Determination of an equivalent torsion spring constant for the valve flap of a tracheoesophageal voice prosthesis

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Introduction

Tracheoesophageal voice prostheses are the best voice recovery technique available for patients who have had their larynges removed [1]. In order to create accurate computer simulations of the fluid dynamics in the tracheoesophageal system, the voice prosthesis behavior needs to be properly modeled. By means of an experimental setup, the opening angle of a hinged flap commercial prosthesis was related to the trans-device pressure drop. The results were used as input parameters in simulations to obtain the force exerted by the airflow on the flap, so that an equivalent torsion spring constant could be determined for the hinged flap mechanism.

Methods

Using an experimental set-up (Figure 1), the prosthesis' flap opening angle was measured for each pressure drop.

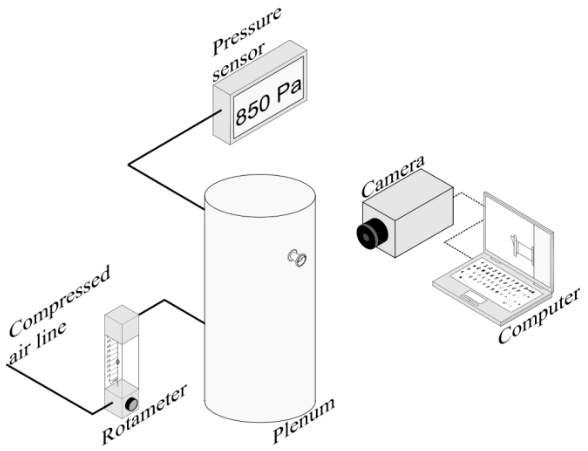

Figure 1: Experimental apparatus used to determine the opening angle of the prosthesis' valve mechanism.

Assuming that the prosthesis behavior is quasi-steady, the opening angles were used to produce geometries for models based on steady finite volume (FVM) and finite element (FEM) simulations, which were used to obtain the force exerted by the airflow on the prosthesis flap. The resulting forces were used to calculate the torque applied on the flap hinge.

Torsional springs within the elastic limit follow Hooke's law, which states that the angular displacement is directly proportional to applied torque. However, most off-the-shelf hinged voice prostheses are manufactured with a pre-tension to increase the resistance to low pressure airflows and avoid leakage [2]. Hooke's law is then written as

$$\tau = \kappa\theta + \tau_0, \qquad (1)$$

in which $\tau\ [\mathrm{Nm}]$ is the torque, $\kappa\ [\mathrm{Nm/rad}]$ is the torsion spring constant, $\theta\ [\mathrm{rad}]$ is the angular displacement, and $\tau_0\ [\mathrm{Nm}]$ is the minimum torque required to open the valve mechanism. The data set from the simulations was then processed using the least squares method to find the curve that best fits the results.

Results and Discussion

Figure 2 shows the results obtained and the adjusted curves. For the FVM data set the obtained torsion spring constant was found to be $\kappa = 4.23 \times 10^{-5}\ \mathrm{Nm/rad}$ and the minimum opening torque $\tau_0 = 8.21 \times 10^{-6}\ \mathrm{Nm}$. And for the FEM data set the results were $\kappa = 3.73 \times 10^{-5}\ \mathrm{Nm/rad}$ and $\tau_0 = 8.92 \times 10^{-6}\ \mathrm{Nm}$.

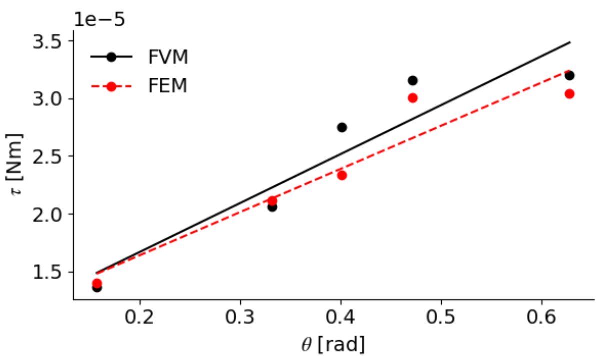

Figure 2: Torque by opening angle curves for FVM e FEM.

Both methods yield very similar results for the torsional spring constant and the minimum opening torque. These results can be used in more complex models to simulate the airflow in the tracheoesophageal system without relying on quasi-steady assumptions.

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References

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