Quantitative evaluation of a voice-producing element

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1. Introduction

Sometimes a total laryngectomy is indicated for patients with advanced laryngeal cancer. A total laryngectomy consists of the surgical removal of the larynx, which includes the vocal folds and epiglottis. The trachea is cut from the larynx and led outside to the neck, where it is sutured to the skin forming a tracheostoma. The most disturbing consequence of a laryngectomy is the loss of a natural way to produce voice.

2. Aim

The aim of this study is to develop a voice-producing element that can replace the voice after a laryngectomy.

3. Material and Method

The concept of a voice-producing element considered consists of two elastic membranes inside a circular housing. A flow of air can be lead between these membranes, which are placed parallel to each other and in the airflow direction. The voice-producing element can be placed inside a shunt valve in laryngectomees. This one-way shunt valve is situated in the tracheo-esophageal wall and allows a flow of air coming from the lungs into the esophagus when the tracheostoma is occluded. Due to aerodynamic forces, the membranes inside the voice-producing element start to vibrate when the air flows between these membranes. The resulting periodic opening and closing of the airway passage sets the air in the vocal tract into vibration. The sound is then converted to speech.

3.1. *In-vitro* experimental tests

In-vitro experimental tests are performed to evaluate the performance of the voice-producing element in accordance with the requirements. These requirements are strongly related to the physiologic situation in a patient.

The tested prototypes are manufactured on a larger geometric scale, to reduce the influence of manufacturing inaccuracies and to allow for more accurate adjustments to specific design variables. The prototypes differ regarding the length of the airflow channel, the initial distance between the two membranes and the membrane stiffness.

3.2. Quantitative evaluation

The quantitative evaluation of each prototype configuration is based on the following parameters:

- The measured air pressures and airflow rates necessary for sound-production.
- The fundamental frequency and the sound pressure level of the sound produced.
- The calculated efficiency of sound-production and the harmonics-to-noise ratio.
- The observed characteristics of the sound produced: the existence of harmonics and the dependency of the pitch to the aerodynamic forces applied. An increase in driving pressure should lead to a sufficient increase in frequency and sound pressure level.

3.3. Dimensional Analysis

Prior to the experimental tests, a dimensional analysis of the voice-producing element prototype has been performed. This analysis makes it possible to scale theoretically the results from a larger scale prototype to a geometrically similar prototype on true scale. The analysis implies the composition of dimensionless parameters from various design variables. The relations between the dimensionless parameters can be determined by the experimental tests. In turn, these relations provide a clearer insight into the airflow problem considered.

4. Results

The tests show that prototypes, which have a maximal airflow channel length and an initial distance of zero between the membranes, perform best with respect to the sound produced. However, for prototypes with such a small through-flow opening, a considerable driving pressure is necessary for sound-production, which might be inconvenient to the patient. The harmonic richness and variability of the sound appears to be good. The fundamental frequency of the sound produced is suitable for female voicing.

5. Conclusions

The *in-vitro* tests of the double-membrane based prototype show the feasibility of a female version prototype of the voice-producing element, since it fulfils most of the requirements.

The voice-producing element considered is expected to have good self-cleaning properties, which are necessary for proper operation under environmental influences. Especially mucus that enters the voice-producing element is of concern. Therefore, *in-vivo* tests are necessary to evaluate the performance of the voice-producing element in patients.

6. Acknowledgement

This study is part of the EUREKA project “NewVoice”. This project also involves the design of a tissue-connector for the attachment of a tracheostoma valve and the voice-producing element to the tissue. A third research line is the development of new applicable biofilm resistant materials.