BJA

British Journal of Anaesthesia 2015, i27–i31

doi: 10.1093/bja/aev212
Review Article

REVIEW ARTICLE

Changes in the electroencephalogram during anaesthesia and their physiological basis†

S. Hagihira*

Department of Anesthesiology and Intensive Care Medicine, Osaka University Graduate School of Medicine, 2-2 Yamadaoka, Suita City, Osaka 565-0871, Japan

*E-mail: hagihira@anes.med.osaka-u.ac-jp

Abstract

The use of EEG monitors to assess the level of hypnosis during anaesthesia has become widespread. Anaesthetists, however, do not usually observe the raw EEG data: they generally pay attention only to the Bispectral Index (BIS™) and other indices calculated by EEG monitors. This abstracted information only partially characterizes EEG features. To properly appreciate the availability and reliability of EEG-derived indices, it is necessary to understand how raw EEG changes during anaesthesia. With hemi-frontal lead EEGs obtained under volatile anaesthesia or propofol anaesthesia, the dominant EEG frequency decreases and the amplitude increases with increasing concentrations of anaesthetic. Looking more closely, the EEG changes are more complicated. At surgical concentrations of anaesthesia, spindle waves (alpha range) become dominant. At deeper levels, this activity decreases, and theta and delta waves predominate. At even deeper levels, EEG waveform changes into a burst and suppression pattern, and finally becomes flat. EEG waveforms vary in the presence of noxious stimuli (surgical skin incision), which is not always reflected in BIS™, or other processed EEG indices. Spindle waves are adequately sensitive, however, to noxious stimuli: under surgical anaesthesia they disappear when noxious stimuli are applied, and reappear when adequate analgesia is obtained. To prevent awareness during anaesthesia, I speculate that the most effective strategy is to administer anaesthetic agents in such a way as to maintain anaesthesia at a level where spindle waves predominate.

Key words: electroencephalogram; reticulate nuclei of thalamus; spindle; thalamus

Editor's key points

- Anaesthetists commonly use processed electroencephalographic data to guide anaesthesia, but the raw EEG can be more informative.
- The raw EEG changes in a characteristic dose-dependent manner for both volatile and i.v. anaesthetics, probably as a result of enhanced inhibitory effects.
- Processed EEG indices such as BIS™ are not as sensitive to noxious stimuli as the raw EEG; use of the raw EEG is a more sensitive way to monitor anaesthesia during surgery.

During the past few decades, EEG monitors, such as the BIS™ monitor (Covidien, Boulder, CO USA), have become widely used. These devices calculate proprietary indices that purportedly show levels of hypnosis as numerical values. Most anaesthetists normally pay attention only to the indices and rarely take interest in the raw EEG. While it is true that EEG indices are convenient to use, they reveal only some aspects of raw EEG. Indeed, raw EEG, presenting richly complete data, initially seem more difficult to interpret. It is easy, however, to observe dramatic changes in the raw EEG as the administered concentration of anaesthetic increases.[1] While raw EEG patterns are anaesthetic-specific, concentration-related changes in EEG waveforms are quite similar

† This Article is accompanied by Editorial Aev223.

Accepted: May 15, 2015

among different agents that potentiate gamma-aminobutyric acid type-A ($GABA_A$) receptors. After just one or two weeks training, it seems likely that most anaesthetists should be able to reliably judge the effects of anaesthetic by observing raw EEG. In fact, Barnard and colleagues[1] have reported that most anaesthetists in their study were able to differentiate EEGs from anaesthetized and conscious states after only a short educational presentation. Furthermore, Bottros and colleagues[2] have reported that anaesthetists, after brief structured education and with access to data from a frontal EEG and relevant clinical data, can make accurate estimates of the processed bispectral index (BIS™).

Many factors, such as noxious stimuli, hypercapnoea, hypocapnoea, and hypothermia, also affect changes in raw EEG waveforms. Among these, noxious stimuli are quite important during surgery, so the influence of noxious stimuli on the EEG waveform is discussed.

If anaesthetists have knowledge of changes in the raw EEG during anaesthesia, it could help them judge the adequacy of EEG indices and enable them to respond more rapidly and confidently in circumstances where equipment algorithms provide misleading indications. EEG waveforms usually depend on electrode position. Here, I describe EEG changes and their neurophysiological background obtained using from hemi-frontal leads such as FP_1–A_1 or FP_z–At_1, which are commonly used in EEG-based anaesthesia monitors.

Changes in the raw electroencephalogram during anaesthesia

Isoflurane, sevoflurane, thiopental, and propofol produce anaesthesia in part by potentiating inhibitory $GABA_A$ receptors.[3] Although each of these agents has its own characteristic EEG waveform, these waveforms undergo similar changes as the concentration of administered anaesthetic increases. Figure 1 shows raw EEG waveforms during isoflurane anaesthesia. During light anaesthesia, amplitude is shallow and frequency is high. When a higher concentration is administered, amplitude deepens and EEG frequency slows. During deep anaesthesia, a 'burst and suppression' pattern becomes apparent, characterized by extreme activity, represented by high-frequency, large-amplitude waves (bursts), alternating with flat traces (suppression). This pattern, excluding brain ischaemia or other factors, indicates that anaesthesia is too deep. Beyond this, flat traces become dominant and, eventually waveforms are no longer apparent. During isoflurane, sevoflurane or propofol anaesthesia, this sequence of changes in pattern is almost identical. The major difference in EEG between the volatile agents (isoflurane or sevoflurane) and propofol is apparent in power in the theta range. During propofol anaesthesia, theta power remains low regardless of concentration, but during isoflurane or sevoflurane anaesthesia, it increases at surgical concentrations of anaesthesia.

It is well known that alpha oscillation (around 10 Hz) are often observed when a person is awake with eyes closed. Such alpha oscillation is mostly observed in occipital regions.[4] On the other hand, alpha rhythms observed during anaesthesia or natural sleep are mostly observed in the frontal region. This alpha rhythm shift is referred to as anteriorization of the alpha rhythm, and is common during isoflurane, sevoflurane or propofol anaesthesia.[5] Usually, anteriorization of the alpha rhythm predominates when anaesthesia is adequate for surgery, and is not clearly apparent just after loss of responsiveness. For example, Blain-Moraes and colleagues[6] have reported that sevoflurane did not result in consistent anteriorization of the alpha rhythm at around 0.8%, which was sufficient for loss of consciousness.

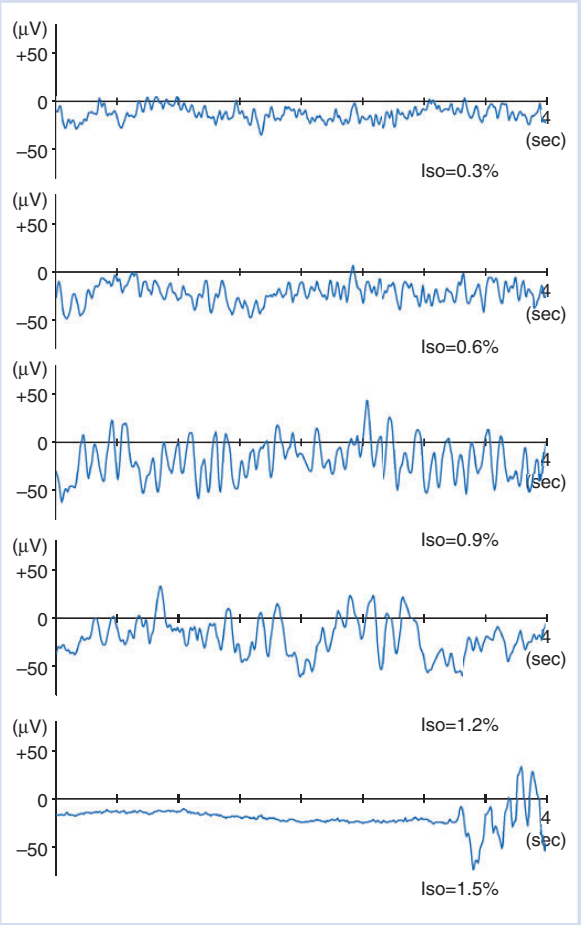

Fig 1 EEG waveform (4 s duration) during 0.3, 0.6, 0.9, 1.2, and 1.5% isoflurane anaesthesia in a 55-year-old ovarian tumor patient undergoing resection.

Changes of electroencephalogram-derived parameters during anaesthesia

To clarify anaesthesia-related changes in EEG, it is necessary to consider how EEG data is analysed and presented by monitoring devices. Several analytic methods have been applied to construct EEG indices or EEG parameters. For example, time domain analysis is used for detection of suppression or calculation of amplitude and to provide burst suppression ratio (BSR) information. Power spectral analysis is the most commonly used tool, and is applied to calculate several parameters including spectral edge frequency (SEF), median frequency (MF), and relative β ratio (RBR). Spectral entropies are also calculated from power spectrum data. Bispectral analysis, the core technology of the BIS™ monitor, quantifies phase relations between the frequency components of EEG signals, and supplies SynchFastSlow (SFS) information.[7] Bispectral analysis will be discussed later in greater detail. It should be noted that BSR, RBR, and SFS results are used as sub-parameters for BIS calculation.[7]

Generally speaking, as isoflurane is administered in greater concentrations, EEG amplitude increases and SEF95 decreases. In other words, the EEG waveform changes from fast wave, small amplitude to slow wave, large amplitude. But this is just a broad view: Figure 2 shows power spectrum changes during isoflurane anaesthesia. At isoflurane 0.3%, frequency is in the beta