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A study on the role of muscle tonicity on the onset of self-excited oscillations in tracheoesophageal speech

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Introduction

Laryngectomees with either a hypertonic or a hypotonic pharyngoesophageal segment (PES) have difficulties in producing the tracheoesophageal voice. In this work, we investigate how the tonicity of the PES affects the onset of self-excited PES oscillations.

Methods

The PES is modeled as a collapsible channel (Figure 1).

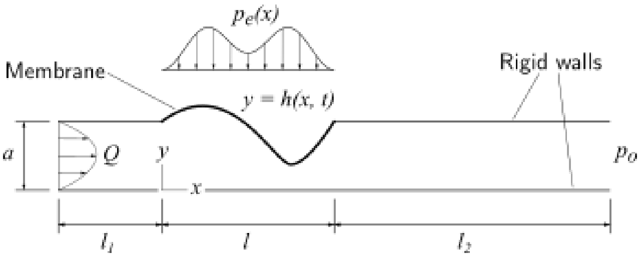

Figure 1: Schematic representation of a collapsible channel.

The simplified formulation of Stewart [1], with few modifications, is adopted. It consists of two dimensionless partial differential equations in x and t. The parameters of the model were set based on published data regarding tracheoesophageal speech. Of special note is the case of the external pressure applied on the membrane (Figure 1), which models the tonicity of the PES. It is set as

$$P_e(x) = \frac{4\bar{P}_e}{3}\left(\frac{1}{2}\sin^2 \pi x + \sin^2 2\pi x\right), \qquad (1)$$

where $\bar{P}_e$ is the mean value of the pressure distribution. This function was chosen as an approximation of the intraluminal pressure in the PES obtained by Welch [2] for laryngectomees at rest. In order to study the onset of self-excited oscillations, first steady-state solutions are obtained, then the governing equations are linearized around the steady-state solution, resulting in an eigenvalue problem. Eigenvalues with a positive real part and a nonzero imaginary part indicate an oscillatory instability. To obtain the steady-state solution, the time derivatives are set to zero in the governing equations, resulting in an ordinary differential equation in x, which was solved using a Chebyshev collocation method [3]. The linearized equations were spatially discretized by the same method, resulting in a generalized eigenvalue problem. The parameter $\bar{P}_e$ is varied, and for each combination of parameters, the stability of the steady-state solution is assessed.

Results and Discussion

The steady-state membrane configuration changes considerably with $\bar{P}_e$. To illustrate, Figure 2 shows the steady-state solutions for $\bar{P}_e = 100$ and $\bar{P}_e = 5000$. These solutions share several similarities with radiographic observations of the PES, of different tonicities, during phonation [4].

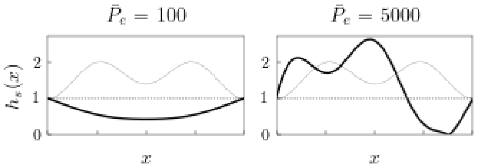

Figure 2: Steady-state solutions for $\bar{P}_e = 100$ and $\bar{P}_e = 5000$. The dashed line shows the form of $P_e(x)$ (not to scale).

Figure 3 shows the eigenvalues of three modes in the complex plane for different $\bar{P}_e$.

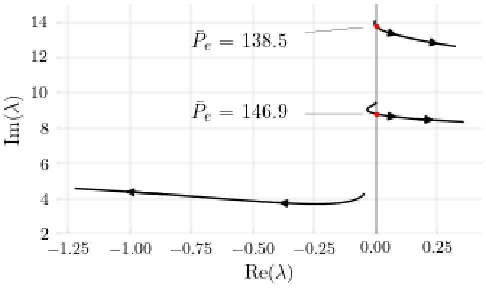

Figure 3: Eigenvalues in the complex plane. The arrows indicate the direction of increasing $\bar{P}_e$.

The onset of self-oscillation happens at $\bar{P}_e = 138.5$. In dimensional units, the corresponding external pressure would be 165 Pa. The frequency for the neutrally stable solution would be 43.5 Hz. While the low threshold may seem to contradict the notion of hypotonicity hindering phonation, there are reports of intraluminal pressures as low as 227 Pa for speaking laryngectomees [5]. Further work is planned to assess the applicability of the model.

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