3D vocal fold geometry mapping using Magnetic Resonance Imaging

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Introduction

Fluid-Structure-Interaction simulations have shown that the subglottal geometry is crucial fort he oscillation behavior of the vocal folds (VF). Nevertheless, hardly any in-vivo geometry of phonating vocal folds has been reported due to the vital function of the larynx. Ex-vivo or animal experiments exhibit the lack of transferability.

Spatial depth of stereoscopy optical recordings is limited. Adequate techniques for in-vivo three-dimensional measurements are Computer Tomography (CT), Ultrasonic Measurements and Magnet Resonance Imaging (MRI). Only the last unites innocuousness for health with good spatial resolution.

MRI offers a conceptually appealing approach since it is a real 3D method. The necessary (ultra) high magnetic fields are well tolerated by the subjects even in long-term studies. Sub-mm resolution is achievable with various tissue contrasts. Those structural advantages are to be seen alongside with still long scanning times and thus the need for adequate synchronization techniques for moving organs. In this study, a synchronization method was developed, which compensated breathing movements.

Methods

The actual vocal fold oscillations are superimposed by abductional and adductional breathing and swallowing movements of the VF. The measurements take several minutes, so movement artifacts have to be avoided by a synchronization approach. The presented, straightforward approach consists of a sound presentation to the subject which guides through the periodically interrupted scan sequence. Parallel to the sound, an trigger impulse is sent to the scanner as shown in Fig. 1. A trigger waveform was delivered to the internal physiological signal controller circuitry of the MR scanner using the scanner's ECG input channel.

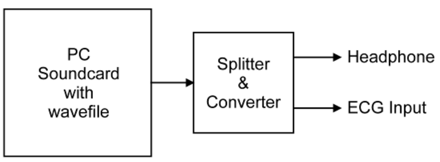

Fig. 1: Basic synchronization scheme used for vocal fold geometry imaging. A fixed tone is supplied to the subject to guide articulatory maneuvers. Simultaneously, a virtual ECG waveform is sent to the scanners internal ECG unit, which initiates imaging. Imaging stops after a few seconds to insert a breathing period before another trigger scheme is applied.

To limit scanning times at a reasonable signal-to-noise ratio (SNR), high magnetic field strengths (3.0 T) in synergy with a 16-element coil array were used. The imaging protocol consisted of two series: (i) segmented, 3D gradient-echo imaging (FOV=(128x128) mm^2, matrix 256x256x80, TR=10.0 ms, TE=1.8 ms, flip angle=15°, acquired slice thickness=1 mm) and (ii) segmented, 3D ultra-short TE imaging to avoid susceptibility artifacts at tissue and air interfaces (FOV=(128x128) mm^2, matrix=144x144x144, TE=0.14 ms, TR=4.3 ms, flip angle=5°). In vivo imaging on male and female subjects was conducted using a 3.0 T (Achieva, Philips, Best, The Netherlands). The subjects phonated in different pitches (modal and head register) and articulations. The articulations were chosen to be [m] and [e] to limit the effect of jaw motion during the measurements. 3D MRI data were included into segmentation to derive boundary conditions for finite-element models of vocal fold oscillation. A detailed overview of the MR settings can be found in [2].

Results

Male and female subjects were imaged. The subjects were voice therapists or familiar with the phonation process to enhance the communication between experimenter and subject. The images phonation types were chest register ($f_{0,female}$ = 440Hz, $f_{0,male}$ = 220Hz) and head register ($f_{0,male}$ = 440Hz). The subjects phonated on [m] and [e] in order to omit jaw motion during the scan. The Cartesian coordinate system of the segmented MRI data was reformatted so that the first axis was parallel to the spine (vertebral disc between C2 and C3). The second axis was set perpendicular to the first axis following the head-feet direction so that the third axis resulted in the left-right direction. An example is depicted in Figure 2, which shows the contours of the oscillating vocal folds for an articulatory maneuver [e]. Vocal fold geometry was derived by identifying the boundaries at the tissue/air interface with a commercial program (Slicer3D).

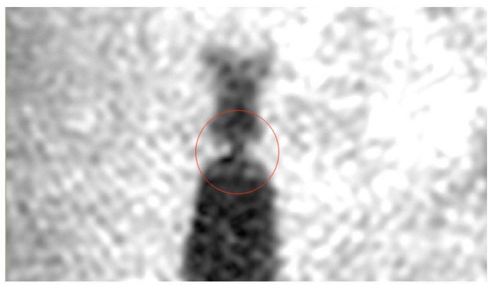

Fig. 2: Contours of the oscillating vocal folds (good quality) of male subject during phonation [e].

For this purpose, polygonal curves were transformed into cubic splines as illustrated in Fig. 3-4, which demonstrate differences in the vocal fold geometry for male and female subjects.

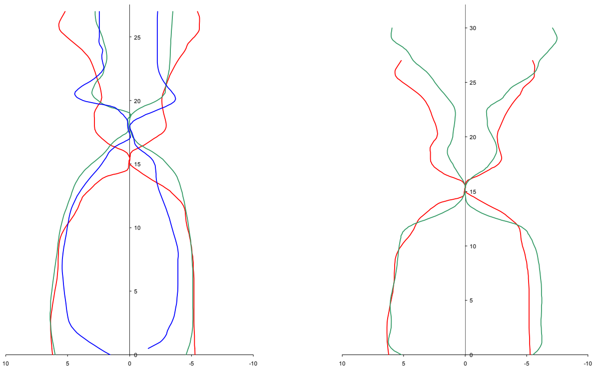

Fig. 3: Comparison of some results. Left-hand side: Female subject. Green: female [e], dorsal slice. Red: female [m], dorsal slice. Blue: female [e], middle slice. Right-hand side: Green: male [n], dorsal. Red: female [m], dorsal.

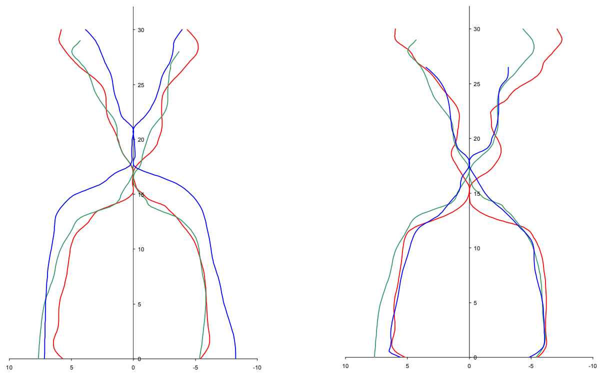

Fig. 4: Comparison of some results. Left-hand side: Female subject. Green: male [e], middle slice. Red: male [m], middle slice. Blue: male, head register [m], middle slice. Right-hand side: Green: male [m], middle. Red: male [m], dorsal. Blue: male [m], ventral.

Discussion and Conclusion

This work demonstrates the feasibility of three-dimensional MR imaging of vocal fold geometry which provides static and se mi-dynamic training and reference data to be used in a finite-element model (see Fig. 5). Looking forward, this synergy between an imaging and computational approach offers several new insights into the anatomy and physiological mechanisms involved in human phonation. Further improvements are required to synchronize data acquisition with vocal fold oscillation. For this purpose, the subject's voice might serve as a triggering sound since the present approach is dependent on the ability of the subject to understand and follow the guiding acoustic signals. The move towards ultrahigh magnetic field strengths (7.0 T) in conjunction with the use of MR coil arrays tailored for laryngeal imaging offers further enhancements in spatial resolution, which hold the potential to provide benefits for 3D mapping of vocal fold geometry [3].

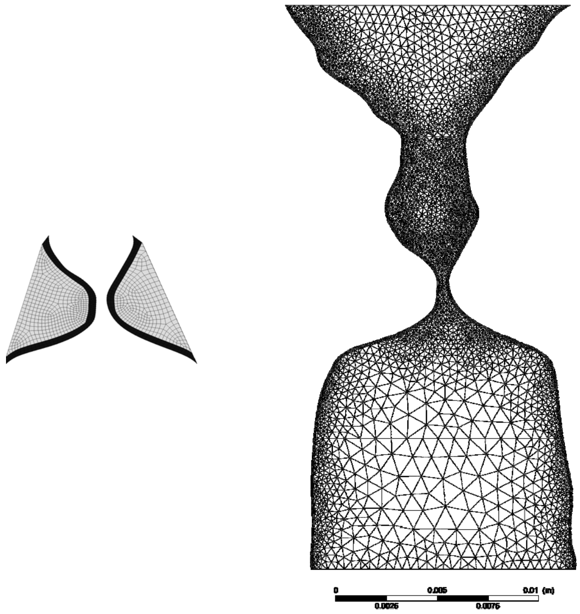

Fig. 5: Exemplary FSI vocal fold model from data set "female [e]". Left-hand side: Two-layer structural FE model from MR images. Right-hand side: Fluid FV model from MR images.

Literature

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[2] T. Frauenrath, A. Gömmel, C. Butenweg, M. Otten, T. Niendorf, 3D Mapping of Vocal Fold Geometry During Articulatory Maneuvers Using Ultrashort Echo Time Imaging at 3.0T. Proceedings of ISMRM-ESMRMB 2010, Stockholm, Sweden

[3] T. Frauenrath, W. Renz, J. Rieger, A. Goemmel, C. Butenweg, T. Niendorf. High spatial resolution 3D MRI of the Larynx using a dedicated TX/RX phased array coil at 7T. Proceedings of ISMRM-ESMRMB 2010, Stockholm, Sweden