Voice Reproduction and Development of a Biomimetic Self-Regulating Double-Clack Valve for a Prosthesis of the Larynx

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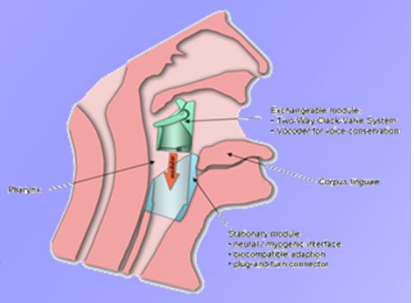
Introduction:

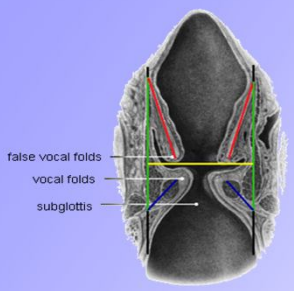
The human larynx is a complex organ, which main functions are phonation, protection, and regulation of the air ways. Patients suffer severely from the diagnosis of a laryngeal carcinoma of the stages T3 and T4. However, postoperative consequences of a total laryngectomy include the loss of the native voice, the loss of regular air ways via mouth and nose, sense of smell, and the inability to build up an abdominal pressure. Therefore a modular larynx prosthesis which enables the laryngectomee to talk with his native voice, to breathe via the regular air ways, and to build up abdominal pressure is desirable. In this work presents new insights for a postoperative solution - a **modular prosthesis** (see right figure) based on a **biomimetic self-regulating double clack-valve** and on a **voice reconstruction module**, a so called *Vocoder*. The *Vocoder* is a device to reproduce the natural human voice. Most important for the use is an additional device required to analyze, conserve and manage voice characteristics of the patient before surgery. The self-regulating double clack-valve is designed to build up an abdominal pressure e.g. to cough. Therefore, our valve-system is working in both directions – a two-way valve system. By bridging the gap of the regular air ways lost by laryngectomy, the sense of smell and taste are restored.

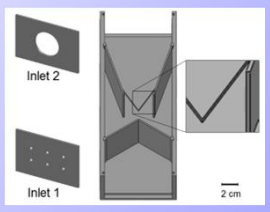


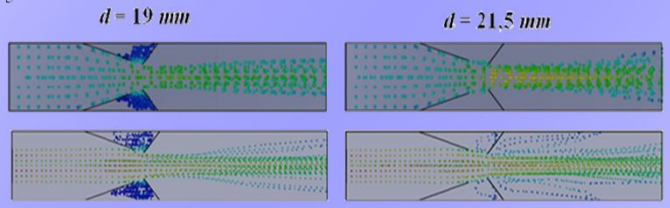
Biomimetic Self-Regulating Double Clack-Valve: *Model and Modeling*

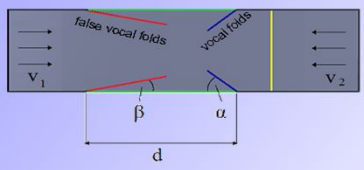
A theoretical and a practical model with each a wide (inlet 1) and a narrow (inlet 2) were built to simulate the larynx and its false and vocal folds as clacks. Dimensions (see figures) were correlated to the biological larynx. In our fluid flow simulation parameters were altered, such as v_1, v_2, α, β and d. In total more than twelve simulation-sets were performed for both inlets. A practical model was designed as shown in the right figure that represent the human larynx with its folds as clack valves.

The clacks were exposed to an air flow, that comes in from the inserted inlet and direction. In this manner inspiration and expiration are simulated. When using the narrow inlet model, the results of the fluid flow simulation (exemplary on figure below) show, that vortices occurred significantly more often than when using the wide inlet model. The results of testing the practical model offer a closure of the backmost clacks using the narrow inlet model and a closure of the front clacks using the wide inlet model.



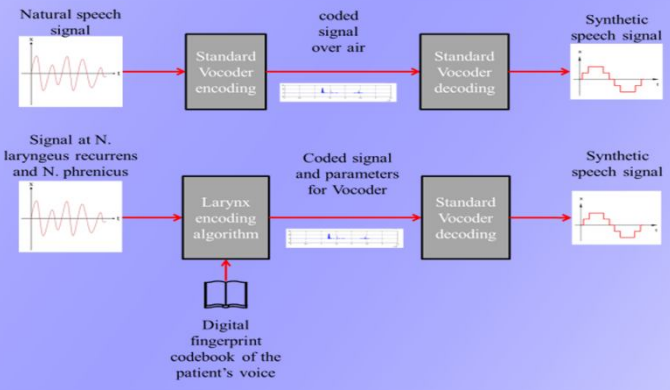






In conclusion, our model reflect the same effect. The wide inlet model facilitates the occurring of Bernoulli's principle. Hence, the front clacks are drawn together and no fluid reaches the backmost clacks. A closure of the backmost clacks using the narrow inlet model happens for two reasons: the characteristic of Bernoulli's principle isn't so strong and the fluid flow reaches the tips of the backmost clacks directly and initiates the closure. The developed "**two way clack valve**" was shown to be working perfectly, while using the narrow inlet – a biomimetic valve. The designed valve represents a fundament for future work on the functional laryngeal prosthesis. With our model we were able to setup a **Biomimetic Self-Regulating Double Clack-Valve** that can be to adapted individually.

Voice Conservation and Electronics: The *Vocoder*



One of the most valuable characteristics of the laryngeal prosthesis is the reproduction of the patient's native voice. An electronic device inside the prosthesis receives input from the *N. laryngeus recurrens* and *N. phrenicus* and generates the voiced parts of speech using the native voice of the patient as a template.

Nowadays, telecommunication systems, e.g. cellular handsets, commonly use *Vocoders* - electronic devices - that are utilizing mathematical models to reproduce vocal tracts of humans. Therefore a *Vocoder* could also be used to emulate the vocal tract after a laryngeal prosthesis, thus generating speech with the patient's native voice. Most *Vocoders* are using Linear Prediction (LP) based codecs ,e.g. *CELP*, *AMR* or similar. LP based algorithms are using aligned tubes of different lengths and radiuses as a model of the vocal tract. The laryngeal prosthesis takes input from the *N. laryngeus recurrens* and the *N. phrenicus* and calculates the necessary variable parameters for the *Vocoder* whereas the fixed parameters are given by hardware programming, e.g. firmware (see left figure).

Due to the uniqueness of an individual's vocal tract, i.e. in shape and size and other characteristics, the voice of a human being is like a distinct fingerprint. Therefore the approach includes the method to capture individual voice characteristics before resection. The algorithm in the laryngeal prosthesis recalculates the neural signals to input parameters for the *Vocoder* so that formants are placed and shaped to reproduce the patient's native voice.

Please contact us for further reading, ideas or cooperation:

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We are looking for partners and funding to keep the project alive!