Effect of metal fragments in brain on electrical monitoring: In vitro and in vivo rat studies

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Abstract. Preliminary results showed, measurements by rheoencephalography (REG) very promising as a practical, noninvasive continuous monitoring modality of traumatic brain/blast injuries. As the impact of metal fragments on the REG signal is unknown, we report here results of our study. The in vitro study confirmed that impedance pulse amplitude waves do not change in the presence of metal (needles) placed between electrodes. In vivo studies: rats under anesthesia (10 rats, 101 trials) were measured after implantation of EEG and REG electrodes in the brain. Metal fragments were represented by 18 g needles inserted and removed between EEG and REG electrodes. Data were stored in a PC. EEG recording typically showed amplitude decrease; REG showed transitory amplitude increase after placement of a needle into either hemisphere. Removal of needles caused a decrease in REG amplitude after a transitory increase. The change in REG amplitude statistically was non-significant. Cerebral blood flow (CBF) autoregulation (AR) persisted following placement of metal fragments in rat brain.

1. Introduction

1.1 Clinical relevance

A major diagnostic limitation for the blast induced head injured patient is the inability to image the cranium using MRI due to the possibility of embedded metal fragments from improvised explosive devices. Additionally CT angiography sometimes fails to detect vasospasm due to the associated metal artifact. On the basis of preliminary results, REG seems to be a practical noninvasive and continuous monitoring modality of traumatic brain and blast injuries. This situation makes bioimpedance method (Rheoencephalogram – REG) particularly relevant due to the lack of ability to obtain transcranial Doppler assessments, angiography or cerebral blood flow measurements in the combat zone. Typically, CBF is monitored in neurosurgery intensive care units once a day by Doppler ultrasound, which in this case measures CBF on the middle cerebral artery; however, this measurement is not a continuous procedure. The probability of detecting vasospasm in recent clinical practice is low, although such a capability would be lifesaving [1]. To accomplish our objectives we conducted this in vitro and an in vivo study, modeling the metal fragments in brain while recording REG and EEG signals.
1.2 REG (rheoencephalogram)

REG is being tested in this study as a potential globally applicable CBF reactivity monitoring modality. REG is a device used to estimate a patient's cerebral circulation (blood flow in the brain) by electrical impedance methods with direct electrical connections to the scalp or neck area [2]. REG pulse amplitude changes reflect brain vasoconstriction and vasodilatation as well as cerebral volume changes. The physical basis of the electrical impedance method is based on the fact that blood and cerebrospinal fluid are better conductors than the brain and other 'dry' tissue [3].

2. Methods

2.1 In vitro study

A loop was created using rubber and plastic tubes filled with 0.9 % NaCl (Figure 1). This loop involved a Doppler in-line flow probe (4N) connected to an ultrasound flow meter (T201 Ultrasonic Blood flow Meter, Transonic Systems, Ithaca, NY); a disposable pressure transducer (Argon Medical Devices, Athens, TX) connected to a Blood Pressure Analyzer (Digi-Med, Micro-Med, Louisville, KY); Codman Micro sensor (Codman ICP Express, Codman & Shurtleff, Raynham, MA), an infusion pump (Power infuser, Infusion Dynamics, Plymouth Meeting, PA), a temperature probe: MT-29/1 Needle thermometer (Time constant: 0.125 sec; diameter: 29 ga BAT-12 Microprobe Thermometer, Physitemp (Clifton, NJ); and two home-made bioimpedance measuring cells: 1) the first was a polyethylene tube, impedance electrodes (2 stainless steel needles with plastic tube fittings with luer connections). 2) The second was the similar polyethylene tube with impedance electrodes (2 copper metal tubes) connected to a bipolar impedance amplifier (Cerberus, Quintlab, Hungary). Metal fragments were represented by 18 g stainless steel needles inserted between bioimpedance electrodes half way. Signals were stored in a PC using DataLyser software (Baranyi). The pump, flow was set to 4 L/h. For numerical comparison, 50-second periods were measured with DataLyser; pulse wave peak amplitudes and FFT peak amplitudes were compared. Further data analysis was performed in Excel (Microsoft, Redmond, WA).

![Figure 1](image-url)

Figure 1. Block schematics of an in vitro measurement. The reservoir (600 ml Pyrex glass container) was uncovered, having free inflow.

2.2. In vivo - Rat measurement

Sprague-Dawley rats (n=12; weighted 463 ± 29 g; n=101 trials) were anesthetized. Catheters were inserted surgically into femoral artery and trachea. Animal experiments were performed using rats placed into a stereotaxic frame. REG and EEG electrodes were implanted. Tests were to insert and remove 18 G needles (about 1 % of brain volume) between REG and EEG electrodes. The electrodes were connected to...
the cables and to EEG and REG amplifiers. Systemic arterial pressure (SAP), exhaled CO₂ concentration, electrocardiogram were also recorded. CBF autoregulation was tested by CO₂ inhalation and SAP changes. Data acquisition was realized with 200 Hz with the same PC and software as in vitro. REG measurement was based on its first derivative; additional measurements and calculations were made by DataLyser and Excel software. REG pulse amplitude values were measured by cursor operation. Data were copied into an Excel spreadsheet. Values of baseline (before any CBF manipulation) and during CBF manipulation were compared. Bio-impedance (REG) data were stored and calculated in Volt units.

3. Results

3.1. In vitro

There was a difference between peak to peak amplitudes: the REG needle electrode voltage was ± 0.2 V and the REG tube voltage was ± 0.4 V; additionally, the REG needle signal was noisy. The two peaks with different amplitudes (Y₁, Y₂) and frequencies (X₁, X₂) were result of an unequal power of infusion pump, also every second pulse was higher in both measuring cells. The temperature sensitivity of this in vitro measurement was characterized by the linear regression lines of measured modalities, demonstrating that the pressure probes (SAP and ICP) show identical slopes to the needle cell, while the tube cell correlation was modest.

Table 1. Results of calculation of pulse peak amplitudes in presence of needle and in absence of inter-electrode needles (left 3 shaded columns) and FFT peaks (right 4 columns). Samples were characterized by the time (in seconds) of recordings (first column). ICP: Codman sensor; SAP: Digi-Med Pressure analyzer and Flow: Doppler flow meter. Numerical values beyond 2 digits were not shown. First column (N) showed the number of peaks involved in the calculation. Time window of analysis was 50 seconds.

| Modality | Pulse Peak | FFT Peaks |
|----------|------------|-----------|
|          | N | Mean | SD | X₁ | Y₁ | X₂ | Y₂ |
| REG tube | present | 94 | 0.37 | 0.06 | 0.94 | 0.00 | 1.90 | 0.01 |
|          | absent  | 94 | 0.39 | 0.06 | 0.94 | 0.00 | 1.88 | 0.02 |
| REG needle | present | 98 | 0.14 | 0.02 | 0.94 | 0.00 | 1.88 | 0.00 |
|          | absent  | 94 | 0.15 | 0.02 | 0.94 | 0.00 | 1.90 | 0.00 |
| ICP      | present | 93 | 0.42 | 0.21 | 0.94 | 0.01 | 1.88 | 0.04 |
|          | absent  | 93 | 0.43 | 0.21 | 0.94 | 0.01 | 1.88 | 0.02 |
|          | absent  | 93 | 0.44 | 0.21 | 0.94 | 0.01 | 1.88 | 0.05 |
| SAP      | present | 93 | 0.48 | 0.19 | 0.94 | 0.01 | 1.88 | 0.03 |
|          | absent  | 93 | 0.49 | 0.19 | 0.94 | 0.01 | 1.88 | 0.02 |
|          | absent  | 93 | 0.48 | 0.19 | 0.94 | 0.01 | 1.88 | 0.04 |
| Flow     | present | 103 | -0.17 | 0.00 | 0.94 | 0.00 | 1.88 | 0.00 |
|          | absent  | 113 | -0.17 | 0.00 | 0.94 | 0.00 | 1.88 | 0.00 |
|          | absent  | 113 | -0.17 | 0.00 | 0.94 | 0.00 | 1.90 | 0.00 |
3.2 In vivo
A qualitative summary of the measurement showed that 10 rats had 101 inter-electrode immersion and removal. In few cases there was bleeding following the immersion and removal of needle which was stopped. In a subgroup of inter EEG electrode needle insertion the EEG amplitude decreased in 69% of the trials while at the same time REG amplitude increased transiently in 92 % of trials. During the needle insertion between REG electrodes (n=12 trials), EEG amplitude decreased and REG amplitude increased, both in 75% of trials. The difference between significant and non significant groups were non-significant (P=0.68). CBF autoregulation persisted following placement of needle in rat brain.

4. Discussion

The advantage of REG monitoring is that it is continuous and non-invasive. The drawback is that no clear pathophysiological background is known to have multiple influencing factors. An extensive overview of such influencing factors was beyond the scope of the present study but was detailed previously by Moskalenko and Jenkner [4, 5]. It was shown that REG reflects lower limit of CBF autoregulation [6, 7]. However, the presence of metal fragments may impact REG signal. On the basis of our studies REG signal seems to be insensitive to the presence of metal fragment. Possible explanation is that the used measuring frequency (125 KHz) was too low to cause any thermal effect; a microwave oven works by usually at a frequency of 2.45 GHz. Further studies are needed to answer the size dependency of metal in the brain.

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