chebyshev approximation based method with the help of the low-resolution field map [3]. Finally, as the two slices are non-parallel, the signal intensity at the intersection bands is lower due to shorter effective TR. Therefore, a post-processing compensation is performed assuming the decay rate can be estimated from neighboring pixels.

For each time point, the velum and posterior pharyngeal wall were outlined in the mid-sagittal plane and the nasopharyngeal and oropharyngeal openings were outlined in the oblique-coronal plane using Osirix image processing software. The contours are exported into Matlab to calculate variables of interest: contact length, contact distance (from the C1-C2 vertebral disc to the center of the velum contact), minimum distance between velum and posterior pharyngeal wall (PPW), oropharyngeal area, and nasopharyngeal area.

Results: Figure 1 shows 6 consecutive images of the two slices indicating the velum movements during speech with 150 mm FOV and 1.2*1.2 mm^2 resolution at 21 fps. The intersection bands are largely removed with post correction. Figure 2 shows a snapshot of measurements of the variables of interest during a sentence "Bob ate apple pie" repeated twice by the volunteer. The two slices are overlapped with their actual orientations (right) to more clearly show the oropharyngeal and nasopharyngeal areas and the boundaries of the velum and PPW.

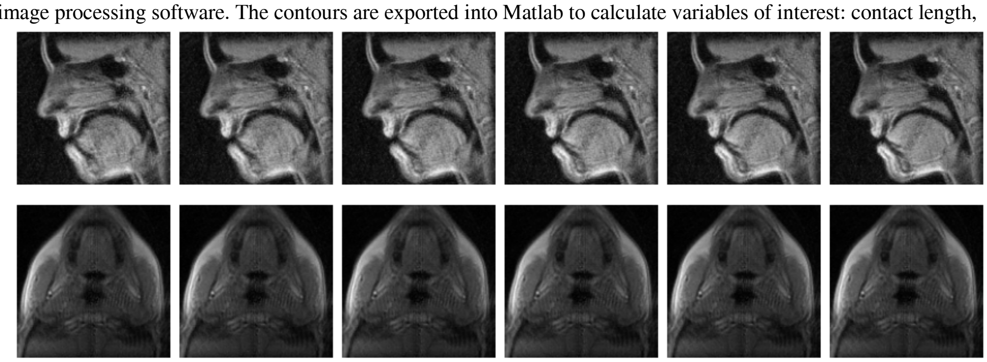

Figure 1. Consecutive reconstructed images of two simultaneously acquired slices using the spiral SSFP sequence.

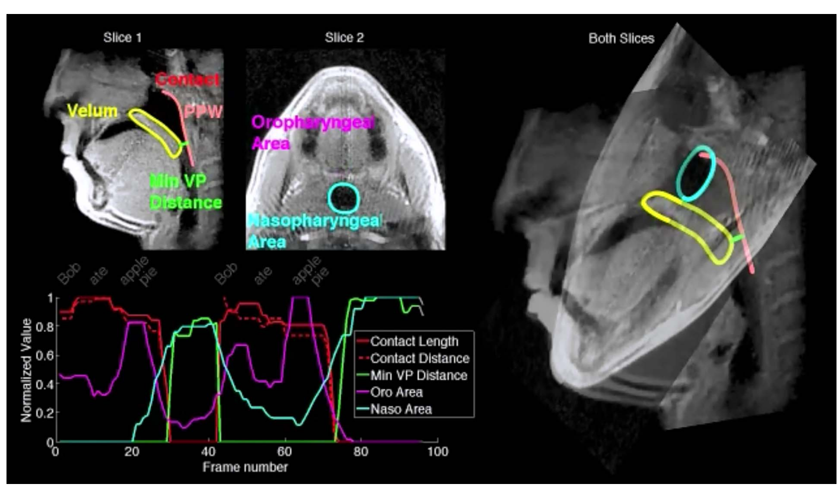

Figure 2. Depiction and measurements of the oropharyngeal and nasopharyngeal areas at each time point during the sentence "Bob ate apple pie".

Conclusions: A real-time spiral SSFP sequence is developed and used in this study. 6x undersampling is achieved with the spatial and temporal parallel reconstruction method combined with off-resonance correction. Post correction for the intersection bands is performed successfully.

The new dual-plane dynamic MRI measurements enable analysis of velar configurations during varied degrees of closure and opening, which could provide useful information for guiding treatment decisions in patients with velopharengeal insufficiency.

References: [1] Lustig, et al. MRM 64: 451-477 2010. [2] Lustig, et al. MRM 58: 1182-1195 2007. [3] Chen, et al. MRM 60: 1104-1111 2008.

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