Real-Time Continuous Monitoring of Cerebral Edema Based on a Flexible Conformal Coil Sensor

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Abstract. Objective: Cerebral edema, as a common secondary disease after stroke, can result in brain hernia and even death, effectively monitoring the process of cerebral edema do benefit the prognosis of stroke patients. While current methods have their inherent drawbacks, we utilized a novel frequency shift (FS) method to reflect the severity of cerebral edema. Method: In this paper, 12 rabbits (10 rabbits for experimental group and 2 rabbits for control group) were enrolled in the 24 h monitoring experiment. Those rabbits underwent monitoring utilizing a novel flexible conformal coil sensor, for which the FS induced by changed equivalent impedance of brain was extracted as the evaluation index. Findings: The results showed that this novel coil sensor can effectively monitor the process of cerebral edema. This innovative method has great potential in clinical usage which can assist medical staff conducting timely treatment in terms of its early warning capability.

Keywords: Cerebral edema · Frequency shift · Coil sensor · Electromagnetic induction · Real-time monitoring

1 Introduction

Cerebral edema is a common secondary disease after stroke disease (Savitsky et al. 2016), which has a negative impact on the rehabilitation and prognosis of patients. Patients with severe cerebral edema may even cause brain hernia and death. Therefore, the monitoring of cerebral edema is necessary and good intervention helps to improve the prognosis. At present, cerebral edema monitoring for clinical patients mainly includes ICP method and CT/MRI imaging (Ristic et al. 2015). Yet ICP is an invasive way and those imaging instruments require extra transit and diagnostic time. Literally, a novel non-invasive monitoring method are desperately needed. The microwave method utilizing sensors such as patch antenna and the electromagnetic induction method using coil sensors have been widely studied (Qureshi et al. 2016; Yan et al. 2017; Chen et al. 2017). In this paper, we designed a novel flexible conformal coil sensor to monitor the process of cerebral

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edema in rabbits by electromagnetic induction. The results showed that this sensor can effectively monitor the development of cerebral edema and the FS signal is positively correlated with the severity of cerebral edema.

2 Methodology

The biological tissues in brain have different dielectric properties where the permitivities and conductivities of different biological tissues (such as gray matter, white matter, blood, etc.) are different at a specific frequency (González and Rubinsky 2006). When brain lesions occur, the cranial contents' distribution and metabolism change, thereby changing the intracranial average permitivity and conductivity (Sun et al. 2014; Yan et al. 2017; Chen et al. 2017).

In order to detect changes in intracranial dielectric properties caused by cerebral edema lesions, a newly designed flexible conformal coil sensor was used to detect the equivalent impedance change according to the two-port network test principle (Griffith et al. 2018). The system consists of the novel coil sensor, a vector network analyzer (VNA, Agilent E5061B, USA), and a gas anesthesia machine, as shown in Fig. 1. The frequency range of the VNA is 1–100 MHz and the sensor was attached directly above the head of the rabbits. The frequency shift (FS) of the sensor's resonance frequency is extracted, which is caused by the disturbance of the physiological changes of the rabbit.

12 New Zealand white rabbits were enrolled in this experiment (experimental group: n = 10, control group: n = 2). In experimental group, cerebral edema model was established by epidural freezing method via liquid nitrogen freezing (Kawai et al. 2003). In this scenario, the severity of cerebral edema gradually deepens with time (Li et al. 2017). Rabbits in control group received same procedure except freezing. After procedure, all rabbits were monitored for 24 h with the novel coil sensor and the sampling rate was 12 times per hour.

Fig. 1. Physical map of the detection system

3 Results

Figure 2 shows the FS data in the experimental group and the control group (mean ± SD). It can be found that the trends were significantly different between the FS signal in those two groups. In the experimental group, FS showed an upward trend with aggravated cerebral edema, reaching 1.08 ± 0.25 MHz at 24th h. In contrast, the FS in control group slightly increased and then fluctuated around 0.18 MHz (0.18 ± 0.01 MHz), in which the slight drift may be caused by the surgery on the scalpe. The data of the experimental group and the control group showed significant difference from the 5th h (t-test, $p < 0.05$), indicating that FS can effectively monitor the pathological changes of cerebral edema.

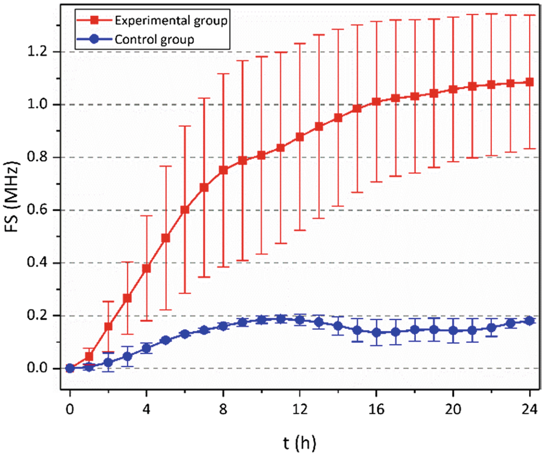

Fig. 2. Results of FS in experimental group & control group

4 Conclusions

Based on the principle of two-port network test, this paper uses a new flexible conformal coil sensor to detect changes in brain dielectric properties caused by cerebral edema. The results showed that this method can effectively monitor the pathological changes of cerebral edema. Compared with control group, experimental group's FS could show significant difference at early stage (2th h after procedure). This indicated that FS can be used as a novel non-invasive monitoring indicator to assist the medical staff giving timely adjustment and implement of the treatment program. Still, this novel sensor for cerebral edema monitoring still needs optimization of the parameters so as to elevate the reliability and sensitivity. Eventually, we hope to improve its early monitoring ability and improve its effectiveness.

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