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On the FE modelling of vocal folds pathologies

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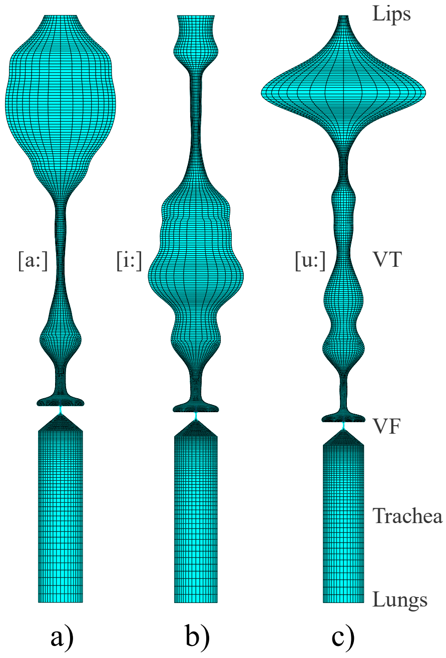
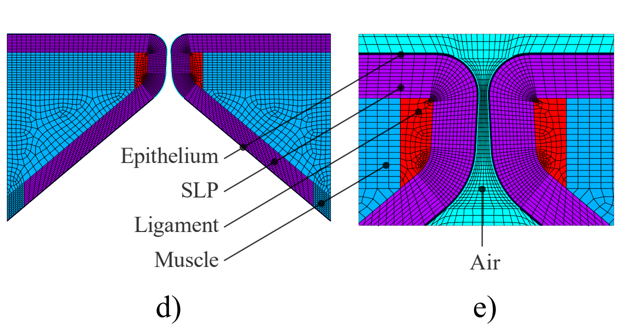
Numerical modelling of some vocal folds (VF) pathologies can be realized by varying properties of VF layers. The aim of this paper is to show how damping of superficial lamina propria (SLP) affects vowel production in the finite element (FE) model of the VF self-sustained oscillation with fluid-structure-acoustic interaction.

Fluid flow and structure domain was solved separately in program system ANSYS. The 2D FE model features several phenomena present during human phonation: compressible unsteady viscous flow modelled by Navier-Stokes equations, setting to a pre-phonatory position, large deformations of the VF, their closure and excitation by lung pressure. The fluid mesh was deformed according to the VF motion using Arbitrary Lagrangian-Eulerian algorithm.





SOLID	E [Pa]	μ [–]	ρ [kg·m^{-3}]
Epithelium	25000	0.49	1040
SLP	2000÷3500	0.49	1040
Ligament	8000	0.49	1040
Muscle	65000	0.40	1040

FLUID	c_{air} [m·s^{-1}]	η [Pa·s]	ρ [kg·m^{-3}]
Air (for 36 °C)	353	1.81351·10^{-5}	1.205

f)

Fig. 1. a) Fluid FE model of the acoustic spaces of the trachea and the vocal tract (VT) for the Czech vowel [a:], b) vowel [i:], c) vowel [u:], d) solid FE model of the four-layered tissue of the VF with e) detail of glottal gap, f) material properties [1]

The FE model was adjusted for using vocal tracts (VT) shaped for three Czech vowels [a:], [i:] and [u:] the geometry of which was obtained from magnetic resonance imaging (MRI) [2]. The VF model used M5 geometry [3] and was composed of four layers. The material properties are given in Fig. 1, for details see [1].

Several variants for four pairs of proportional damping coefficients and four Youngs moduli E_{SLP} of the SLP layer were computed, see Table 1. Using the following equation

$$\beta = \frac{b_{p2} - \frac{f_1}{f_2} b_{p1}}{\pi \cdot \left(f_2 - \frac{f_1^2}{f_2}\right)}, \qquad \alpha = 4\pi^2 f_1 \cdot \left(\frac{b_{p1}}{\pi} - f_1 \cdot \beta\right), \tag{1}$$

where f_1 and f_2 are natural frequencies of the VF, we obtain proportional damping coefficients α and β for arranged pairs of damping ratios b_{p1} and b_{p2}: $(0.05; 0.1)$, $(0.1; 0.2)$, $(0.2; 0.3)$ and $(0.3; 0.4)$.

Table 1 shows how the different elasticity, damping values and vocal tract shapes influence the frequency f of the self-oscillations, maximal width of glottis WG_{max} and open quotient OQ.

Table 1. Computed vocal fold vibration characteristics

E_{SLP} [Pa]	First two natural frequencies of VF f_1 [Hz]	f_2 [Hz]	α [s^{-1}]	β [s]	[a:] f [Hz]	[a:] WG_{max} [mm]	[a:] OQ [–]	[i:] f [Hz]	[i:] WG_{max} [mm]	[i:] OQ [–]	[u:] f [Hz]	[u:] WG_{max} [mm]	[u:] OQ [–]
2000	70.653	142.537	0.5083	0.0002	Computation crashed			Computation crashed			Computation crashed		
			1.0165	0.0004	130	0.54	0.36	143	0.65	0.49	133	0.63	0.39
			60.3776	0.0006	130	0.49	0.38	139	0.55	0.51	135	0.57	0.41
			119.7386	0.0007	132	0.47	0.38	141	0.54	0.55	133	0.51	0.41
2500	71.919	148.337	1.7917	0.0002	128	0.48	0.35	141	0.56	0.41	127	0.50	0.37
			3.5834	0.0004	123	0.44	0.35	130	0.49	0.43	130	0.49	0.38
			64.4495	0.0006	127	0.38	0.38	135	0.48	0.49	130	0.43	0.40
			125.3155	0.0007	122	0.37	0.37	132	0.46	0.49	123	0.41	0.40
3000	72.946	153.013	2.7622	0.0002	122	0.40	0.34	139	0.50	0.40	125	0.44	0.35
			5.5243	0.0004	110	0.36	0.33	133	0.45	0.43	116	0.39	0.40
			67.5990	0.0006	108	0.35	0.35	118	0.38	0.39	109	0.35	0.33
			129.6737	0.0007	111	0.35	0.40	99	0.34	0.35	98	0.36	0.33
3500	73.827	156.96	3.5315	0.0002	114	0.35	0.39	94	0.33	0.36	123	0.33	0.37
			7.0631	0.0004	98	0.32	0.32	86	0.28	0.30	108	0.33	0.35
			70.1592	0.0005	VF did not open			VF did not open			VF did not open		
			133.2553	0.0007									

From the results we can observe that damping values do not affect oscillation frequency and open quotient much. Maximal width of glottis decreases a little bit with increasing value of damping. The oscillation frequency and the maximal width of glottis decreases with increasing Young's modulus of SLP layer while the opening coefficient remains almost unchanged.

Acknowledgements

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