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Editorial Views

EEGs, EEG Processing, and the Bispectral Index

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MOST anesthesiologists are familiar with basic electroencephalography; they have at least heard of delta, theta, alpha, and beta frequency ranges, terms such as "burst suppression," and such. Most have been introduced—if only at a medical meeting, at a lecture, or in a journal article—to some form of computerized encephalogram processing and display technology. However, very few anesthesiologists understand the science and engineering that underlie the recording and processing of the EEG. This is unfortunate because anesthesiologists have played a leading role in the development of techniques that are now used throughout medicine. It is therefore appropriate that we publish the extensive review of EEG signal processing that appears in this month's issue. [\[1\]](#)

The impetus for the development of "processed EEG" systems can be summarized as "time and simplicity" or, alternatively, as "workload management." Standard EEG machines are not well suited to the operating room. They generate huge amounts of paper (a machine running at 25 mm/s creates a 270-meter strip of paper for a 3-hr case) that make it very difficult to observe trends; an event that occurred only a few minutes ago is now buried many pages deep in the paper stack. The complex waves of the raw EEG also are not interpreted easily—certainly not in the hectic setting of the operating room. Hence, methods were developed to compress, simplify, and display various "processed" summaries of the EEG. Such processing devices are used primarily to detect cerebral ischemia (e.g., during carotid surgery) or to guide drug administration (e.g., barbiturate protection during aneurysm surgery, as part of the care of patients with intracranial hypertension or refractory seizures in the intensive care unit, among others). Most available EEG processing devices perform these tasks well. Unfortunately, the "Holy Grail" of perioperative EEG monitoring, reliable

assessment of the "depth of anesthesia," has eluded us. An experienced electroencephalographer can make qualitative assessments of depth by looking for patterns in the raw EEG. However, an electroencephalographer cannot describe depth in quantitative terms ("well, he is a bit deeper than he was a few minutes ago, but not as deep as just after he went to sleep") and can discuss trends in only a vague fashion. Many parameters derived from the processed EEG (e.g., spectral edge frequency [SEF], total power, among others) vary predictably within a particular patient receiving a single drug or from patient-to-patient during relatively narrow portions of the continuum between awake and deeply asleep. If a particular case is long enough, the system and the patient can be "calibrated" by looking for reproducible responses to drugs or stimuli. Similarly, predictable changes occur with some single-agent infusions (particularly opioids) that allow accurate prediction of blood concentrations. However, after decades of work, we have been unable to reliably define identifiable patterns that tell us whether a patient is "unconscious" or "unaware," will react to an incision (either with movement or autonomic changes), or is about to awaken.

This situation may have changed with the introduction of a new approach to intraoperative EEG processing. I am referring to the device manufactured by Aspect Medical Systems and one parameter calculated and displayed by this device: the "bispectral index" or BIS. The unit is a relatively standard one- or two-channel EEG signal acquisition, processing, and display device. One can view the analogue EEG, along more "traditional" processed displays, including the "compressed spectral array" (CSA) and the "density spectral array" (DSA), and the SEF (for details about these parameters, please see Rampil et al. [\[1\]](#)). As such, it is little different from other commercial devices or from EEG signal analyzers that can be set up on any computer using available software (e.g., LabView, MacLab, among others). However the Aspect device also displays a single BIS value that is claimed to be a measure of the depth of anesthesia. Because of the history of work in this field, this represents an extraordinary statement.

With this background, a few words are in order regarding the origins of Dr. Rampil's article, [\[1\]](#) particularly the part dealing with the BIS. Several years ago, as articles evaluating the BIS started to appear, reviewers, and readers began complaining that it was inappropriate to publish articles describing the use of a "black box," for which the fundamental method of operation was a trade secret. Four electrodes were placed on a patient's head, and a BIS value appeared on a screen. In the awake patient, the BIS display says 96. Thiopental is administered and the BIS drops to 43. These values have no units or any evident physiologic meaning and cannot be recreated by an independent investigator-unless that investigator has the Aspect device. Does a value of 45 mean that there is "half as much BIS" as when the machine displays a value of 90? What is a BIS? Where does this number come from? What is the box doing? The answer was not found in literature readily understandable by most anesthesiologists.

Because the device is available commercially, it is appropriate to publish studies that evaluate its performance. At the same time, the nagging concerns about "how does it work?" remained. Hence, I contacted Dr. Rampil, a member of the Associate Editorial Board and

one of the foremost experts in EEG signal processing. I asked him to write a state-of-the-art review about the entire field of EEG signal acquisition and processing and to specifically put the BIS into this broader context. I also spoke with representatives of Aspect Medical Systems and indicated that I thought it imperative that they make public more information regarding the operation of the device; they agreed. Readers should know that Dr. Rampil has served as a consultant to Aspect Medical Systems and that Aspect provided him with specific information needed to write the article. They even helped to create some of the figures. Some may view this as being a serious conflict of interest or as violating the independence of the Journal. I disagree, and I believe the article serves a greater good by providing the interested reader with information that would not be available otherwise. In addition, Dr. Rampil has not evaluated the performance of the Aspect unit, restricting himself to a discussion of "how it works," rather than "how well it works."

From where does the BIS come? What are its "advantages" (with respect to assessing depth of anesthesia) over previous EEG descriptors? And why are the workings of this device "proprietary?" To start, let us examine why more "traditional" descriptors of the EEG (such as the SEF) fail to measure depth reliably. In simple terms, the problem is that the EEG does not change in a linear or monotonic fashion with changing anesthetic depth, nor do all anesthetic agents produce similar EEG patterns. For example, total EEG power or SEF may increase during very light anesthesia and then decrease until burst suppression occurs, at which point many calculation methods fail or display a paradoxical increase. It is possible to have identical values of the SEF at widely different points on the continuum between awake and deeply anesthetized or at different points with different agents. This observation is true of every single-parameter measure derived from the "power spectrum" of the EEG (SEF, total power, frequency-band ratios, and others).

The BIS is derived quite differently. Rather than producing and tracking a single descriptor of the EEG, the EEG monitoring unit calculates several different descriptors. As described in the article, these are the "BetaRatio," the "SynchFastSlow," and a measure of burst suppression (a combination of "burst suppression ratio" and "QUAZI"). None of these descriptors are particularly remarkable per se. However, Aspect then collected EEG recordings from thousands of patients undergoing anesthesia with multiple different anesthetic regimens. They also collected clinical information related to anesthetic depth, such as whether patients responded to spoken commands or recalled auditory cues presented via headphones or whether heart rate or blood pressure increased with incision, among others. These recordings were then processed, and a database or library was created of the EEG descriptors and the corresponding clinical states. The descriptors were then ranked by the ability to predict a particular clinical situation, and a statistical analysis was performed to construct combinations of the descriptors that would best correlate with the clinical condition. This statistically based, empirically derived use of combinations of descriptors-rather than a single descriptor-is the key to the working of the device. One way to conceptualize the process is as follows. Let us refer to the different parameters already mentioned simply as X, Y and Z. The master database indicates that, for example, the typical awake patient has an X value of 50, a Y value of 10, and a Z value of 0. Because we want a BIS

of 100, by definition, to represent an awake state, we "define" the combination of 50/10/0 to be equal to 100. In the future, any time the machine "sees" a data set of 50/10/0, it displays a BIS equal to 100. A sedative drug is then administered, and the processors yield values of 40/18/0. The master database indicates that this combination of values typically is associated with, for example, the loss of response to verbal commands. Someone decides that this state is 20% of the way between awake and deeply asleep—so let us call this a BIS equal to 80. This empiric, reiterative process of calculating the three parameters, of comparing them to the database, and of assigning a BIS value is continued across the entire spectrum between awake and deeply asleep. The BIS numbers themselves are selected to create a linear scale between the two extremes.

Obviously, the summary described is a gross oversimplification. Nevertheless, it is important to understand that there is no simple mathematic relationship between the parameters that "add up" to the BIS. A skilled engineer could build some variation of the processors that reside within the Aspect unit (or might even build a device that calculated 3, 4, or 5 parameters totally different from the ones used by Aspect). However, without the EEG library and its behavioral and functional correlates, the processors will yield nothing of value. Conversely, anyone willing to spend the time, the effort, and the money to collect, analyze, and correlate this information can construct a device that might perform as well as or better than the BIS.

Similar to Dr. Rampil, I want to avoid a discussion of how well the BIS works. A large body of literature exists, and new articles are appearing daily. Anesthesiologists are purchasing the Aspect device and will judge for themselves whether the system provides useful information. The purpose of the article in this month's issue is to provide readers with an understanding of EEG signal processing, including the BIS. Such understanding should be a part of our assessment of any new technology.

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