Effect Of Metal Fragments in Brain on Electrical Monitoring: In Vitro and in Vivo Studies

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Abstract

A major diagnostic limitation for the blast induced head injured patient is the inability to image the cranium due to the significant number of embedded metal fragments from IEDs, making MRI prohibitive. 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. However, it is not known whether or not the presence of metal fragments affects the REG signal.

Here we report results of an in vitro and a rat study in which we tested the impact of metal fragments in the brain on electrical signals (EEG, REG).

The in vitro study confirmed that impedance pulses changed in the presence of metal (needles) placed between electrodes, changed as a function of temperature and pressure, but pulse wave amplitude did not change.

Under Nembutal anesthesia 12 rats (n=92 trials) were measured after implantation of EEG and REG electrodes in the brain. Metal fragments were represented by 18 g needles (about 1 % of brain volume), inserted and removed between EEG and REG electrodes. Data were sampled with 200 Hz; stored and analyzed with DataLayser software.

EEG recording typically showed amplitude decrease; REG showed transitory amplitude increase after placement of a needle into either hemisphere. Removal of needles caused decrease in REG amplitude after a transitory increase. Hence there was a significant change in REG amplitude but statistically it was non-significant.

Introduction

On the basis of preliminary results, REG seems to be a practical noninvasive and continuous monitoring modality of brain injuries.

However, the presence of metal fragments may impact the REG signal.

Here we present results of in vitro and in vivo studies modeling metal fragments in the brain while recording REG and EEG signals.

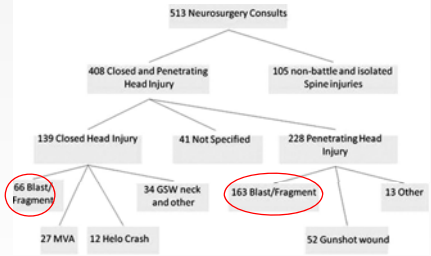
Military Relevance

Operation Iraqi Freedom (2003-2008)*: highest concentration of severe closed and penetrating head trauma at NNMC and WRAMC since Vietnam

(*513 neurosurgery consultations).

Bell, Armonda et al, Military Traumatic Brain and Spinal Column Injury: A 5-Year Study of the Impact Blast and Other Military Grade Weaponry on the Central Nervous System. J Trauma. 2009;66:S104 -S111.

*Breakdown of Population

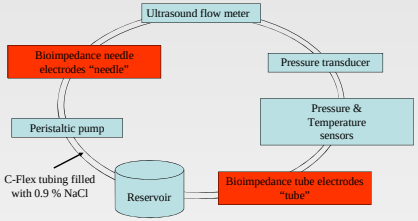


A major diagnostic limitation for the blast induced head injured patient is the inability to image the cranium due to the significant number of embedded metal fragments from IEDs, making MRI prohibitive. Additionally the use of CT angiography sometimes fails to detect vasospasm due to the associated metal artifact. However, cerebral angiography has revealed an amazingly high number of symptomatic vasospasm cases in this selected patient population. This has only recently been described, as blast-induced delayed cerebral vasospasm (Armonda et al, 2006). This situation makes the 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. If the presence of vasospasm could be confirmed with REG measurements then we could potentially have a non-operator dependent, non-invasive means of measuring patients at risk for cerebral ischemia from vasospasm associated with penetrating brain injury and blast. This could potentially open vast new therapies in cerebral revascularization.

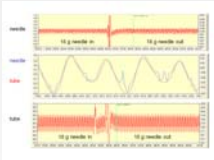
Methods – In Vitro

A loop was created using C-Flex and PVC tubing 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 microprobe (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, with internal diameter of 9 mm and impedance electrodes were 2 stainless steel needles with diameter of 0.6 mm, with 7 mm inter-electrode distance and plastic tube fittings with luer connections. 2) the second was the same polyethylene tube, with internal diameter of 9 mm and impedance electrodes were 2 copper metal tubes (30 mm in length and 8 mm internal diameter) connected to a bipolar impedance amplifier (Cerberus, Quintlab, Hungary). Inter-electrode distance (end of a copper tube to other) was 10 mm. Measurement frequency was 125 kHz. Metal fragments were represented by 18 g stainless steel needles inserted between bioimpedance electrodes half way.

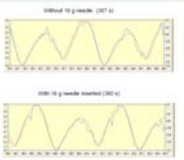
Signals were stored in a PC using an AD card (PCI-MIO-16XE-10, National Instruments, Austin, TX) with 16 bit resolution, using DataLyser software (Baranyi). The sampling rate was 200 Hz. Doppler pulse wave and mean flow value, 2 pressure waves, temperature, 2 bioimpedance (REG) pulse waves and a voltage proportional to pump volume output were stored. For 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).



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

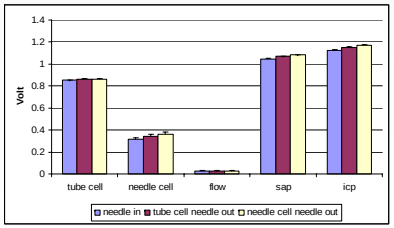


Bioimpedance signals were recorded from needle cell (upper trace) and tube cell (lower trace) with (left) and without (right) inter-electrode needle. Artifacts on both traces indicate the exact time of insertion/removal. Medium trace compares bioimpedance signals: a signal from needle cell was noisy compared to tube cell signal.



Bioimpedance signals from both tube (red) and needle (blue) measuring cells, without (upper trace) and after insertion of 18 g inter-electrode needle (lower trace).

Results – in vitro



Changes in pulse amplitude (minimum-maximum distance) in tube and needle measuring cells, in flow and pressure (SAP, ICP) pulses with inserted needles (blue), removal of needle from tube cell (brown), and removal from needle cell (yellow). Y axis is in Voltage; time window of measurement was 50 seconds. Data are mean ± SD.

Results – in vitro

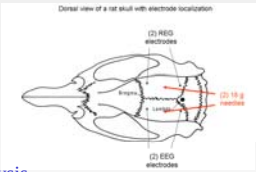
Modality / Sample time	Pulse Peak N	Pulse Peak Mean	Pulse Peak SD	FFT Peaks X1 Hz	FFT Peaks Y1	FFT Peaks X2 Hz	FFT Peaks Y2
REG tube							
200-250	94	0.37	0.06	0.94	0.00	1.90	0.01
360-410	94	0.39	0.06	0.94	0.00	1.88	0.02
REG needle							
200-250	98	0.14	0.02	0.94	0.00	1.88	0.00
280-330	94	0.15	0.02	0.94	0.00	1.90	0.00
ICP							
200-250	93	0.42	0.21	0.94	0.01	1.88	0.04
280-330	93	0.43	0.21	0.94	0.01	1.88	0.02
360-410	93	0.44	0.21	0.94	0.01	1.88	0.05
SAP							
200-250	93	0.48	0.19	0.94	0.01	1.88	0.03
280-330	93	0.49	0.19	0.94	0.01	1.88	0.02
360-410	93	0.48	0.19	0.94	0.01	1.88	0.04
Flow							
200-250	103	-0.17	0.00	0.94	0.00	1.88	0.00
280-330	113	-0.17	0.00	0.94	0.00	1.88	0.00
360-410	113	-0.17	0.00	0.94	0.00	1.90	0.00

Results of calculation of pulse peak amplitudes in presence (200-250) and in absence of inter-electrode needles 280-330 and 360-410 (yellow columns) and FFT peaks (right 4 columns). Samples are characterized by the time (in seconds) of recording (first column). ICP: Codman sensor; SAP: Digi-Med Pressure analyzer, and Flow: Doppler flow meter. Numerical values below 2 digits are not shown. Second column (N) shows the number of peaks involved in the calculation. The two peaks with different amplitudes (Y1, Y2) and frequencies (X1, X2) are caused by the unequal pulse amplitude of the infusion pump (see Figures), in which every second pulse was higher in both measuring cells. Time window of analysis was 50 seconds.

	Linear regression	Correlation coefficient
Tube cell	y = 0.0048x + 0.8493	R2 = 0.5298
Needle cell	y = 0.0217x + 0.2983	R2 = 0.9844
Flow cell	y = 0.0272	R2 = 0
SAP	y = 0.0175x + 1.0312	R2 = 0.9735
ICP	y = 0.0235x + 1.103	R2 = 0.9986
Temperature	y = 0.0047x + 1.1452	R2 = 0.9972

Linear regression and correlation coefficient (R^2) of pulse amplitudes in measured modalities during inserted needles (first point), removal of needle from tube cell (second point) and removal from needle cell (third point).

Methods - in vivo



Data analysis

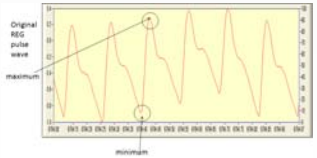
The data reduction was preformed by:

Calculating the individual pulse waves amplitudes (minimum – maximum distance) during 10 pulse waves. The baseline value was considered as 100 %. Two group of individual pulse waves amplitudes (minimum – maximum distance) during 10 pulse waves were used per trial: one baseline and and one during challenge (maximal amplitude in case of CO_2 inhalation and minimal amplitude during clamping).REG pulse amplitude and values (area below the curve) were measured by DataLyser (Baranyi, WRAIR). Calculations and graphics were done with Excel software.

Values of baseline (before any CBF manipulation) and during CBF manipulation was compared as a function of time and measured by the time at their minimum or maximum.

Informative tables of summary descriptive statistics and graphical displays was constructed to contrast the basic data of interest.

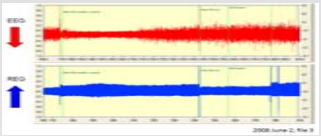
Data preparation for statistical analysis will be performed with DataLyser and Excel SW. Statistical analysis was performed in Minitab SW.



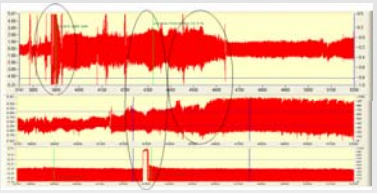
Measurement of REG pulse values in DataLyser with cursors
The X-axis is in milli-seconds, the Y-axis is in arbitrary units.

The pressure and impedance signal amplitudes were not effected by changes in pump flow rate. However, amplitude differences were observed when the 1st derivative was taken.

Results – in vivo



Effect of needle insertion on REG and EEG



REG reactivity persisted following placement of metal fragments in rat brain. REG amplitude increased after placement of metal into brain.

Additional REG amplitude increased following CO2 inhalation (13.3 %) and REG amplitude decreased during SAP increase

A qualitative summary of the measurement showed that 10 rats had 92 inter-electrode immersions and removals. In a few cases there was bleeding following the immersion and removal of needles (bleeding was stopped). In a subgroup of inter EEG electrode needle insertion the EEG amplitude decreased in 69% of the trials, and REG amplitude increased transiently in 92 %. During needle insertion between REG electrodes (n=12 trial), EEG amplitude decreased and REG amplitude increased, both in 75 % of the trials.

	EEG decrease	EEG no change	REG increase	REG decrease	REG no change	Number of trials
EEG	9	4	12	0	1	13
%	69	31	92	0	8	
REG	9	3	9	3	0	12
%	75	25	75	25	0	

Percentage changes in EEG and REG amplitudes following needle insertion. EEG: total number of case; %: percentage.

Rat	Average of REG amplitude changes: Significant	Average of REG amplitude changes: Non significant	Total trials	Significant Changes trials
2008JUNE06	36.08	20.91	10	3
2008JUNE05	61.08	96.78	16	3
2008JUNE04	76.02	18.20	19	11
2008JUNE02	102.49	57.55	18	5
2008 MAY30	29.66	14.74	11	8
2008 MAY29	96.89	142.89	8	1
2008MAY 28	33.04	139.98	6	5
2008MAY27	61.24		4	4
2008MAY22	24.30	79.03	6	2
2008MAY20		24.58	3	3
TOTAL =10			101	43
MEAN	57.87	66.07		
SD	29.32	51.52		
P		0.68		

The difference between significant and non significant groups were non significant(P=0.68).

Disclaimer

Material has been reviewed by the Walter Reed Army Institute of Research. There is no objection to its presentation and/or publication. The opinions or assertions contained herein are the private views of the author, and are not to be construed as official, or as reflecting true views of the Department of the Army or the Department of Defense.

Research was conducted in compliance with the Animal Welfare Act and other federal statutes and regulations relating to animals and experiments involving animals and adheres to principles stated in the Guide for the Care and Use of Laboratory Animals, NRC Publication, 1996 edition.

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