European Journal of Anaesthesiology 2001, **18**, 785–788

EDITORIAL

Noninvasive bioelectrical neuromonitoring in anaesthesia and critical care

In the past few years we have learned more about the brain in context with anaesthesia than ever before. But the most complex organ of all continues to hold immense mysteries. Shedding light on these will be crucial for monitoring purposes and for preventing, diagnosing and treating neurological and mental illnesses. Neuromonitoring is a discipline with enormous potential and should be an essential part of modern anaesthesia and critical care [1].

Compressed spectral array (CSA) is one of the bioelectrical methods often used today. From the raw electroencephalogram (EEG) it is possible to calculate an EEG power spectrum using fast Fourier analysis. If this is performed repeatedly CSA is obtained. From the EEG power spectrum calculation of different parameters such as the peak frequency (or peak-power frequency), the frequency at the centre of gravity, the mean dominant frequency or the well-known SMF (mean power frequency) can be performed. Last but not least, there is the important spectral edge frequency (SEF) parameter. SEF90 is the frequency below which 90% of the power in the spectrum resides. We would like to point out that a single feature such as mean power frequency or spectral edge frequency may not be sensitive to all possible changes in spectral distribution. However, there is no evidence, at present, suggesting that additional parameters describing a complex spectrum improve the clinical utility of simple univariate parameters. Different manufacturers define different spectral edge frequencies, for example SEF90 or SEF95. But even if the SEFs are defined at exactly the same level, the same bioelectrical signal can lead to different results. The reason for this is that we have to take into account the different technical parameters, such as the upper and especially the lower cut-off frequency. A comparison of the different SEFs in the literature is therefore not possible, if different systems are used.

The number of publications on the topic of noninvasive neuromonitoring has increased exponentially (Fig. 1). Note the number of papers published on the bispectral index (BIS), an EEG parameter used to monitor the depth of anesthesia. Results similar to those in Fig. 1 are produced by the Internet search engine ISI Web of Science®. Of 1674 178 listed documents in the years 2000 and 2001, 37 matched the term 'neuromonitoring' and 136 the term 'bispectral index'.

Multivariate statistical methods were used to combine different EEG features into an easy-to-use number called BIS, which ranges from 100 – indicating that the patient is awake – to zero, indicating a total lack of brain activity [2]. At induction of anaesthesia the BIS falls rapidly from an awake value (80–100) to below 40. Tracheal intubation and skin incision result in an increase in BIS. Bispectral analysis originally had nothing to do with anaesthesia. Bispectral analysis is a mathematical procedure used for describing ocean waves. This was described by Hasselman and his colleagues in 1963 [3]. Like almost all technical developments, this one was first used in the military area for the analysis of sonar and radar signals in military tracking systems. One of the first clinical uses of bispectral analysis was mentioned by Barnett and colleagues in 1971 [4]. His group used the bispectral analysis of EEG signals during waking and sleep. This brings us quite close to anaesthesia in terms of topic. In 1991, Kearse and colleagues published a contribution in *Anesthesiology* entitled 'Bispectral analysis may predict anesthetic depth during narcotic induction' [5]. As a consequence, multicentre studies such of that of Peter Sebel in 1997 were published [6].

The bispectrum is calculated in a two-dimensional space of frequency$_1$ (f_1) vs. frequency$_2$ (f_2). A strong relationship between f_1 and f_2 creates a large bispectral value represented as a vertical spike rising out of the frequency vs. frequency plane [2]. The calculation of the BIS begins with sampled EEG that is filtered to exclude high and low frequency artefacts such as ECG

https://doi.org/10.1046/j.1365-2346.2001.01028.x Published online by Cambridge University Press

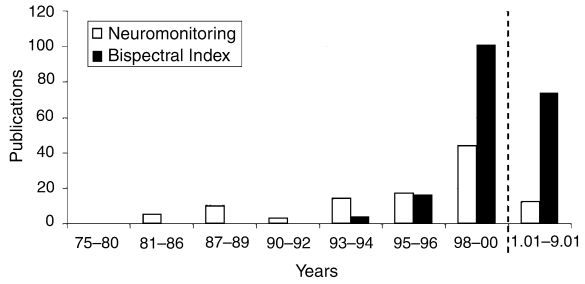

Fig. 1. Numbers of scientific publications from January 1975 to September 2001. Source: MEDLINE; Search: 'Neuromonitoring' and 'Bispectral Index'.

or pacer spikes, eye blink events or a wandering baseline (low frequency electrode noise). A burst suppression detection algorithm is also implemented. Then the fast Fourier transformation and the bispectrum of the current EEG epoch are calculated. The resulting spectrum and bispectrum are smoothed using a running average. Then subparameters such as the 'beta ratio' are computed. The resulting BIS is defined as a proprietary combination of these quantitative EEG subparameters. The BIS should decrease continuously with a decreasing level of consciousness. Although there is currently no theoretical or mechanistic link proposed between neural network physiology in cerebral cortex and the intrafrequency coupling notion of the BIS, the empirical correlation appears to exist. But there are also limitations. Ketamine [7], nitrous oxide [8] and a wide spectrum of opioid doses [9] are not reflected adequately by BIS in correlation with drug concentration and/or clinical response. Inhalation of isoflurane or sevoflurane in increasing concentrations may also result in paradoxical BIS readings [10].

Hall and Lockwood from the Royal Postgraduate Medical School, Hammersmith Hospital, in London compared BIS values from fronto-central and bifrontal montages [11]. BIS values derived from each montage were found to differ in an unpredictable manner. The bifrontal montage is easy to apply but is not comparable to a fronto-central montage. They concluded that the BIS may be useful for following trends in anaesthetic depth in individual cases but that it is less helpful when making comparisons between patients or as single value.

Now that we have briefly listed some of the advantages and disadvantages of the BIS parameter, let us take a quick look at one of the company's marketing strategies. This is aimed at moving away from the native EEG and placing more emphasis on the calculated value. This can be seen both in the headlines and on the monitor of the appliance. The latter is the best example because the digital value for the BIS can be found there in an overdimensional format. The trend of this value is then displayed in a smaller format and at the top right of the monitor, the all-important native EEG is displayed in such a small format that it can hardly be recognized. In addition to this, a 1-channel version is being offered replacing the extremely useful 4-channel version. This development should be opposed at all costs. It goes without saying that the anaesthetist will not routinely work with 32 or 64 EEG channels, but a single EEG channel means a major loss of information and does not even allow the comparison of bioelectrical activity of both

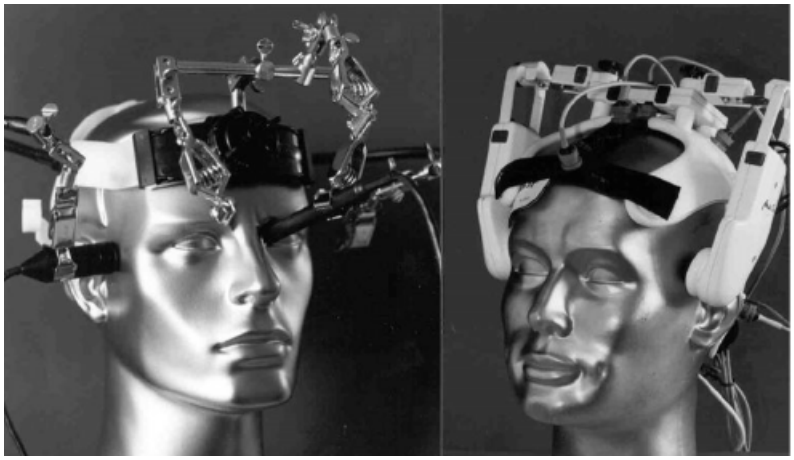

Fig. 2. Multifunctional constructions for noninvasive neuromonitoring (University of Graz, Austria).

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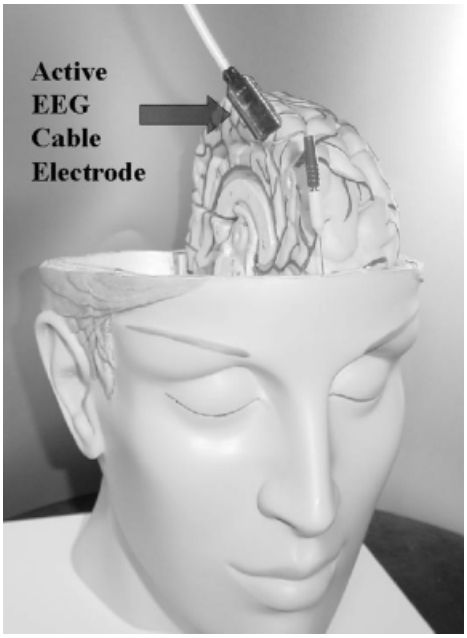

Fig. 3. Active EEG-cable electrodes (University of Graz, Austria). Supported by the Jubiläumsfonds der Oesterreichischen Nationalbank (Project 8134).

hemispheres. This is a step backward in patient monitoring and cannot be justified.

The spectrum of new neuromonitoring modalities in the critical care setting extends beyond recordings of brain waves and brainstem potentials of a few millionths of a volt. Robotic ultrasound probes that can detect very small changes in blood flows in the brain are used with colour-coded three-dimensional technology. The potential and the problems of near infra-red spectroscopy are being studied intensively (Fig. 2) [1].

A European Union study has shown that more than 2 million people in Europe sustain severe head injuries every year, most often in traffic accidents. We also need better ways to monitor cerebral function and the depth of anaesthesia, which is increasingly difficult to determine with muscular paralysis and combined anaesthesia techniques [12].

Innovation is the key to progress in neuromonitoring. Revolutionary advances in basic neuroscience together with improvements in electrophysiological recording techniques – for example to amplify electrical activity directly on the surface of the scalp – is essential for monitoring bioelectrical brain function (Fig. 3) [13–17].

The recording and processing of brain-specific signals is a fast moving science. New areas of noninvasive monitoring include computer-assisted EEG or evoked potential recordings, transcranial Doppler sonography, near infra-red spectroscopy, and investigating metabolic and clinical parameters of cerebral function. These are being pursued by both scientists and clinicians regularly confronted with neuromonitoring. Integrated active cable electrodes are a new development for EEG recordings. The whole EEG amplifier is integrated in a cable so that a preamplifier box is no longer required (Fig. 3). Active electrodes are an expensive solution to the problem of interference in the EEG, and in many cases their use may be unnecessary. But where the data must be obtained under conditions of high ambient electrical noise, such as in an intensive care unit or electrically noisy operating rooms, active electrodes improve the quality of the EEG recordings markedly.

Neuromonitoring requires continuous education. Quality should be the priority. Specific education, for example neuromonitoring workshops as well as interactive, computer-assisted seminars with multimedia training provide a solid knowledge base [18]. A continuing increase in the need for neuromonitoring and that 'neuromonitoring expert' will be a hot job in the 21st Century could be predicted.

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