Do Low-density Cerebral Oximetry Measures Accurately Detect Variability of Cerebral Perfusion During Cardiac Surgery?

Sergio A. Ramirez1,2, MD, LeRone Simpson1,2, MD, Harry L. Graber1, PhD, Yong Xu1, PhD, Yaling Pei1, PhD, Douglas Pfeiff1, BS, Vinay Tak1,3, MD, Joshua Burack1,2, MD, Wilson Ko1, MD, Randall L. Barbour1, PhD, and Daniel C. Lee1,3, MD

Introduction

• Cerebral oxygenation and perfusion are important clinical parameters, since hypoxia is the primary cause of neurological injuries [1].

• These parameters may help guide intraoperative monitoring during procedures associated with neurological complications [2,3].

• While stroke and cognitive dysfunction are complications of many surgical procedures, the incidence following cardiac surgery remains highest [4,5]. Consequently, prompt identification of cerebral hypoxia before irreversible injury occurs is paramount.

• Devices currently approved by the Food and Drug Administration (FDA) provide non-invasive monitoring of cerebral oxygen saturation based on low-density configurations of transmitters and sensors [6,7,8].

• Intraoperative cerebral monitoring using cerebral oximetry, coupled with intervention to keep brain oxygen saturation above a fixed threshold, has not significantly reduced the incidence of stroke following cardiac surgery [9].

• Given the heterogeneity of cardiac surgical patients, who commonly present with one or more pre-existing risks (e.g., hypertension, diabetes, cerebral / coronary / peripheral atherosclerotic disease), it is uncertain whether oximetry based on sampling small areas over the frontal lobe is representative of regional cerebral perfusion.

• In this study we have explored whether low-density optical sensor arrays, derived from small subsets of four larger arrays, are able to provide representative measures of the true state of regional cerebral perfusion in patients undergoing cardiac surgery.

Methods

Six heart surgery patients were recruited for this study (Table 1). Optodes were attached to a headgear and arranged in arrays covering 4 sites (Fig. 1).

Optical recordings and a record of surgical supportive events were taken during surgery using a Near-Infrared Spectroscopic (NIRS) imaging system (NIRx DYNOMAP) and examined retrospectively to identify clinically significant events.

Anesthesia monitor (Dräger-Narkomed 6000) was used during surgery to simultaneously measure physiological parameters such as mean systemic arterial and pulmonary arterial pressures.

A global estimate of light-source intensity variability and superficial hemodynamic fluctuations was computed.

Least-squares linear regression was used to subtract the contribution of the global factor from each raw data time series [10]. The normalized difference method [11] was used to recover time series of volumetric images from the pre-processed data (see Fig. 2).

Analysis of hemoglobin (Hb) levels was done using a modified Beer-Lambert law (MBL) [12] algorithm to compute time series of oxy, deoxy and total Hb. Calculation of the HbO2 concentration was carried out for each channel as depicted in Fig. 3. Channels labeled S1-D4 and S4-D1 are a reciprocal pair, with the roles of S and D reversed.

The signals measured contain cerebral and overlying tissue contributions. In contrast, channels S1-D3 and S4-D2 consist largely of signals from overlying tissue. This would appear to allow for selective removal of the superficial-tissue component of the data recorded by the S1-D4 and S4-D1 channels [13].

Correlation coefficients are computed for all pairs of channels having the same S-D separation distance (see Fig. 4).

The superficial-signal corrected time series of HbO2, Hb, HbO2, & Hb, for all channels with S-D separation ≥3 cm, were compared in regard to the magnitudes of the detected Hb concentration changes. A large, relatively abrupt change in Hb level is taken as a function that a clinically significant event is occurring (see Fig. 5a(i)). The overall sensitivity—the percentage of S-D channels that report the clinically significant event—was calculated, as a function of the trigger level (see Fig. 5b(i)).

Table 1. Clinical information for the study participants. Abbreviations: AV = atrio-ventricular, CABG = coronary artery bypass graft, CPB = cardiopulmonary bypass, VF = ventricular fibrillation.

Conclusion

• While subjects were under general anesthesia, their intraoperative cerebral perfusion remained highly heterogenous.

• Minor changes in source-detector pair location result in notably differing signal recordings.

• FDA-approved non-invasive cerebral oximetry devices, based on low-density arrays, are unlikely to yield accurate representation of complex heterogeneous cerebral perfusion.

• In contrast, a tomographic imaging method with a rich array of oximeters would retain the possibility to capture time-varying heterogeneous spatial maps of cerebral perfusion.

References


[8] Norin: www.norin.com/Regional-Oximetry


Acknowledgements

This work was supported under grants no. S5429NS00007-03 and no. 5R44NS049734-03 to Randall L. Barbour; and by the New York State Department of Health.