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Intracranial Pressure Waveforms Indicate Vasodilation during Remote Ischemic Conditioning

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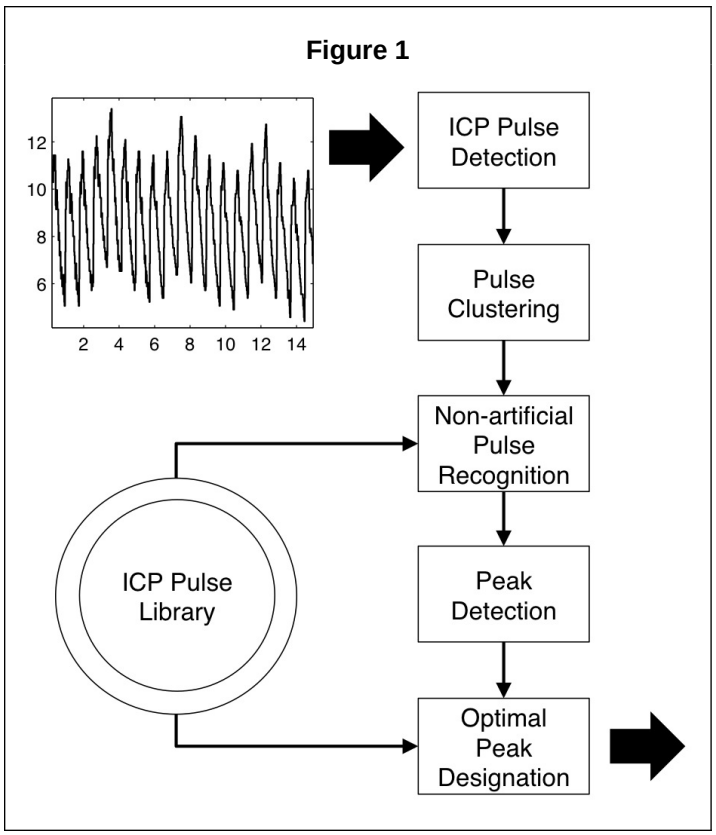
Introduction

Remote ischemic conditioning (RIC) is a powerful endogenous mechanism where brief periods of ischemia in a tissue such as the leg confers protective benefits from ischemic injury to distant tissues such as the brain. To further understand the physiology behind RIC, particularly the short-term hemodynamic changes, we use indirect methods based on changes in the pulse-waveform shape of the intracranial pressure (ICP)

Our previous work using ICP waveform analysis identified trends in the waveform shape that suggest transient cerebral vasodilation occurs during RIC. We confirm this finding using data prospectively collected as part of our phase I clinical trial of RIC for aneurysmal subarachnoid hemorrhage (aSAH).

Figure 1



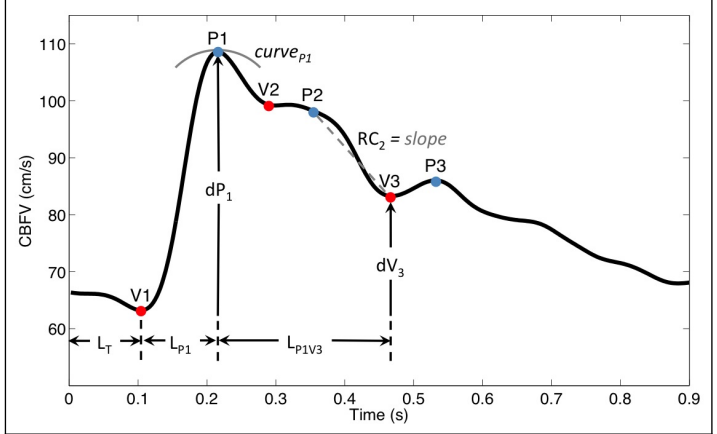
Methods

During the RIC procedure ICP was measured using intraventricular monitors simultaneously recorded with ECG (Fs = 400 Hz). ICP analysis was performed using the Morphological Clustering and Analysis of Intracranial Pulse (MOCAIP) algorithm which extracts 128 metrics from the ICP pulse-waveform (Figures 1 and 2). Previous studies in patients undergoing CO2 inhalation identified a template of 72 metrics that consistently increase or decrease during vasodilation of the cerebral vasculature. The proportion of metrics that match this template (VDI) was found for each session and compared with VDIs from a control set of normal pressure hydrocephalus (NPH) patients using a Mann-Whitney test.

Results

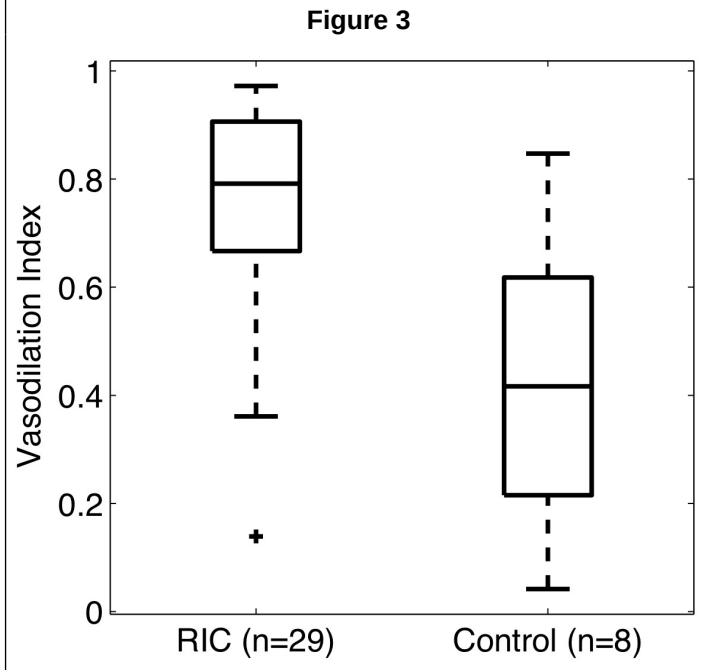
Fifteen aSAH patients had ICP monitoring during 29 RIC sessions of approximately 40 minutes. ICP segments of the same length were collected for 8 NPH patients. The median VDI was significantly higher in the RIC patients (0.79, 0.42, $p<0.01$) (Figure 3)

Figure 2



Metric Notation	Description
dV_1, dV_2, dV_3, dP_1, dP_2, dP_3	Amplitude of landmark relative to the minimum point prior to initial rise
L_{V1P1}, L_{V1P2}, L_{V1P3}, L_{V2P2}, L_{V3P3}	Time delay along landmarks
$Curv_{V1}$, $Curv_{V2}$, $Curv_{V3}$, $Curv_{P1}$, $Curv_{P2}$, $Curv_{P3}$	Absolute curvature of each landmark
K_1, K_2, K_3, RC_1, RC_2, RC_3	K_1, K_2, K_3 are the slope of each rising edge and RC_1, RC_2, RC_3 are time-constants of each descending edge
mCBFV, diasV	Mean CBFV and diastolic CBFV
L_T	Time delay of V1
mCurv	Mean absolute curvature of the pulse
WaveAmp	Maximum among dP_1 and dP_2
dP_{P1P2}, ...	Ratio among landmark amplitudes
L_{V1P1}/L_T, ...	Ratio among time delays
$Curv_{V1}/Curv_{V2}$, ...	Ratio among curvatures
K_1/RC_1, ...	Ratios among slopes/RCs

Figure 3



Median VDI for RIC cases=0.79 vs. median VDO for controls = 0.42 ($p<0.01$)

Conclusions

Pulse-waveform changes observed during the RIC procedures indicate vasodilation when compared to control patients. Intracranial pressure waveform analysis is a useful tool to detect real time changes in the state of the cerebrospinal circulatory system, providing additional insight into the mechanism and effects of RIC.

References

Hu, X., P. Xu, and F. Scalzo. **Morphological Clustering and Analysis of Continuous Intracranial Pressure**. *IEEE Trans Biomed Eng*. 2009

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