Pressure-Flow Relationship in a Biophysical Model of Phonation

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Abstract: Simulation data are presented from a computer model that combines vocal fold tissue mechanics, laryngeal aerodynamics, and vocal tract acoustics. These simulations are based upon the laws of physics that govern airflow, vibration of the vocal folds, and wave propagation in the vocal tract. The model has been used to demonstrate self-oscillatory characteristics of the vocal folds and the flow pattern in the larynx. In this study, simulations were performed for lung pressure ranging from 4 to 24 cm of water. Adduction control was simulated with activation of thyroarytenoid (TA) muscle that caused increased tension and bulging of the vocal folds. Preliminary data suggest that the relationship between mean pressure and mean flow is almost linear.

INTRODUCTION

In a previous study, the pressure-flow relationship in an excised canine larynx model was investigated by Alipour et al. (1) and the existence of a linear relationship between mean subglottal pressure and mean flow at various adduction levels was demonstrated. The glottal flow resistance, the ratio of the time-averaged transglottal pressure to mean glottal flow was calculated and found to be an inverse function of the vocal process gap. The excised larynx is an excellent model for study of aerodynamic properties of phonation such as pressure, flow, particle velocity, sound intensity, oscillation frequency and amplitude (2). However, the lack of muscular contraction makes the adduction control a little difficult and artificial. Since glottal resistance is considered an important aerodynamic parameter in describing voice disorders, the present study was designed to investigate it through a theoretical approach. The model is based on the laws of physics of airflow, acoustics, and tissue mechanics, which we collectively refer to as biophysical model of phonation. The model is capable of control of elastic and viscous properties of air and tissue, muscle activation, glottal shape, and acoustic loading. These controls can be used to study the pressure-flow relationship during phonation in a wide range of conditions.

The aerodynamic behavior of a larynx depends upon the interdependence of subglottal pressure, glottal adduction, and vocal fold length and tension. The purpose of this study was to investigate the flow characteristics using lung pressure and glottal adduction as the control variables. The results of this simulation study may lend insight into the role of glottal flow resistance in the assessment of human phonation.

RESULTS

The biophysical model of voice production comprised of three components. Each component is responsible for a major task of voice production. These are tissue mechanics, glottal aerodynamics, and vocal tract acoustics. The mathematical descriptions of these models in this short paper are not possible. These components are described elsewhere as separate models (3,4). Also, a detailed description of these models and their interactions will be available in a soon to be published book by the authors (5).

The adduction can be controlled either by the changes in the superior and inferior glottal width, or by increase in the vocal-fold bulging (see Figure 1). In this study a second order curve is used for the bulging, yielding a bulging of zero (flat vocal folds) to maximum (when vocal folds touch the midline). A scale factor of zero to 1 corresponding to the TA activation level is applied to the maximum bulging as a control parameter.
Figure 2 shows the contour plot of the fundamental frequency of phonation as a function lung pressure and TA activation level. These curves simulate the oscillation characteristics of the model of a male human larynx for the vowel /a/. As mentioned in the previous section, the TA activation level is our adduction control parameter. Both of these variables have positive effect on the frequency. This is consistent with findings of Titze (5) and Alipour et al. (1) using canine excised larynges. The maximum increase is expected where the contour lines are closer.

Figure 3 shows typical pressure-flow findings for simulated phonation in our biophysical model. An almost linear relation can be observed between mean subglottal pressure and mean flow rate at the various levels of adduction (TA activation level). As the adduction increased (i.e., as TA activation increased), the regression lines through the data indicate an increased slope of the pressure-flow relation. This is similar to results of canine excised larynges reported by Alipour et al. (1). However, the data are not as linear as excised larynx data, especially in the region of low-pressure values (less than 8 cm H2O). One reason for the difference may arise from the existence of vocal tract in the biophysical model and its lack in the excised larynx model.

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REFERENCES