Comparative experimental analysis of impedance and ultrasound measurements to evaluate cerebrospinal fluid for hydrocephalus diagnosis

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Background, Motivation and Objective

Hydrocephalus (HCP), also known as “water of the brain”, is characterized by an abnormal increase of the cerebrospinal fluid (CSF) inside the ventricles of the brain. In Germany, there were 15,891 cases of HCP in 2019, and it increased to 16,259 cases in 2021. In the USA, more than 125,000 patients are diagnosed with hydrocephalus. HCP is produced either when the CSF is not properly absorbed by the brain or when a blocklage for the CSF flow occurs, and in most of the cases syrurgical shunts need to be inserted in the brain to adapt the CSF drainage.

To avoid the risks associated to the surgery, early prevention of HCP can be done by continuously monitoring variations of the CSF flow or of the intracranial pressure in the brain, which are pathological conditions of HCP. Invasive continuous monitoring of the brain dynamic volume variation can be performed by using a bioimpedance sensor catheter, where an increment in the electrical impedance is associated to a higher CSF volume. A new method to non-invasively, safetely and continuous monitoring the hemodynamics of the CSF is based in the transcranial Doppler ultrasonography, which provides not only information about the systolic and diastolic brain flow, but also of how the flow curve changes from a HCP-diagnosed patient to a healthy one. In this work, an in-vitro comparative analysis of the impedance measurement by using a bioimpedance sensor catheter, and of the flow and pressure measured by an ultrasound sensor will be performed. New insights into measurements of the fluid dynamics of the CSF by this new proof of concept based on a Doppler ultrasonic sensor will be obtained from this work.

Statement of Contribution/Methods

Firstly, in-vitro measurements of the bioimpedance are performed. For this purpose, a microelectrode array comprising two pair of outer electrodes (OE) and two pair of inner electrodes (IE) has been fabricated in the clean room. The microelectrodes are developed in Platinum-iridium (Pt-Ir) over a ceramic that is used as a carrier. A saline solution in distilled water is used to emulate the CSF fluid. Impedance measurements for a frequency range between 1 Hz and 300 KHz were performed by submerging the microelectrode in a CSF phantom saline solution.

Secondly, an in-vitro setup to measure the brain flow and the intracranial pressure (ICP) is established in the laboratory. The arteriovenous (AV) blood flow is reproduced by a pulsatile pump, which is regulated through two valves (one at the input and the second at the output). Different flow rates produced by the peristaltic pump are measured by using the doppler mode of an ultrasound flow sensor, which relates frequency shift of the reflected acoustic signal to the fluid speed. Simultaneoulsy, intercranial pressure is recorded by using a piezoelectric honey-well sensor, which is being placed next to the ultrasound sensor, so that both signals (flow and pressure) are synchronized and can be compared withouth any time shift between them.

Results/Discussion

CSF dynamics have been quantitatively recorded by using bioimpedance sensors and intracranial doppler ultrasound sensors. In this study, it is demonstrated that difference in conductivity between two mediums, reflected by an increase in the impedance, can be accurately recorded by using an bioimpedance sensor. However, impedance change is not a sufficient parameter to diagnose hydrocephalus cases, and that is why intracranial doppler monitoring is also required. In vitro results show that CSF flow, intracranial pressure, resistive index and diastolic blood flow can be extracted by using tranascranial doppler ultrasonography. Ultrasonic frequencies can enhance the axial resolution of the monitoring system up to 0.6 mm. Thus, ultrasound-based measurements show a very high preccission. This research work demonstrates that non-invasive transcranial doppler sensors can also be used in intensive care units for the monitoring of cerebral circulation and CSF flow.

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