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Finite Element Modelling of the Effect of Stiffness and Damping of Vocal Folds Layers on their Vibrations and Produced Sound

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Abstract: The study presents a two-dimensional (2D) finite element (FE) model of the fluid-structure-acoustic interaction during self-sustained oscillation of the human vocal folds (VF). The FE model combines the FE models of the VF, the trachea and the simplified human vocal tract shaped for phonation of Czech vowel [a:]. The developed FE model comprises large deformations of the VF tissue, VF contact, fluid-structure interaction, morphing the fluid mesh according to the VF motion (Arbitrary Lagrangian-Eulerian approach), solution of unsteady viscous compressible airflow described by the Navier-Stokes equations and airflow separation during the glottis closure. The effect of stiffness and damping of lamina propria on VF vibrations and produced sound are analyzed. Such variation of the lamina propria properties can be caused by certain VF pathologies such as sulcus vergeture.

Introduction

Production of human voice is an acoustic problem including fluid-structure interaction (FSI). There are many computational models published in literature. Zhao et al. [1] developed 2D axisymmetric FE model with prescribed movement of VF. In recent works of the authors [2] FE model of flow-induced oscillations of the VF was developed. In this paper is presented newly developed 2D FE model of phonation with in literature widely used M5 geometry of the VF [3].

Method

The 2D FE model was developed using the program system ANSYS 15.0. Vocal folds tissue was considered as four-layered (see Fig. 1) with homogenous isotropic material properties of each layer including several variants for values of Young's modulus (E_{SLP}) and damping ratio of the lamina propria.

Results and discussion

Examples of the resulting maximum and minimum values of the acoustic pressure in particular locations of the vocal tract are shown in Table 1. From the results we can for example observe that increasing Young's modulus (E_{SLP}) of lamina propria leads to increase of maximum pressure under the VF.

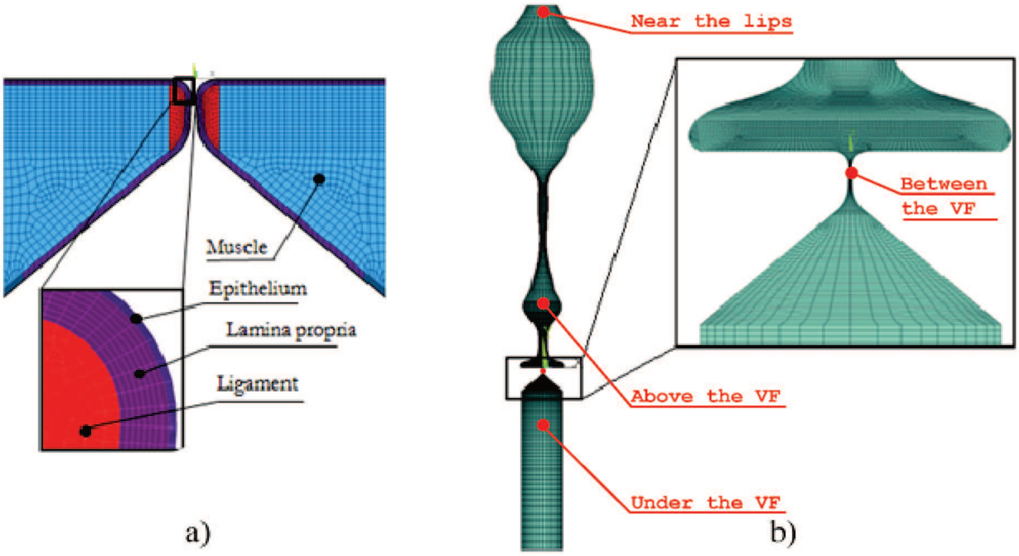

Fig. 1: a) FE model of the four layered tissue of the VF b) FE model of the acoustic spaces of the trachea and the vocal tract for Czech vowel [a:], measuring points are emphasised.

Tab. 1: Computed values of the acoustic pressures in particular locations of the vocal tract.

E_{SLP}	**Acoustic pressure [Pa]**							
	under the VF		between the VF		above the VF		near the lips	
	max	*min*	*max*	*min*	*max*	*min*	*max*	*min*
1500	307,19	-42,26	381,18	-366,72	214,54	-329,76	23,75	-21,37
2000	334,37	-43,89	373,21	-397,37	213,38	-343,25	23,27	-21,00
2500	329,83	-3,31	411,76	-348,94	188,33	-340,80	21,04	-18,14
3000	339,52	0,03	389,37	-377,89	170,09	-328,68	18,93	-17,39
4000	354,17	0,03	358,33	-432,26	184,45	-355,92	19,29	-16,96
5000	372,15	0,03	445,51	-368,07	192,06	-352,48	19,48	-19,21

Summary

The developed FE model can be used to study the effects of pathological changes in VF tissue on their vibrations and the produced sound.

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