How the maximum divergence angle of the glottis can affect phonation mechanism

Elias Sundström*, Liran Oren, Charles Farbos de Luzan, and Sid Khosla

Department of Otolaryngology – head and neck surgery, University of Cincinnati, Cincinnati, Ohio, USA

Keywords: phonation mechanism; intraglottal vortices; FSI

Introduction

During vocal fold vibration, there may be a mucosal wave in the superior-inferior (vertical) direction, resulting in a convergent shape during opening and a divergent shape during closing. In our previous work we characterized the dynamics of the medial glottal wall geometry during vibrations in the full excised canine larynx model [1]. We found that the glottal divergence angle during closing is proportional to the magnitude of the acoustic intensity and the intraglottal negative pressure. The latter may act as additional aerodynamic force that contributes to the closing mechanism of the folds' vibration. The magnitude of the negative pressure is affected by the strength of the vortices that develop near the superior aspect of the folds [2]. These intraglottal vortices develop when the flow separates from the glottal wall due to the divergent shape of the glottis.

The goal of the current study is to systematically examine how the maximum divergence angle of the glottis affects intraglottal vortical strength during closing. Our hypothesis is that the vortical strength would be maximized at some critical angle of the divergent glottis. This hypothesis is based on the rationale that vortical strength also depends on the flow proximity to its confined walls. The shear layer of a vortex near a confined wall is smaller compared with a vortex in quiescent flow, which makes the vortex more energetic.

Methods

The geometry for the model extended from the pharynx to the subglottal region. The shape of the vocal folds was based on the M5 model [3]. The false folds were excluded from the study. An idealized vocal fold was considered between the pharynx and the subglottal region. The Navier-Stokes equations were solved numerically for prediction of the flow behavior. Fluid-structure interaction between the vocal fold and the viscous fluid was controlled with a prescribed motion, where the maximum opening occurred at the inferior edge. The motion in the superior aspect was systematically varied so that the divergence angle of the glottis during closing varied from 0 to 100 deg. Local control surface deformation of the vocal fold was handled with mesh morphing [4] and a large relative motion was handled with an overlapping mesh approach to enable full closure.

Results

In-plane vorticity for three different intraglottal divergence angles is shown in Figure 1. For a maximum divergence angle of 0 deg the folds are parallel and the intraglottal flow remains attached to the wall. There is no formation of intraglottal vortices. As the maximum divergent angle increases, the intraglottal vortices begin to form near the superior edge. The maximum vortical strength is observed for a maximum divergence angle of 30 deg. As the maximum divergence angle is further increased, the size of the vortex increases as the shear-layer's detachment point migrates towards the inferior edge. The vortical strength, however, begins to decrease.

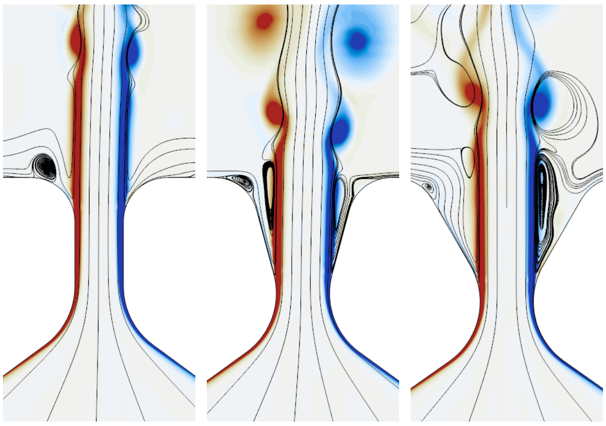

Figure 1: In-plane vorticity with overlayed streamlines in the glottal region. Maximum Intraglottal angles: 0º (left), 30º (middle), and 60º (right).

Discussion

A divergent shape during closing can be clinically achieved by making the glottis stiffer inferiorly. The current study shows that a divergence angle around 30 deg would maximize the intraglottal vortical strength, which is important for the mechanism of folds vibrations.

Acknowledgments

The authors acknowledge the support of NIH Grant No. R01DC009435.

References

[1] Oren L., Gutmark E., and Khosla S. Medial surface dynamics as a function of subglottal pressure in a canine larynx model. J of Voice, [In print].

[2] Oren L., Gutmark E., and Khosla S. Intraglottal pressure distribution computed from empirical velocity data in canine larynx, Journal of Biomechanics, 47, pp. 1287-1293, 2014.

[3] Kucinschi BR, Scherer RC, DeWitt KJ, Ng TT. Flow visualization and acoustic consequences of the air moving through a static model of the human larynx. Journal of biomechanical engineering, 128, pp. 380-390, 2006

[4] Sundström et al. Effects of Normal Variation in the Rotational Position of the Aortic Root on Hemodynamics and Tissue Biomechanics of the Thoracic Aorta. Cardio Eng Tech, 2019 (in-print

**corresponding author e-mail: sundstes@uc.edu*

**corresponding author e-mail: sundstes@uc.edu*