Invited Paper

Monitoring cerebral tissue oxygen saturation during surgery: a clinician's perspective

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ABSTRACT

Organ protection and physiology optimization are important goals when taking care of anesthetized patients undergoing surgery. Postoperative cognitive dysfunction and perioperative stroke are unwarranted potential outcomes. Neurovascular coupling, the match between cerebral metabolic demand and substrate supply, should be regarded as the essential cerebral physiology which needs to be monitored during surgery. The brain-targeting near-infrared spectroscopy (NIRS) technology has the potential to fulfill this goal. Proposition of why and how to monitor essential cerebral physiology via advanced NIRS technologies is discussed. We also discussed the limits of the current NIRS technologies which merely measure cerebral tissue oxygen saturation in pooled cerebral arterial, capillary, and venous blood.

Keywords: Cerebral tissue oxygen saturation, near-infrared spectroscopy, essential cerebral physiology, neurovascular coupling, organ protection, outcome

1. INTRODUCTION

From 2010 to 2012, we applied frequency-domain near-infrared spectroscopy (FD-NIRS) (Oxiplex TS, ISS Inc., Champaign, IL, USA) in anesthetized surgical patients to investigate the effect of drug-induced change in systemic hemodynamics (blood pressure and cardiac output) and ventilation-induced change in carbon dioxide (CO_2) on cerebral tissue oxygen saturation ($SctO_2$). The data have been reported [1-5]. This manuscript gives us an opportunity to examine the current advantages, limitations and future potential of the brain-targeting NIRS technology.

2. ESSENTIAL PHYSIOLOGY

We showed that FD-NIRS is a robust technology in $SctO_2$ measurement and is sensitive and consistent in detecting $SctO_2$ change caused by a change in systemic hemodynamics or blood CO_2 level. However, multiple factors can leads to a change in $SctO_2$ and therefore difficulty occurs when making a clinical decision merely based on the $SctO_2$ number provided by NIRS. In principle, the goals of anesthesiologists when taking care of an anesthetized patient are as follows: 1) the ability to monitor essential physiology; 2) the ability to optimize the essential physiology based on #1; and 3) the ability to improve outcome based on #1 and #2 combined. Human physiology is a broad scope. What qualifies as an essential physiology needs to be carefully considered because there are so many parameters which can be monitored and generated at the same time; however, the ability of a practitioner to watch and interpret physiological data is limited in the time-sensitive and labor-tense Operating Room. Can the brain-targeting NIRS technology provide information which can be qualified as essential physiology?

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During surgery and especially when the patient undergoes anesthesia, it is crucial to maintain the fine balance between cerebral metabolic demand and substrate supply. This demand-supply match is termed as neurovascular coupling, which is essential in preventing cerebral ischemia and over-perfusion [6,7]. To execute this mechanism, a robust and reactive cerebral vasomotor tone is needed so that vascular constriction and dilation can readily occur to fulfill the adjustment of cerebral blood flow based on the level of neural activity (Figure 1). It is thus intuitive to state that an ideal status of cerebral vasomotor tone is essential in ensuring the integrity of the brain, namely, the match between demand and supply. NIRS technology is targeting essential physiology if it monitors cerebral vasomotor tone and neurovascular coupling (Figure 2). The recent research focusing on the monitoring of cerebral autoregulation (the correlation between cerebral blood flow and cerebral perfusion pressure) using NIRS devices is an encouraging step because the execution of autoregulation relies on a robust and reactive cerebral vasomotor tone.

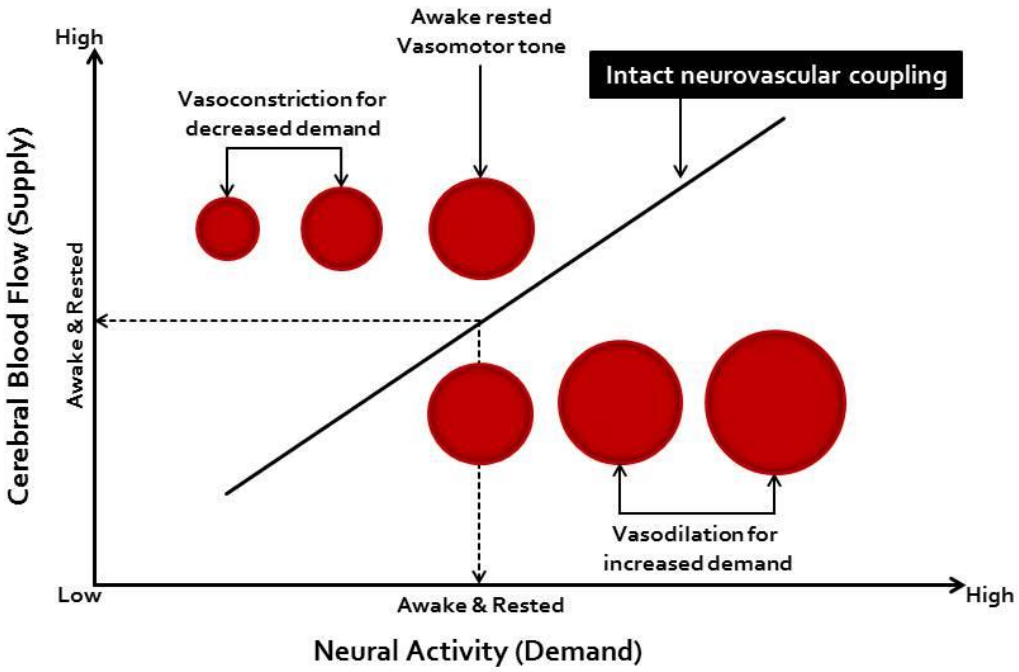

Figure 1. Conceptual illustration of neurovascular coupling. When neural activity (demand, x-axis) increases, cerebral blood flow (supply, y-axis) will increase accordingly as a consequence, and *vice versa*. This mechanism ensures the fine match between cerebral metabolic demand and substrate supply. The consequential change in flow relies on the sensational change in cerebral vasomotor tone, namely, the dilation or constriction of cerebral resistance vessels (red circles). Cerebral resistance vessels are illustrated in three different conditions (awake & rested, constricted, and dilated).

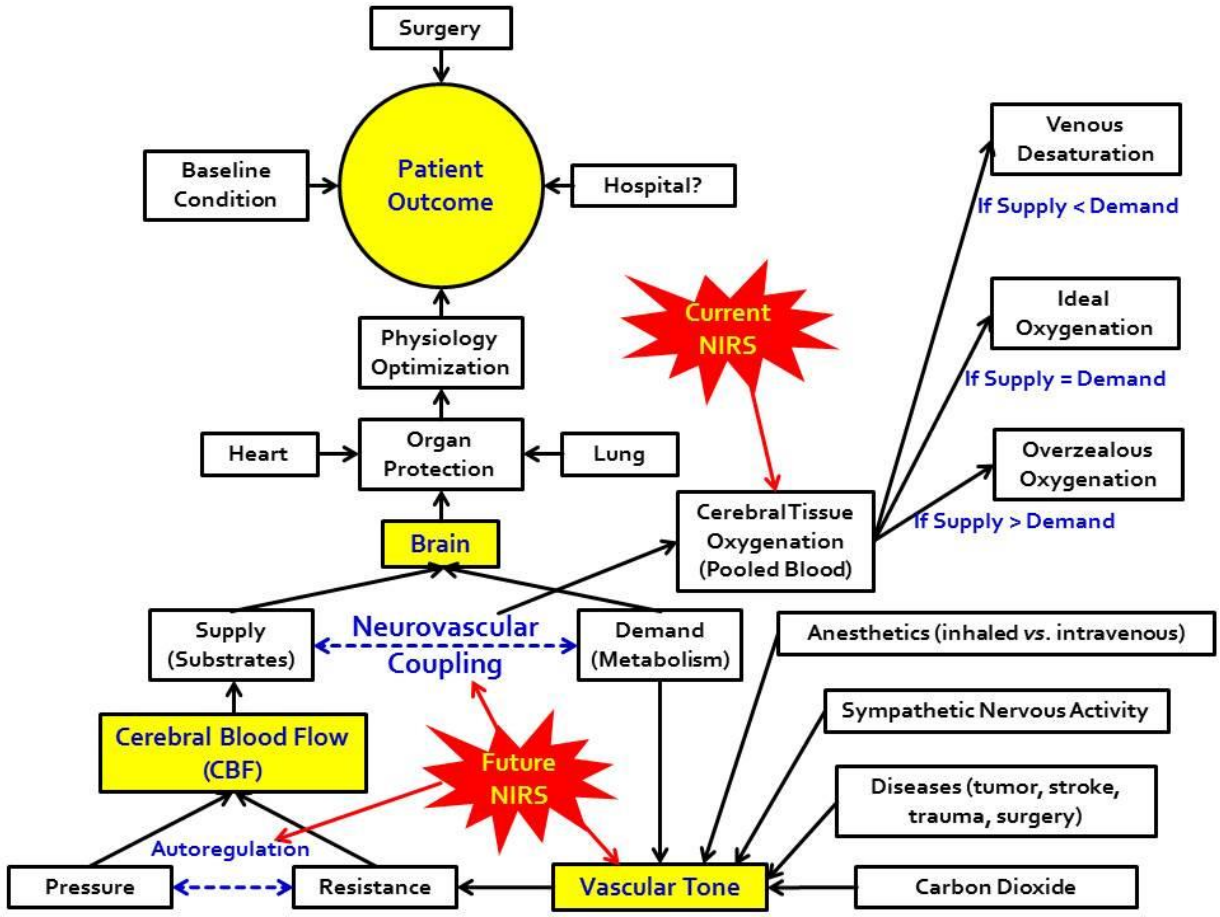

Figure 2. Diagram illustrating relationships between patient outcome, organ protection, neurovascular coupling, cerebral vascular tone, and parameters monitored by near-infrared spectroscopy (NIRS). One of the fundamental goals in taking care of surgical patients is to improve postoperative outcome. Organ protection and physiology optimization are key elements in achieving this goal. The wellbeing of the brain relies on a functional neurovascular coupling mechanism, namely, the match between substrate supply and metabolic demand. Cerebral blood flow (CBF) carries out the supply. CBF is jointly determined by cerebral perfusion pressure and cerebral vascular resistance as a simplified analogy of Ohm's Law. In turn, resistance is determined by cerebral vascular tone. A robust and sensational cerebral vascular tone is the key in the execution of neurovascular coupling [6,7]. In addition to the metabolic demand, cerebral vascular tone is also affected by other factors, including carbon dioxide, various diseases, sympathetic nervous activity, and anesthetics, etc. The future brain-targeting NIRS has the potential to non-invasively and continuously monitor the integrity of neurovascular coupling, the reactivity of cerebral vascular tone, and the functionality of cerebral autoregulation (the relationship between CBF and cerebral perfusion pressure). Currently, NIRS provides cerebral tissue oxygen saturation ($SctO_2$) in pooled arterial, capillary, and venous blood. Cerebral desaturation, a decrease in $SctO_2$, is popularly regarded as a sign of either inadequate oxygen supply or an increase in oxygen consumption, or both. However, whether or not an increase in $SctO_2$ when comparing with the baseline level represents a desirable physiological condition is unclear. Overzealous cerebral tissue oxygenation may be caused by unnecessary cerebral over-perfusion secondary to conditions such as an impaired cerebral autoregulation or an extreme hypertension. The key concepts are yellow-colored in this diagram.

3. MORE PERSPECTIVES

For a better clinical application, some limitations of NIRS technology need to be overcome. First of all, NIRS measures pooled blood; however, the clinically meaningful cerebral desaturation is a venous, not arterial, phenomenon because the systemic arterial blood which perfuses the brain is almost always well saturated if there are no major cardiopulmonary diseases. Thus, the ability to differentiate arterial and venous blood can better fulfill the clinical need. Second, a decrease in $SctO_2$ can be due to an increase in cerebral O_2 consumption, a decrease in cerebral O_2 delivery, or a decreased arterial and/or an increased venous blood contribution to NIRS measurement, alone or in any combination. Thus, the knowledge of the cause of cerebral desaturation can better facilitate the clinical decision making. Unfortunately, this information is not provided by the current NIRS devices. For example, our observation of the decrease in $SctO_2$ secondary to a drug-induced increase in blood pressure may not be due to a decrease in cerebral blood flow [1]. Instead, it may be caused by a decreased arterial blood contribution to NIRS measurement secondary to autoregulation-induced arterial vasoconstriction [3]. If this speculation is true, cerebral desaturation in this scenario will have different physiological (intact cerebral autoregulation) and clinical (no intervention needed) implications.

4. SUMMARY

In summary, the brain-targeting NIRS technology has the potential to monitor the essential physiology related to the match between cerebral metabolic demand and substrate supply in anesthetized surgical patients. The currently adopted parameter, $SctO_2$, has limitations. Studies are warranted to better understand the physiological implications behind the signal. Moreover, technological advancements in NIRS itself are also the key of its successful clinical application in the future.

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