Blood Pressure-Related Hemodynamic Shifts in the Cerebral Cortex During Cardiac Surgery

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Abstract
New-infrared spectroscopic (NIRS) cerebral oximetry is currently employed to non-invasively sense brain perfusion. Novel analyses of NIRS data from a single patient during heart surgery are part of a continuing study aimed at identifying differences between the sensing capabilities of separate optical units and smaller arrays that are being used in routine intraoperative cerebral oximetry, using a NIR oxymeter manufacturer. We use a continuous wave NIR diffuse Optical Tomography imaging system sampled at 15-hertz, 760 and 830 nm at 3 sites, with 32-pixel array that yields 211 detector channels. The NIR oximeter was used to compute estimates of oxygenated and deoxygenated hemoglobin (HbO2 and HbR) (Schmidt 2005).

Introduction
• Neuroinvasive deficits are a common side effect of surgery, especially cardiac (Miller 1996 and Swino 2008)
• Many hemodynamic alterations during surgery affect MAP and subsequent brain perfusion
• Some of these shifts may have dramatic, dropping levels of minute in just a few seconds and reaching MAP as low as single digit
• NIRS monitoring of cerebral oxygenation has been well described and utilized clinically (Wolf 2007 and Murken 2007)
• Local brain responses to these perturbations have not been fully characterized
• Without a full understanding of how the brain responds, it is unlikely that a proper monitoring schema can be developed

Results
Summary: Brain is regionally heterogeneous across sites

Methods
• 2 wavelengths (760 nm and 830 nm) of time series data were collected from 8 patients during cardiac surgery, using arrays shown in Fig. 1, which yield 211 source-detector pairs (channels)
• Biomedex Lambda IV was used to compute estimates of oxygenated and deoxygenated hemoglobin (HbO2 and HbR) (Schmidt 2005)
• Control trials were defined as periods of about 1.5 minutes duration, whereas patient was hemodynamically stable – MAP changes <3% very little if any as a drop or subsequent recovery is seen in mean arterial pressure (MAP) of at least 20 mmHg for 30 seconds, and 24 control time periods of similar duration were studied in the uses of the analyzer. Spearmen correlation coefficients between MAP and oxygenation signal (HbO2) for each channel-time period were determined for five significant types of channel-MAP correlations were significantly different among sites, for both control (p<0.05) and event (p<0.001). A sensitivity analysis was performed to determine the magnitude of change during each event in each detector channel, for both Hb and oxygen saturation (HbO2). While a large fraction of the array (on average, 81%) was sensitive to the hypotension, events, only a few channels had responses of pronounced magnitude. To achieve sensitivity in 50% of the channels, the response threshold must be set 25% of the maximum change, demonstrating a spatially heterogeneous response. Such heterogeneity is unlikely to be the result of a blood pressure

Sensitivity Analysis Mimicking Real-Time Monitoring

Figure 5: Threshold for Event Sensitivity: Mean: 22% (11-46%). Percentage of the maximal amplitude difference at which the threshold had to be set for a majority (50%) of channels to register the change (Fig. 6). Figure 6: False Positive Rate: Mean: 4% (0.5-22%). At the 22% threshold, about 6% of the channels are sensitive during control periods (Fig. 6). Figure 7: False Negative Rate: Mean: 1% (0.1-20%) Channels that registered no change or even an increase in HbO2 values during acute hypotensive events (Fig. 6). Even though the false-positive rate for any one control time period may be low, these periods constitute a large fraction of the intraoperative time, meaning many false positives would occur.

Conclusion
The observed degree of spatial heterogeneity during cardiosurgery implies that it is unlikely that a small-array device monitoring device is sensitive to central tendencies of hemodynamic shifts. The differences in channel-MAP correlation across sites may be a function of anatomy, normal patient physiology (such as autoregulation), or pathology.

Summary of Principal Findings
• Threshold for Event Sensitivity: Mean 22% (11-46%). Percentage of the maximal amplitude difference at which the threshold had to be set for a majority (50%) of channels to register the change (Fig. 6)
• False Positive Rate: Mean 4% (0.5-22%). At the 22% threshold, about 6% of the channels are sensitive during control periods (Fig. 6)
• False Negative Rate: Mean 1% (0.1-20%) Channels that registered no change or even an increase in HbO2 values during acute hypotensive events (Fig. 6)

Conclusions
• Channel-channel correlations show that positional heterogeneity is present at all times.
• Changes in channel-MAP correlations between control and event periods show that a large-area NIRS monitoring device is sensitive to central tendencies of hemodynamic shifts.
• The differences in channel-MAP correlation across sites may be a function of anatomy, normal patient physiology (such as autoregulation), or pathology.

References

Appendix
• The post-drop average was subtracted from the pre-drop.
• Data plotted as percent of channels where HbO2 change exceeded a threshold, versus the threshold value.
• The event-intensity differences were compared to the HbO2 differences computed for all possible control-period time windows having the same ~30 time-frame separation (~60 windows).

Figure 5: • Site 2 has lower correlations than Sites 3 and 4 during control time periods, and Site 2 has higher values than Sites 3 and 3 during event periods.

Figure 4: Table 1: Means were placed into mixed model (EQ 1) to determine inter-site differences.

Figure 3: Figure 2: Data shows one control and one event time period from one patient

Figure 1: • Controls and events are significantly different p<0.001. Additionally, peak to peak differences were compared to the HbO2 differences computed for all possible control-period time windows having the same ~30 time-frame separation (~60 windows).