Monitoring Cerebrovascular Pressure Reactivity with Rheoencephalography

KM Brady MD[1], JO Mytar BS[1], KK Kibler BS[1], RB Easley MD[1], RC Koehler PhD[1], M Czosnyka PhD[2], P Smielewski PhD[2], M Bodo MD, PHD[3], FJ Pearce PhD[3], RA Armonda MD[4]

[1]Department of Anesthesiology and Critical Care Medicine, Johns Hopkins University School of Medicine, Baltimore, MD

[2] Department of Academic Neurosurgery, Addenbrooke's Hospital, Cambridge, U.K.

[3] Department of Resuscitative Medicine, Walter Reed Army Institute of Research, Silver Spring, MD.

[4] Department of Neurosurgery, National Naval Medical Center, Bethesda, MD.

Abstract

Background

Traumatic brain injury is a leading cause of death and disability for children in the United States, and has been identified as a major cause of morbidity and mortality from blast exposure. Finding optimal perfusion pressure for patients with head injury is a central element of ICU care, and remains a disturbingly arbitrary process. Monitoring and optimizing cerebrovascular pressure reactivity has been proposed and endorsed at the option level by the brain trauma foundation. The traditional method for monitoring pressure reactivity is with the pressure reactivity index, or PRx, which requires an intracranial pressure monitor. We hypothesized that pressure reactivity could be quantified with a rheoencephalography index, or REGx, which creates a potential to optimize blood pressure without intracranial surgery.

Method

We measured rheoencephalography or REG, intracranial pressure, cortical red cell flux, and arterial blood pressure in 9 piglets with gradual, progressive hypotension. Static autoregulation curves were constructed for gold standard determination of the lower limit of autoregulation. Intracranial vascular compliance was trended as low frequency changes in the REG pulse amplitude, which were compared with slow changes of intracranial pressure. The PRx was measured as low-frequency linear correlation between arterial blood pressure and intracranial pressure. The REGx was measured as low-frequency correlation between arterial blood pressure and REG pulse amplitude.

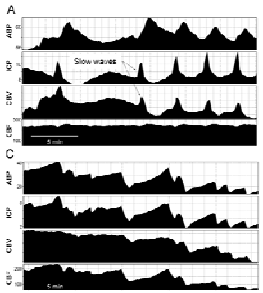
Results

Slow waves of intracranial pressure have been shown to trend cerebral blood volume, and are a marker of changing cerebrovascular compliance. Trending the pulse amplitude of the REG can reproduce slow waves of intracranial pressure, suggesting that the pulse amplitude of REG is a function of vascular compliance. The PRx produced an accurate metric of vascular reactivity in this cohort, with area under the receiver-operator characteristic curves of 0.91. REGx was moderately correlated to the PRx, (spearman r = 0.63, p < 0.0001; Bland-Altman bias-0.13). The area under the receiver-operator curve for the REGx was 0.86. Disagreement occurred at extremes of hypotension.

Conclusion

REGx has potential for development as a monitor of cerebrovascular pressure reactivity. The success of the REGx shows that the pulse frequency blood volume change carries important information about vascular compliance and autoregulatory activity. The REG may be improved with high pass filtering of the respiratory variation, which could confound pulse amplitude determination during extreme hypotension.

Background



•Slow changes in arterial blood pressure and intracranial pressure / cerebral blood volume are inversely related when autoregulation is intact.

•Slow changes in arterial blood pressure and intracranial pressure / cerebral blood volume are positively correlated when autoregulation is impaired

The PRx has been used to monitor cerebrovascular pressure reactivity, the mechanism of pressure autoregulation. In the figure above, A and B show a normotensive piglet, with negative correlation between arterial blood pressure and intracranial pressure, indicating intact autoregulation. C and D show a hypotensive piglet, with positive correlation between arterial blood pressure and intracranial pressure, indicating impaired autoregulation. ABP: arterial blood pressure, ICP: intracranial pressure; CBV: cerebral blood volume estimated using near-infrared spectroscopy; CBF: cerebral blood flow.

REG is a monitoring modality that measures electric impedance across brain tissue. REG is a function of the ratio of fat (insulating) and blood/csf (conducting). The pulse amplitude seen in the REG tracing is a function of the volume of blood ejected into the cranium during each cardiac cycle.

Objective

Our objective was to create an alternative metric of pressure reactivity that would not require an intracranial pressure monitor.

We hypothesized that we could re-create the slow ICP and CBV waves by trending the pulse amplitude of the REG, which is a function of cerebral blood volume and vascular compliance.

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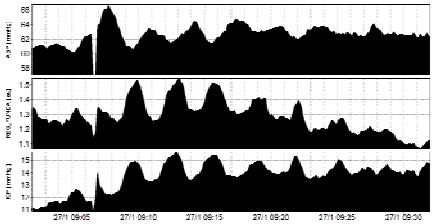
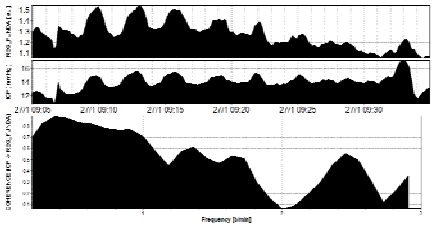
Methods

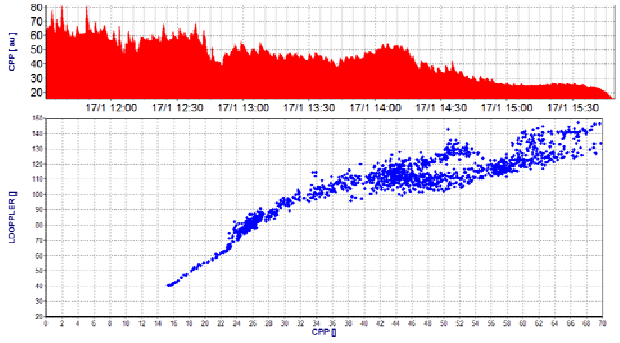
- 9 piglets with progressive hypotension by inflation of a balloon catheter in the inferior vena cava
- Continuous monitoring of REG (invasive), ICP, cortical red cell flux (laser-Doppler), and ABP
- REG pulse amplitude was trended and compared with low-pass (10 second) filtered ICP waveforms



•An example from one piglet shows (left), that both ICP and REG pulse amplitude are inverted in phase to the arterial blood pressure of a normotensive piglet at low frequencies, as would be expected with intact autoregulation.

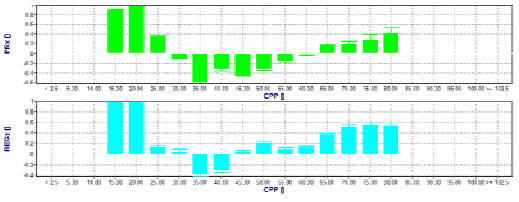


•Further, the ICP and REG pulse amplitude were highly coherent at low frequencies in this experiment. This important early result was encouraging to pursue the REG pulse amplitude as a surrogate trend of cerebral blood volume and vascular compliance: substituting the REG pulse amplitude for ICP in the PRx equation.

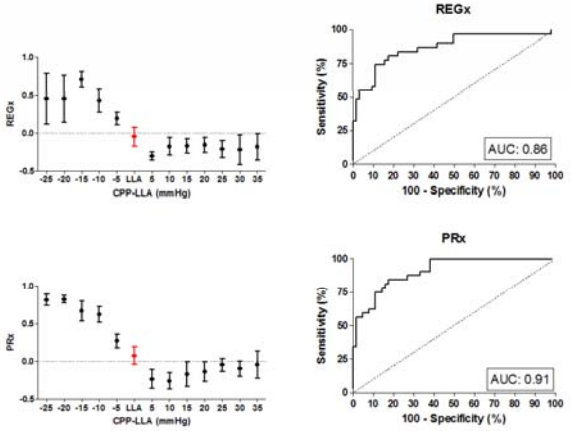


•For each animal, as ABP was lowered, and cerebral perfusion pressure (CPP) trended to zero, cortical red cell flux was plotted as a function of CPP. The lower limit of autoregulation (LLA) was determined as the intersection of the two best-fit lines on the Doppler plot with the lowest combined residual error squared. For this animal, the lower limit of autoregulation was 30 mmHg, a number consistent with normal piglet physiology.

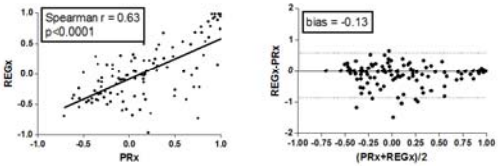
•The PRx and REGx were sorted and averaged according to CPP. In this animal, CPP less than the LLA was associated with elevations of both the PRx and the REGx. This is the method used clinically to determine optimal CPP with the PRx, and allows a side-by side comparison of the 2 indices for accuracy and agreement.



Results



The PRx was a very accurate detector of the LLA in this cohort of animals. The REGx did well, with some noise occuring at extremes of hypotension. To show this, we plotted the REGx and PRx as a function of CPP normalized to the animals individual LLA. One expects to see a positive index at CPP below the LLA, and a zero or negative index at CPP in the range of autoregulation. Knowing the LLA for each animal allows determination of receiver-operating characteristics, and both have an acceptable area under the curve (AUC), with exceptional accuracy noted from the PRx data.



Correlation and Bland-Altman analysis of the PRx and REGx shows that the REGx is slightly biased to a low result when the PRx is positive, consistent with the low scores seen at extremes of hypotension in the plots above. It seems then, that the REGx is giving the most accurate information at CPP around the LLA.

Conclusions

The REGx is a promising modality for measuring cerebrovascular pressure reactivity . For functional deployment of the modality, the following issues should be explored:

1. Does removal of the respiratory variation with a high-pass filter improve the accuracy of the REGx during extreme hypotension?
2. Does non-invasive measurement of the REG give similar accuracy?

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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.