Numerical investigation of the integrated neuromuscular control and flow-structure interaction during phonation using an image based high-fidelity computer model

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Introduction

Vocal fold vibration is considered largely a mechanical process. The versatility of human voice comes with the ability to change the mechanical status (geometry and internal stress) of the vocal folds through activation of laryngeal muscles. Despite being of high interest to researchers, the relationship between the muscle activation, the mechanical status of the vocal folds, and the resulted flow-structure interactions during phonation is not well understood. Previous simulation works often used simplified vocal fold geometry and eigen analysis [1,2]. The current study aims to use a high-fidelity continuum computer model that couples the muscular mechanics and flow-structure interactions to study the relationship between laryngeal muscle activation, vocal fold geometry and internal stress and the resulted vocal fold vibration pattern in an image-based realistic laryngeal model. The preliminary results have revealed a complex effect of thyroarytenoid muscle activation on the vibration pattern and flow rate.

Methods

The vocal fold model was reconstructed from a MRI scan of a dissected canine larynx shown in Figure 1. For the muscles, both the passive and active stresses were considered. The passive stress was modeled using fiber-reinforced materials and the active stress was modeled using Hill-based contractile elements. Details of the muscle model was presented in a previous work [3]. The muscle model was integrated in a finite element vocal fold model, which was coupled with both Navier-Stokes and Bernoulli flow solvers to simulate the sustained vibration of the vocal folds. Various activation conditions of the intrinsic laryngeal muscles and their effects on flow-structure interactions were investigated.

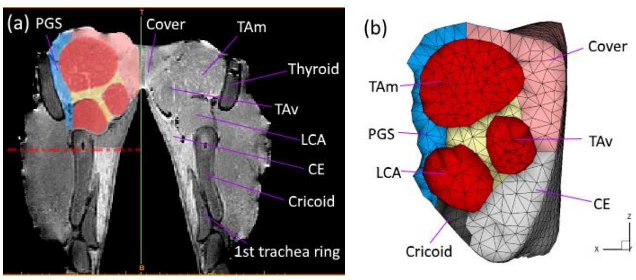

Figure 1: The MRI scan of the canine larynx (a) *and the vocal fold model used in the current study* (b), only the left side vocal fold is shown.

Results and Discussion

The glottal waveform and vocal fold vibration pattern from two activation conditions are compared here. In the first condition, the cricothyroid (CT) muscle was activated by 20%. In the second condition, the vocalis muscle (TAv) was activated by 80% on top of the 20% CT activation. Activation of the vocalis increased the fundamental frequency from 144Hz to 162Hz. Frequency increase due to TA activation was also reported in a previous experiment [4]. The maximum flowrate decreased from ~400 mL/s to ~240 mL/s. The results showed that the decrease in the flow rate is caused by the medial bulging at the inferior aspect due to TAv activation which has affected the flow-structure interactions.

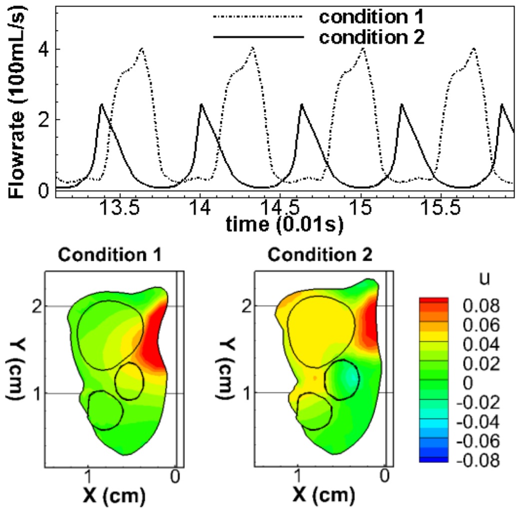

Figure 2: Glottal waveform (top) and mid-coronal profile of the vocal fold at max opening (bottom) for the 2 activation conditions. Contour based on lateral displacement.

The current approach shows potential in revealing the relationship between laryngeal muscle activation and vocal fold dynamics. More activation conditions are currently being investigated.

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