Cerebral saturation and cerebral blood flow in head-injured patients

TO THE EDITOR: We were pleased to learn from the paper by Taussky et al.¹ (Taussky P, O'Neal B, Daugherty WP, et al: Validation of frontal near-infrared spectroscopy as noninvasive bedside monitoring for regional cerebral blood in brain-injured patients. *Neurosurg Focus* 32(2):E2, February 2012) that near-infrared spectroscopy (NIRS) determinations of cerebral saturation bear a tight linear correlation ($p < 0.001$) with cerebral blood flow (CBF) in patients with traumatic brain injury (TBI). The concept that NIRS may serve as a simple and readily accessible surrogate for CBF is clinically important. We therefore read the paper closely and were ultimately surprised and disappointed by their Fig. 1. The line depicting the correlation appears to bear no relation to the data. We reduced the 22 data points to numeric values and performed our own linear correlation. It revealed an essentially horizontal line with an R value of 0.04; that is, there is no significant correlation. In addition, the slope of the line (see our Fig. 1) is very different from that presented by Taussky et al. in their figure. Regrettably, we draw the conclusion that there is no useful correlation between frontal NIRS saturation and CBF in patients with TBI.

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Fig. 1. Graph of linear regression analysis.

Disclosure

The authors report no conflict of interest.

Reference

1. Taussky P, O'Neal B, Daugherty WP, Luke S, Thorpe D, Poolley RA, et al: Validation of frontal near-infrared spectroscopy as noninvasive bedside monitoring for regional cerebral blood in brain-injured patients. *Neurosurg Focus* 32(2):E2, 2012

RESPONSE: With great interest, we reviewed the letter by Drs. Drummond and Patel in which they appear to visually recreate our data set from our Fig. 1 and analyze it via simple linear ordinary least-squares regression, obtaining an R value of 0.04 and concluding that NIRS O₂ and CT perfusion CBF do not correlate linearly. While we are unsure of the exact numbers and methods that they used to obtain their regression, we believe the difference in our analysis is attributable to the fact that we made the assumption of a physiological correlation: if CBF = 0, then NIRS oxygenation = 0. Therefore, our “best-fit” linear regression line goes through the origin ($x = 0, y = 0$).³ This can be seen if one looks at our figure and our regression line trajectory. Best-fit linear regression through the origin (RTO) is not a common regression method but is appropriate on a number of theoretical assumptions—albeit with known mathematical limitations.^{3,4,8}

In our series, we believe that a standard linear regression without comparing against the RTO method of such experimental data may lead to incorrect scientific conclusions, ones that have little physiological interpretation.¹ For example, if there is a significant relationship between x and y that is nonlinear, then the value of R will be smaller than 1.0 or even 0 because of the presence of a potential nonlinear relationship (hyperbolic or U-shaped), which could result in a “nonsignificant” R value. Therefore, the best-fit linear RTO method was, in our opinion, the correct statistical method for analyzing these limited data. Further, the RTO method has been proven useful in analyzing experimental data² and, for the purposes of this study, helped to define the physiological meaning of the data (that is, as CBF approaches 0, NIRS O₂ approaches 0).^{1–4,8} Best-fit forms of linear regression and RTO are also used in the calibration⁵ and interpolation of data. Therefore, we believe a tight linear relationship exists for our assumptions in this best-fit regression analysis as described, although we recognize that there may in fact be a more complex nonlinear⁷ relationship that we cannot prove outside of our limited data set. For example, we could not induce absolute hypoxia-ischemia in human participants to test this physiological extreme, although a similar CBF-NIRS linear relationship has been shown in a piglet model.⁶ Since we did not have enough data to model both linear and nonlinear relationships, we only reported the best-fit linear data as we described, which

we believe best describe the linear “compensated” or balanced CBF supply and demand O_2 state, with the other physiological extremes not being adequately described by our data in humans.

We conclude that while our data from only 8 patients are limited, we screened 1287 patients in our neuroscience intensive care unit to complete our research, which is valid regardless of which method of statistical analysis was used⁴ and is the first of its kind to compare NIRS and CBF in humans in the neuroscience intensive care unit by using the CT perfusion method. Clearly, a larger prospective study is needed to validate and expand this model and to elaborate other important physiological interrelationships, which may have coexistent nonlinear state relationships when tissue is infarcted or is characterized by extreme hypoxia. Future research should focus on the impact of the O_2 extraction fraction, presence or absence of autoregulation, “metabolic coupling” of brain temperature and cerebral metabolic consumption of O_2 , systemic partial pressure of O_2 on arterial blood gas samples, digit-obtained NIRS pulse oximetry, which we did not compare in our preliminary study. We strongly believe that NIRS shows great potential as a noninvasive, continuous bedside monitoring device; however, the extent to which it truly correlates with CBF will only be shown by future, larger studies.

Finally, in their letter, Drs. Drummond and Patel refer to our study population as patients with TBI, which is not correct. Our patients included those with aneurysmal subarachnoid hemorrhage, ischemic stroke, or intraparenchymal hemorrhage with edema who were brain injured but not traumatically so.

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