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Automatic detection and analysis of the EEG Sharp Wave–Slow Wave patterns evoked by fluorinated inhalation anesthetics

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HIGHLIGHTS

- Epileptiform patterns that possess both "Sharp Wave" and "Slow Wave" components (SWSW patterns) appear during volatile anesthesia in anesthetic concentration- and anesthetic type-dependent way.
- The novelty of the proposed method of automatic detection of epileptiform patterns during anesthesia consists in the analysis of morphology of individual SWSW patterns and not, as it was the case so far, on the quantification of 5s EEG segments containing monophasic activity and/or spikes.
- The on-line analysis of SWSW patterns' rate and morphology offered by the proposed method is important in view of possible side effects of volatile anesthetics.

ABSTRACT

Objective: The aim of this study was to develop a method for the automatic detection of Sharp Wave–Slow Wave (SWSW) patterns evoked in EEG by volatile anesthetics and to identify the patterns' characteristics.
Methods: The proposed method consisted in the *k*-NN classification with a reference set obtained using expert knowledge, the morphology of the EEG patterns and the condition for their synchronization. The decision rules were constructed and evaluated using 24 h EEG records in ten patients.
Results: The sensitivity, specificity and selectivity of the method were 0.88 ± 0.10, 0.81 ± 0.13 and 0.42 ± 0.16, respectively. SWSW patterns' recruitment was strictly dependent on anesthetic concentration. SWSW patterns evoked by different types of anesthetics expressed different characteristics.
Conclusions: Synchronization criterion and adequately selected morphological features of "slow wave" were sufficient to achieve the high sensitivity and specificity of the method.
Significance: The monitoring of SWSW patterns is important in view of possible side effects of volatile anesthetics. The analysis of SWSW patterns' recruitment and morphology could be helpful in the diagnosis of the anesthesia effects on the CNS.

1. Introduction

Numerous studies have showed that despite the obvious advantages of using fluorinated inhalation anesthetics such as isoflurane, sevoflurane or desflurane in clinical practice, these anesthetics may result in the appearance of the EEG patterns, characteristic of epileptic discharges (e.g. spike-slow wave or Sharp Wave–Slow Wave patterns) as well as physical epileptic symptoms such as convulsions (Woodforth et al., 1997; Yli-Hankala et al., 1999; Jantti and Yli-Hankala, 2000; Vakkuri et al., 2001; Schultz et al., 2001; Sato et al., 2002; Olejarczyk et al., 2009b, 2010). EEG monitoring during anesthesia could provide objective information on the functional state of the brain and appearance of some side effects associated with the administration of a particular anesthetic agent. Moreover, it could result in safer induction of anesthesia by providing an early warning of upcoming undesirable events. Nevertheless EEG monitoring is not considered obligatory in current anesthesia practice. This problem has been considered by several authors (e.g. Chinzei et al., 2004; Sarkela et al., 2007; Sonkajarvi et al. 2009).

The focus of this study is the detection and quantitative description of the EEG patterns frequently observed at some stages of anesthesia that possess some features in common with

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epileptiform discharges, such as the repeatability of sharp component (or "spike") and slow components (e.g. "slow wave"). For the purpose of this study, these particular patterns will be referred to as Sharp Wave–Slow Wave (SWSW) patterns.

Attempts to automate the detection of a definite, epileptiform-like EEG pattern already have a long history. Wilson and Emerson have reviewed and compared various methods for the detection of sharp transients described in the years 1975–2002 (e.g. Wilson and Emerson, 2002). They stressed that automatic detection and analysis of the frequency of transient occurrence as well as their topology and morphology may be important in the diagnosis of epilepsy. The methods that were described have used various techniques of data analysis, from template matching to learning algorithms with 5–275 features (e.g. Ubeyli, 2008; Aarabi et al., 2007, 2009; Nonclercq et al., 2009; Larsson et al., 2009; Halford 2009; Hermann et al. 2010). They offered a sensitivity ranging from 15% to 97%. Some of the methods were based on morphological features of spikes (Gotman and Gloor, 1976; Gotman and Wang, 1991, 1992; Gotman et al., 1979). None of the mentioned methods considered synchronous appearance of the signals at a few derivations as a selection criterion.

The vast majority of methods developed to detect epileptiforms was constructed for the applications in the analysis of signals obtained in patients with epilepsy. Analysis of EEG recorded during anesthesia is a harder task due to a larger variability of patterns' features that vary with anesthetic concentration.

In the method presented here we took advantage of an expert knowledge, we also considered morphology of the EEG patterns and their synchronization to create a reference set, composed of two subsets – one containing the patterns labeled by an expert and the another one containing remaining patterns that appeared synchronously at least at two channels and had similar morphological features. The reference set constructed in this way was then used to construct the *k*-NN classifier and perform classification of the patterns. Our results indicate that the automatic method of SWSW patterns' detection allows for evaluation of how the patterns' recruitment and characteristics depend on anesthetic's type as well as on concentration's level. It can therefore provide a useful tool to improve surgical planning and patient outcome. Preliminary results were published in the conference proceedings (Olejarczyk et al., 2008; Olejarczyk et al., 2009a).

2. Materials and methods

2.1. Anesthetic procedure

The study population included ten adult patients undergoing orthopedic surgery (total knee arthroplasty) under general and regional anesthesia in the Department of Anesthesiology, Intensive Therapy and Emergency Medicine at the Medical University of Silesia in Katowice, Poland. The mean age of the patients was 65.9 ± 4.3 years. Four patients were anesthetized with isoflurane (Aerrane, Baxter), three with desflurane (Suprane, Baxter) and three with sevoflurane (Sevorane, Abbott). All patients were classified as class I (normal, healthy patients) and class II (patients with mild systemic disease) according to American Society of Anesthesiologists (ASAs) Physical Status Classification System, with no prior neurological deficit. Individuals with a history of allergic reactions to the drugs used in this study, with epilepsy and with other previously diagnosed neurological deficits and/or psychiatric disorders, receiving neuropsychiatric medication or addicted to any psychoactive substances were excluded from the study. Neurological deficits were excluded by examining the patient's medical history and conducting the preliminary EEG recording. The study was approved by the Ethical Committee of the Medical University of Silesia, and written informed consent was obtained from all of the patients involved.

To avoid the influence of opioids and N_2O on the central nervous system, an epidural catheter was placed in the lumbar part of the vertebral column to obtain adequate analgesia via the introduction of 0.5% bupivacaine in saline solution. General anesthesia was induced either intravenously (IV) with propofol 2–2.5 mg/kg and vecuronium (Norcuron, Organon) 0.08–0.10 mg/kg or with the VIMA (Volatile Induction and Maintenance of Anesthesia) technique, which was performed with sevoflurane in a single patient. After laryngeal mask (LMA Supreme, LMA) insertion, the lungs were ventilated to obtain normoventilation (35–37 mm Hg of end-tidal CO_2), and anesthesia was maintained by a mixture of oxygen and air containing isoflurane, desflurane or sevoflurane. The low-flow anesthesia technique was used, with the flow of fresh gas set between 0.5 and 1.0 l/min. After the IV induction was performed, the EEG recording was started after a waiting period of 30 min sufficient to eliminate the effect of the intravenously administered propofol. The concentration of the anesthetic agent was increased gradually by 0.2 MAC (Minimal Alveolar Concentration) until a burst suppression pattern appeared in the EEG signal or to maximal level of 2 MAC and then decreased by 0.2 MAC until the end of surgery and removal of the laryngeal mask. During volatile induction, the anesthetic concentration was increased rapidly and, during the maintenance of anesthesia, decreased in the manner described above.

2.2. EEG recording

The EEG was recorded in ten patients using the S/5 Compact Anesthesia Care Monitor (GE Healthcare) with the S/5 ™ EEG Module (Datex-Ohmeda, Finland). The EEG signal was registered with sampling frequency of 100 Hz per channel and filtered with a band-pass filter from 0.5 to 30 Hz. Since the S/5 ™ EEG Module permits to register EEG signals from only four channels, the following EEG derivations: F3C3, F4C4, P3O1 and P4O2 were used to monitor the activities of the left–right hemisphere and the front-back cerebral regions.

A control EEG recording was performed before the induction of anesthesia. The duration of data sets recorded from the individual patients during the anesthesia ranged from 112 to 195 min. A standard procedure of EEG recordings involves recordings of clinical comments concerning seizure, muscle tremor, etc. In studied cases non of such events was observed.

2.3. Automatic method of SWSW patterns' identification

The method was constructed using knowledge of the neurophysiologist who indicated 1s long fragments of EEG signal (by expert indicated windows (EIWs), see dark vertical bars, Fig. 1), each of which contained at least one Slow Wave-Sharp Wave (SWSW) pattern satisfying the following criteria:

(1) Each pattern had two components: a "sharp wave" and a following "slow wave". The "sharp wave" started with the signal rapidly increasing and then rapidly decreasing (see evolution of the signal between *a*, *b* and *c*, Fig. 2). Thereafter, in the first part of the "slow wave", the signal again rapidly increased, then slowly decreased until crossing zero, which was considered as the end of "slow wave" (see evolution of the signal between *c*, *d* and *e*, Fig. 2).

(2) "Slow wave" was clearly distinguishable from background, of the amplitude, at least twice as large as the mean amplitude of the background.