OVER the last decade, scores of different algorithms have been proposed which extract some number from the raw electroencephalogram purporting to estimate some sort of “depth of anesthesia”—and more specifically—whether the patient is conscious or not. All of these algorithms seem to be correct approximately 65 to 85% of the time. In this issue of Anesthesiology, Schneider et al. propose yet another index. However, they have introduced some significant points of difference which presage a new approach to the problems of estimating effect of anesthesia, and hence the ability of the anesthesiologist to deliver the correct dose and combination of anesthetic drugs to the patient.

There are a number of novel concepts in this work. First, they emphasize that the changes in the electroencephalogram (and level of consciousness) should not be estimated in isolation, but rather estimated in the context of all the other information and events that occur during the operation. This other information might include preexisting demographic data, anesthetic drug delivery, the presence or absence of surgical stimulation, and cardiovascular stability. For example, a patient with an electroencephalogram dominated by slow delta waves, but with only 2% end-tidal desflurane and no surgical stimulation, is not in the same state as another patient with the same electroencephalogram but with a 7% end-tidal desflurane concentration and undergoing the manipulation of a fractured long-bone. The first patient is in a state of sedation, perhaps analogous to natural slow wave sleep, whereas the second patient is in a true state of general anesthesia.

The second concept is that all this other nonelectroencephalographic information should then be integrated into a single overall “gestalt” of the patient’s situation at any point in time. To achieve this, the authors apply fuzzy logic analysis methods. The possible advantage of these approaches is that the monitor is evaluating the input data in a manner that is a bit closer to how a human would evaluate information. It accepts that there are some data ranges where there is uncertainty in allocating the patient to some binary classification (such as conscious or unconscious states). Also, the monitoring algorithm includes some redundancy, so that it can continue to function properly even when some of the input data are missing. The results of this article do suggest that the inclusion of the electroencephalographic indices on top of the standard cardiovascularly based measures of anesthetic delivery significantly improved the evaluation of the level of consciousness. This is a hint that the inclusion of suitable electroencephalographic indices adds useful information that might improve the clinical care of patients. The unanswered, but critical, question arises: “Is it better to combine the different electroencephalogram and cardiovascular indices at the level of the machine, or is it better to present the different indices independently to the clinician—who then secondarily combines this information in her/his head?” Arguments in favor of the machine processing are: a more quantitative analysis; less bias; ceaseless vigilance; and the minimization of sensory overload on the anesthesiologist. Conversely, the weaknesses of the approach in Schneider’s article are that: the science of machine learning is still at a relatively elementary level; they probably do not include all the relevant inputs; and there is a very reasonable distrust of any “black box” involved in the process of patient monitoring.

Another important component of their experimental design is that, in addition to discriminating around the point of loss of responsiveness, they also included a section of their experimental protocol which involved giving high

No Monitor Is an Island

Depth of Anesthesia Involves the Whole Patient

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concentrations of hypnotic drugs to the patients, and so inducing a period of deep anesthesia. One of the problems with existing monitors is that they cannot reliably indicate whether the patient is close to the edge of regaining consciousness or whether the anesthesiologist has given sufficient hypnotic drug to ensure that there is a buffer zone, that is, the patient is safely distant from the point of wakening. It would appear from figure 3 in Schneider’s article that, unlike the bispectral index,\(^2\) the new index—the anesthesia multimodal index of consciousness—does not show a plateau in the dose–response curve after the point of loss of consciousness.

The results also seem to be relatively generalizable to clinical practice, as the investigators gathered data from many centers and used 10 different hypnotic drug regimens for the general anesthesia. The main proviso is that the conclusions probably do not apply to nitrous oxide– or ketamine-based general anesthesia. This is because the electroencephalographic measures in this article rely on the extraction of information from a single frontal channel. Recently, we have witnessed something of a renaissance in our understanding of the neuronal mechanisms underlying the phenomenon of consciousness.\(^5\) It has been suggested that the final common pathway of loss of consciousness for all groups of anesthetic drugs lies in a loss of connectivity between parietal and frontal regions of the brain.\(^4\) Thus, we are moving beyond the older heuristically derived measures of electroencephalogram slowing, as typified by the bispectral index and spectral entropy monitors, to a new generation of indices (such as symbolic transfer entropy\(^4\) and perturbational complexity index\(^2\)) which attempt to quantify the loss of long-range spatiotemporal complexity that occurs with unresponsiveness. We do not know whether there exists any analysis of the electroencephalographic waveform, derived from a single frontal channel, which could actually reliably correlate with these changes in spatial correlations; but the saturation of the delta wave amplitude is one possible candidate that has been linked to anesthetic mechanisms, as revealed by neuroimaging.\(^6\) Another arena of keen interest that is not directly addressed in this article is the development of measures of nociceptive blockade and hence some sort of guide for intraoperative opioid administration.\(^7\) Whether the cardiovascular component of the anesthesia multimodal index of consciousness is useful in this respect is not mentioned in the current article.

The “depth of anesthesia” monitor of the future must surely incorporate a convergence of all three of these streams of development—namely the ability to integrate the electroencephalogram with other exogenous information; the application of techniques derived from scientifically validated understanding of the mechanisms of consciousness; and some index of nociceptive blockade.

Competing Interests

The author is not supported by, nor maintains any financial interest in, any commercial activity that may be associated with the topic of this article.

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