Nahrstaedt H, Schauer T, Seidl RO. **Bioimpedance based measurement system for a controlled swallowing neuro-prosthesis**. In Proc. of 15th Annual International FES Society Conference and 10th Vienna Int. Workshop on FES, 2010, 49-51.

Bioimpedance based measurement system for a controlled swallowing neuro-prosthesis

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Abstract

Dysphagia has a huge impact on the quality of life. In this contribution, a measurement system is presented which allows an assessment of the swallowing process. Additionally, the system detects aspiration. Basis of the system is a two-channel bioimpedance measurement at the neck which can be extended by an EMG recording from the larynx's musculature. The feasibility of aspiration detection was experimentally demonstrated on an animal model. The proposed measurement may be used in both therapy and diagnosis of dysphagia. Within this contribution the idea of a controlled neuro-prosthesis is outlined.

Keywords: *Dysphagia, Bioimpedance, EMG, Larynx, Aspiration detection, Neuro-prosthesis, Airway, Swallowing, Intramuscular electrical stimulation.*

Introduction

Swallowing is a complex vital process that takes place either consciously or sub-consciously depending on the current phase of the swallowing. Controlled by cortical processes, which are coordinated in the brain stem (pattern generators), multiple muscles have to be activated in a timely manner for a swallow.

Swallowing disorders (dysphagia) can lead to serious complications, including malnutrition and pneumonia, which may be fatal. The complete closure of the larynx and its timing take a central role in safe swallowing, especially since the larynx is a bifurcation between the trachea and the oesophagus. In case of closure failure, saliva, liquid or food is going into the airway (aspiration), which may have the consequences described above.

The causes of swallowing disorders are mostly severe head injuries and strokes. Every second stroke patient suffers from dysphagia, which is chronic in one quarter of the patients [1].

The primary objective of rehabilitation is the restoration of disturbed functions by, for example, sensory stimulation or teaching of special swallowing techniques. Necessary conditions for success are sufficient cortical potential after the injury and an existing connection from the cortex to the muscles. If this connection is lost or the muscles cannot be sufficiently controlled, a rehabilitation of the swallowing process is not possible. Hence, the patient is dependent on a diet via a feeding tube and a tracheal cannula.

In these cases, electrical stimulation of the external laryngeal muscles as a therapeutic approach seems to enhance the swallowing process [2]. Another possibility is to stimulate the internal laryngeal muscles in such a way that the vocal cords close and aspiration can be prevented [3]. In both cases, intramuscular stimulation seems to be superior to transcutaneous stimulation [4-5]. The stimulation has to be released in a timely manner. In previous studies, the stimulation was triggered either by the patient himself via a hand-switch [3] or by the electromyography (EMG) of submental muscles [5]. However, neither method is able to adapt to the swallowing success or skills of the patient.

One approach to evaluate the swallowing success could be the measurement of bioimpedance (BI). Impedance is defined as the relation of voltage to current over an electrical conductor. There are two possible methods to measure BI.

In the two-point method, the voltage is measured directly over the current electrodes. The current, which is induced into the patient through the current electrodes, causes a voltage drop across the electrode-skin contact. As this resistance is time-variant, it will lead to a measurement error. This undesirable effect can be avoided by using the four-point measurement method where the voltage is recorded separately over additional electrodes by a high impedance instrumentation amplifier. Since no current can flow through the voltage electrodes,

there is no disturbing time-varying voltage drop across the electrode-skin contact. The instrument we have developed supports both methods.

A four-electrode method using separate current and voltage electrodes is applied for a transcutaneous measurement of bioimpedance at the neck as proposed in [6]. In a previous work [7], it was shown that the BI is correlated to the distance from the hyoid bone to the thyroid cartilage, a measure of airway closure during swallowing. In this work, it is further examined whether such BI measurements can also be used for the detection of aspiration. A measurement system based on two combined BI measurements could then serve as a sensor concept for a regular swallowing neuro-prosthesis.

Idea and concept of a BI controlled swallowing neuro-prosthesis

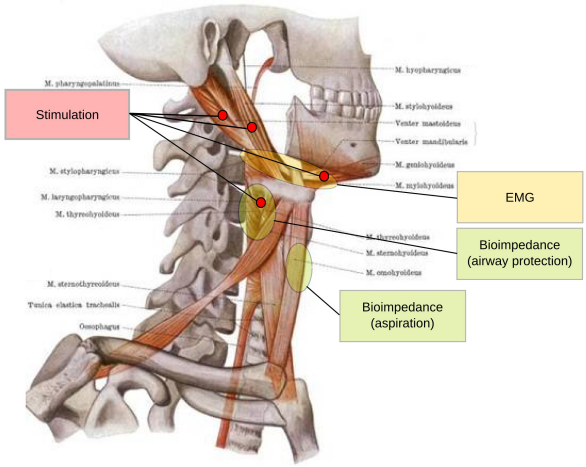

Fig. 1: Model of the measurement and stimulation system as basis for a swallowing neuro-prosthesis

The goal of the BMBF-funded research project BigDysPro is the development of a controlled neuro-prosthesis that supports swallowing by stimulating the appropriate muscles using intramuscular electrodes. The system continuously assesses the success of the stimulation using BI measurements and adjusts to the needs of the patient accordingly. For a synchronized start of swallowing and stimulation, the remaining residual activity of the muscles is recorded by EMG measurements and acts as a trigger for the stimulation. If the patient chokes despite these measures, the device is able to detect this from the BI measurement and triggers a protective cough or throat-clearing induced by another stimulation. In Fig. 1, the stimulation and measurement areas are shown. For the measurement of airway closure, changes in the BI at the level of the epiglottic vallecula are acquired. Aspiration detection takes place via electrodes on the thyroid cartilage at the level of vocal cords.

Material and Methods

We have developed a measuring system which allows two independent BI measurements and provides four channels of EMG. The BI can be measured in parallel using two EMG channels.

Current source

The device has two identical galvanically isolated current sources which operate at one of eight available current settings (maximal amplitude 200 µA). The current sources have a maximum load impedance of 2 kΩ. One current source generates a sinusoidal current with a frequency of 50 kHz while the second current source is set to a frequency of 100 kHz. When measuring, these two frequencies are easily distinguishable from another using a band-pass filter. Thus, two independent BI measurements can be performed simultaneously.

In the current sources which drive a current through a patient to the device ground, measurement errors can occur if one part of the current flows capacitively to the device ground instead of flowing entirely through the patient. This may happen when the therapist touches the patient. In contrast to this, the current source we used features a differential design so that such effluent currents can be compensated. To avoid DC components in the current, which may endanger the patient, one Y1-capacitor is connected in series to each output terminal.

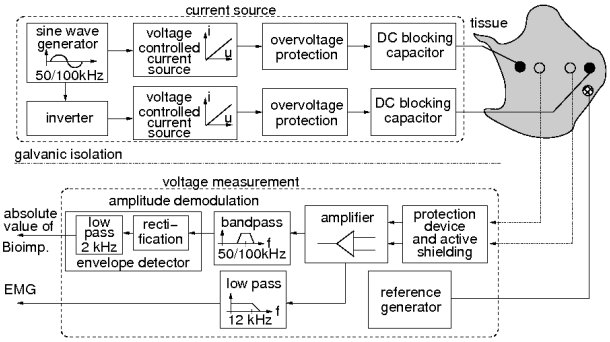

Fig. 2: Structure of a BI / EMG measurement channel

Voltage measurement

Each of the four amplifiers (INA128, TI) features input protection resistors which protect the patient attached to the device from any dangers in case of failure. In addition, protection diodes ensure that the instrumentation amplifier is not damaged. With this setup it is possible to measure during an active electrical stimulation. Fig. 2 shows the structure of one BI / EMG measuring channel.

EMG-Measurement

In order to extract the EMG from measurement data, the amplified signal of the analogue input is filtered with a 12 kHz low-pass filter. Thus, the

high-frequency voltage parts deriving from the BI are removed.

Demodulation

An amplitude demodulation circuit extracts the amount of BI from the measured sinusoidal signal. First, the signal is bandpass filtered in order to isolate the measuring frequency. Next, the signal is rectified and low-pass filtered. The processed signal corresponds to the amplitude of the sine wave and therefore to the amount of the measured BI.

Micro-controller and connection to a PC

The processed analogue signals (up to 4 EMG and 2 BI signals) are sampled simultaneously by a 24-bit A/D converter (ADS1278, TI) with a frequency of 4 kHz. The micro-controller (STM32F103, ST) sends the data to a PC via a galvanically isolated serial-USB converter.

Results

An essential part for the development of the described neuro-prosthesis is an aspiration detection. At the moment, only a radiological examination can reliably prove that aspiration has occurred. To test the feasibility of an aspiration detection BI, measurement tests have been performed on an animal larynx. A fresh bovine larynx was prepared in a way that it could be suspended freely in order to convey liquids through it. The bioimpedance measurement was recorded using the four-point measurement method. The electrodes were placed at the level of the vocal cords.

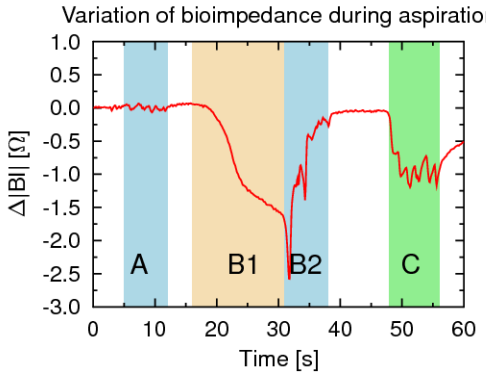

Fig. 3: Measurement result during the passage of various fluids through the larynx. A - water, B1 - yoghurt, B2 - water, C - buttermilk

Various fluids have been inserted into the larynx with a pipette. The respective time segments are marked and plotted in Fig. 3 together with the measured change of BI over time. Water (section A) causes only small changes in the BI. As yoghurt (section B1) is viscous, the BI reacts with a delay. In section B2, yoghurt that is left in the larynx, is rinsed down by water and causes peaks in the BI. The respective maximum is reached if and only if some liquid has passed the position of the electrodes near the vocal cords. In section C, buttermilk has been dispensed intermittently which explains the oscillations in the trace. The deflection of BI is a function of the liquid's chemical/physical characteristics (its electrolyte conductivity and viscosity).

Conclusions

The presented measurements on an animal larynx show that BI may be suitable for detecting aspiration. It is necessary to perform comparative studies on patients with the help of videofluoroscopy to validate the measuring system. The introduced measuring system will be of major help in further developing the described neuro-prosthesis.

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Acknowledgements

This work was partly funded through grant by the German Federal Ministry of Education and Research (BMBF) within the project BigDysPro (FKZ 01EZ1007A).

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