Influence of volume and flow change on the electrical impedance signal (in vitro)

M Bodo[1], A Garcia, F Pearce, S Van Albert, R Armonda[2]
Walter Reed Army Institute of Research, Silver Spring, MD; [2]National Naval Medical Center, Bethesda, MD, USA

E-mail: michael.bodo@med.navy.mil

Abstract. On the basis of preliminary results, rheoencephalography (REG) shows promise as a practical, noninvasive and continuous monitoring modality of brain injuries. However, REG literature reflects uncertainty about whether the signal reflects flow or volume. Presented here are results of in vitro studies manipulating flow/volume to model clinical conditions (such as brain ischemia and vasospasm) while recording the electrical impedance signal. A loop was created using tubing filled with 0.9 % NaCl. This loop was comprised of a Doppler in-line flow probe connected to an ultrasound flow meter, a peristaltic pump, a pressure transducer and home-made electrical impedance measuring cell, incorporating a balloon catheter. Bipolar impedance amplifiers were used for measuring impedance pulse waves. Data were stored on a PC and processed off-line. This in vitro study confirmed that 1) Doubling flow rate influenced the pulse amplitude and mean flow of the Doppler signal; 2) Doubling flow rate had no influence on the amplitudes of the pressure or electrical impedance signals; 3) An increase in amplitude was observed in the pressure and electrical impedance signals when the first derivative was taken. 4) Balloon inflation decreased electrical impedance and Doppler flow pulse amplitudes; 5) With balloon inflation, Doppler and electrical impedance signals showed an identical relationship to decreased flow (R^2=0.966).

1. Introduction

Acute management of patients with traumatic brain/blast injury remains a challenge. To minimize secondary injury and improve outcome, it is critical to detect neurological deterioration early, when it is potentially reversible (Rubin et al, 2009). On the basis of preliminary results, rheoencephalography (REG) shows promise as a practical, noninvasive and continuous monitoring modality of traumatic brain and blast injuries. REG literature reveals disagreement about whether the signal reflects flow or volume. The U.S. Food and Drug Administration defines rheoencephalograph as "a device used to estimate a patient's cerebral circulation, without specifying flow or volume. Since electrical impedance is measured in ohms, REG measurements do not quantify flow or volume. The magnitude of REG pulse amplitude is a function of conductive particles between two electrodes. In order to test the clinical applicability of REG, we simulated two pathophysiological changes—flow and volume. Our hypothesis was that electrical impedance (REG) pulse amplitude would decrease as a result of both manipulations (flow and volume decreases). Results of in these vitro studies are reported here.

[1] Michael Bodo, 503 R. Grant Avenue, Silver Spring, MD, 20910, USA

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.						
1. REPORT DATE **2010**		2. REPORT TYPE			3. DATES COVERED **00-00-2010 to 00-00-2010**	
4. TITLE AND SUBTITLE **Influence of volume and flow change on the electrical impedance signal (in vitro)**					5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)					5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Walter Reed Army Institute of Research,Silver Spring,MD,20910**					8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT **On the basis of preliminary results, rheoencephalography (REG) shows promise as a practical, noninvasive and continuous monitoring modality of brain injuries. However, REG literature reflects uncertainty about whether the signal reflects flow or volume. Presented here are results of in vitro studies manipulating flow/volume to model clinical conditions (such as brain ischemia and vasospasm) while recording the electrical impedance signal. A loop was created using tubing filled with 0.9 % NaCJ. This loop was comprised of a Doppler in-line flow probe connected to an ultrasound flow meter, a peristaltic pump, a pressure transducer and home-made electrical impedance measuring cell, incorporating a balloon catheter. Bipolar impedance amplifiers were used for measuring impedance pulse waves. Data were stored on a PC and processed off-line. This in vitro study confirmed that 1) Doubling flow rate influenced the pulse amplitude and mean flow of the Doppler signal; 2) Doubling flow rate had no influence on the amplitudes of the pressure or electrical impedance signals; 3) An increase in amplitude was observed in the pressure and electrical impedance signals when the first derivative was taken. 4) Balloon inflation decreased electrical impedance and Doppler flow pulse amplitudes; 5) With balloon inflation, Doppler and electrical impedance signals showed an identical relationship to decreased flow (R~0.966).**						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**		

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Journal of Physics: Conference Series **224** (2010) 012111 doi:10.1088/1742-6596/224/1/012111

2.Methods

An electrical impedance measuring cell was constructed to simulate changes in flow and volume. A closed loop was created with PVC and C-Flex tubing filled with 0.9 % NaCl. This loop included a Doppler in-line flow probe (4N) connected to an ultrasound flow meter (T201 Ultrasonic Bloodflow Meter, Transonic Systems, Ithaca, NY); a disposable pressure transducer (Argon Medical Devices, Athens, TX) was connected to a Blood Pressure Analyzer (Digi-Med, Micro-Med, Louisville, KY), and two stainless steel metal tubes (14 mm in length and 3 mm internal diameter) were used as electrical impedance electrodes. Signals were stored in a PC using an AD card (PCI-MIO-16XE-10, National Instruments, Austin, TX) with 16 bit resolution. The data sampling rate was 200 Hz. Data were collected and analyzed with DataLyser software.

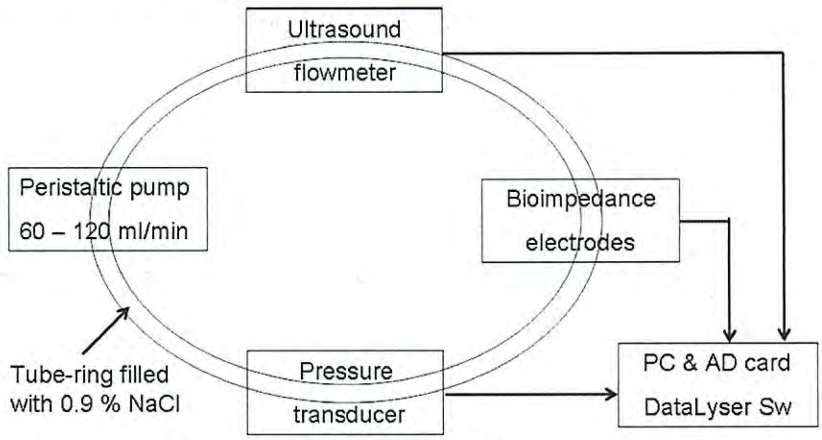

Figure 1. Block schematics of measurements.

2.1. Flow

To simulate flow change, a peristaltic pump (Masterflex, L/S, Cole-Palmer, USA) was connected to the closed loop; flow rate was set first to 60 mL/min, then increased to 120 mL/min. A bipolar impedance amplifier (KR-Ea RHEO Preamp, OTE Galileo, Italy) generated the impedance signal. Measurement frequency was 45 kHz and the resistance between the two electrode tubes was above 10 ohm (maximum balance). Electrical impedance and pressure values were calculated by taking the first derivative.

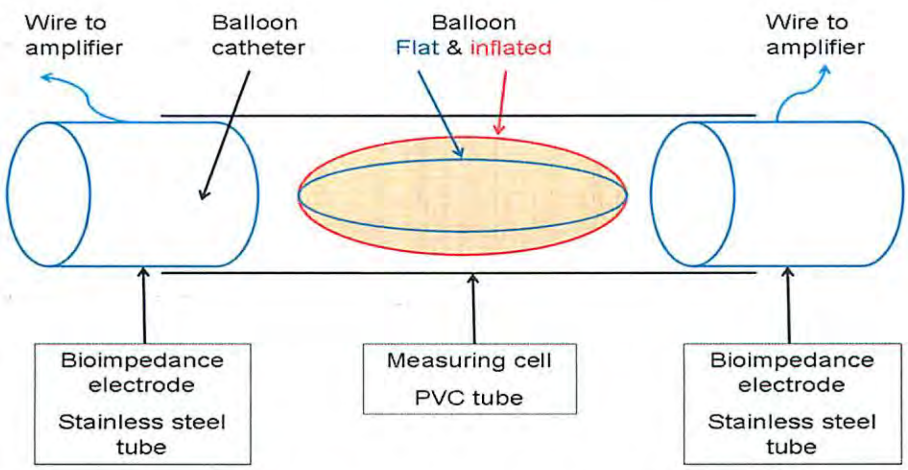

Figure 2. Schematics of electrical impedance measuring cell with balloon inflation.

2.2. Volume

To simulate decreased volume (vasoconstriction/vasospasm), a balloon catheter (PTCA Dilatation catheter, NCR14 9/4.0, Boston Scientific, SCIMED, Maple Grove, MN) was inflated, placed into impedance measuring cell (figure 2) with a syringe in 0.5 cc steps. A pump (model P720, Instech Laboratories, Plymouth Meeting, PA) was connected to the closed loop to generate pulse waves at a constant rate. The bipolar impedance amplifier used to generate the impedance signal was Cerberus (Quintlab, Hungary). Measurement frequency was 125 kHz. Electrical impedance and Doppler flow pulse amplitude measurements (minimum – maximum distance) were made at 0 (no inflation), 0.5, 1.0 and 1.5 cc inflation. Eight pulse amplitudes were measured and averaged.

3. Results

3.1. Flow

Doubling of flow produced corresponding increases in Doppler signals: pulse amplitude and mean flow increased two-fold. First derivative calculations (dZ/dt and dP/dt) made it possible to convert changes in impedance and pressure signals to corresponding amplitude increases.

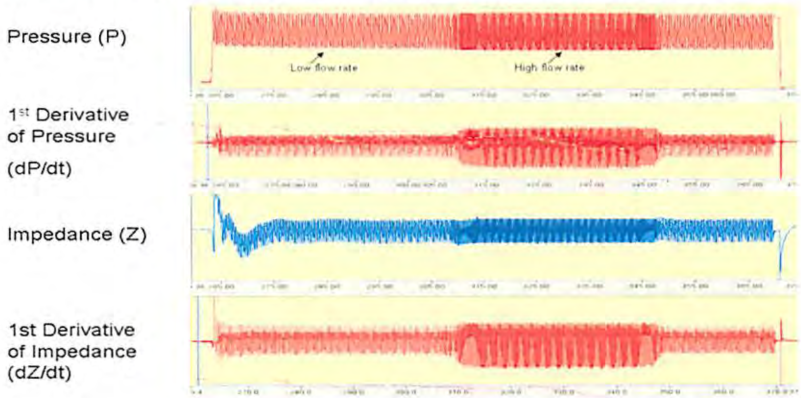

Figure 4. Pressure and impedance traces with low and high flow rate.

Table 1. Comparison of Doppler flow and electrical impedance during low and high flow rates. The effects of increased flow rate were comparable between Doppler flow and impedance when the impedance derivations (first derivative and its integral) were calculated.

		Doppler Flow			Impedance		
	Pump Flow Rate	Display	Amplitude	Mean	Amplitude	1st Derivative (dZ.dt)	Integral of 1st Derivative
	mL/min	mL/min	mL/min	mL/min	a.u	a.u.	a.u.
mean	60	67	68.13	3.58	2.83	0.09	0.44
SD			17.3	0.005	1.51	0.05	0.004
mean	120	124	124.98	4.15	2.83	0.18	0.91
SD			47.9	0.01	1.54	0.09	0.003
ratio	2.00	1.85	1.83	1.16	1.00	2.00	2.07

3.2. Volume

Balloon inflation to simulate vasoconstriction/vasospasm decreased the electrical impedance pulse amplitude, a result identical to that obtained for Doppler pulse change. Pulse amplitude of both the Doppler and electrical impedance signals decreased as a function of balloon inflation (R^2=0.966).

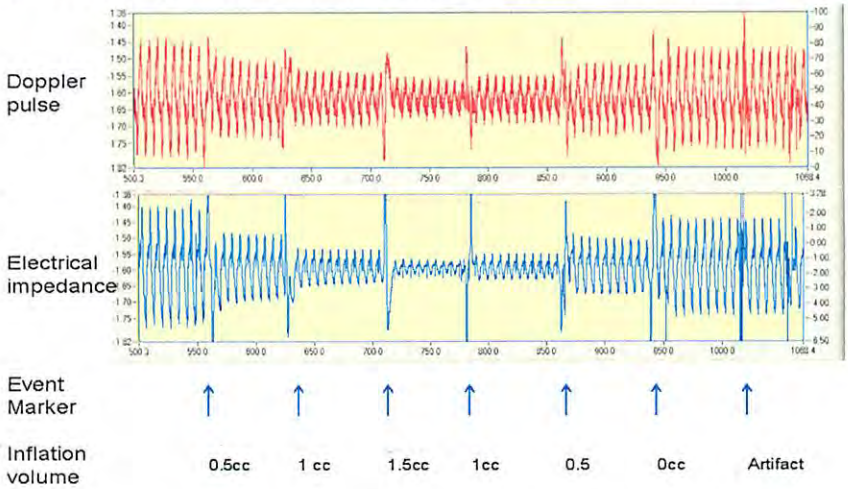

Figure 3. Effect of balloon inflation/deflation on Doppler flow and electrical impedance pulse amplitudes.

4. Conclusion

Although these in vitro electrical impedance studies manipulating flow and volume contribute to an understanding of the basic relationship between electrical impedance and flow/volume changes, biological conditions are much more complex than the simple model discussed here. Other factors influencing the REG signal have been previously summarized [1]. Results of these in vitro electrical impedance studies manipulating flow and volume were as follows:1) Modeling vasospasm/brain ischemia detected decreased pulsatile volume and flow; 2) Doppler and electrical impedance signals showed an identical relationship to decreased flow; 3) Electrical impedance pulse change reflected volume change; however, the increased flow resistance caused by balloon inflation also decreased flow.

5. Reference

[1]. Moskalenko YE ed 1980 *Biophysical aspects of cerebral circulation* (Oxford: Pergamon)

Acknowledgements

Lajos Baranyi for use of DataLyser software and Janice Meer for assistance with the manuscript.

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.