USEFULNESS OF BRAIN SIGNALS FOR THE DETECTION OF LOSS OF CONSCIOUSNESS IN ANESTHESIA
Overview of the Problem and Results from a Clinical Study

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Keywords: General anesthesia, Loss of Consciousness detection, Bispectral index.

Abstract: Loss of consciousness (LOC) detection is essential for better anesthesia guidance. Clinical signs and brain monitoring are currently used in operating rooms to assess the state of consciousness. However, a patient-independent, accurate and reliable indicator of LOC is not currently available. We studied 69 patients undergoing general anesthesia, investigating a possible relationship between loss of consciousness and BIS and EMG signals registered during induction. Neither BIS and EMG values at LOC, nor their abrupt fall proved to be good indicators of loss of consciousness. Further work needs to be done in order to reliably detect loss of consciousness.

1 INTRODUCTION

Hypnosis, analgesia and muscular blockade are the three components of general anesthesia. From all three, hypnosis is the most important; it is a pharmacologically induced sleep state, a reversible state of unconsciousness (Bonhomme and Hans, 2004).

Loss of consciousness (LOC) detection has an important role at induction of anesthesia. Identifying the precise moment when it occurs will determine the hypnotic dosage required for each individual patient and provide important information to help avoiding awareness episodes and overdoses. Furthermore, detecting LOC is the first step in the development of fully automated anesthesia delivery systems based on the conscious state of the patients.

In this work, we investigated how the Bispectral index (BIS), the most widely used anaesthesia monitor of consciousness, reflects loss of consciousness during induction of anesthesia. It has been shown that BIS values at the moment of LOC can vary widely (Tesniere et al., 2003). We examined not only BIS values at LOC, but also the abrupt fall that occurs in the BIS and electromyography (EMG) signals during the transition from the conscious state (awake) to unconsciousness ("sleep") at induction of anesthesia.

This paper is organized as follows: in section 2 a short review of LOC detection methods is presented; section 3 includes our clinical study and conclusions are pointed out in section 4.

González C., Mendes M., Amorim P., Mendes J. and Nunes C. (2009).
USEFULNESS OF BRAIN SIGNALS FOR THE DETECTION OF LOSS OF CONSCIOUSNESS IN ANESTHESIA - Overview of the Problem and Results from a Clinical Study.
In *Proceedings of the International Conference on Bio-inspired Systems and Signal Processing*, pages 311-315
DOI: 10.5220/0001546403110315

2 SHORT REVIEW

Since the early days of anesthesia, several clinical signs have been used for LOC assessment, such as pupil diameter, sweat or tears production, heart rate and muscular tone (Strickland and Drummond, 2001). Nowadays, in the clinical setting, LOC is usually identified as the moment when the patient looses the eyelash reflex or stops responding to specific commands (proper name calling or tapping in the forehead) or stimuli (pressing a button every time they see a red light), which are very imprecise and dependent on patient's collaboration. These methods have several disadvantages: assessment of lack of response to name calling and mechanical stimulus require the patient to be frequently stimulated, so anesthesia induction cannot be smooth and quiet; also any method based on a voluntary act by the patient often fails because patients loose critical judgement before losing consciousness.

In the last two decades, brain monitoring techniques have been developed to assess the hypnotic state of the patients. They were designed to reflect real-time electrical activity of brain cells but were not specifically created for LOC detection. In clinical practice, they are used in combination with clinical signs to provide as much information as possible about the level of consciousness of the patients.

Among all the developed indices, the Bispectral Index (BIS) (Kelley, 2003) is the most well-known and broadly used. It processes electrical activity (electroencephalographic signal, EEG) detected in the forehead by means of electrodes and shows a value, from 0 to 100, which indicates the level of hypnosis: 0 is associated to absence of electrical activity and 100 corresponds to the awake state. The BIS system uses a proprietary algorithm, based on bispectral analysis, which performs amplification, digitalisation and signal processing of EEG in order to obtain the above mentioned index.

The BIS signal and the electromyopraphy of the frontal muscle, produced spontaneously and also acquired with the BIS unit, were the subject of a clinical study presented in this paper, where their relationship with the exact moment of LOC was also analyzed.

3 CLINICAL STUDY

3.1 Patients and Methods

Adult patients scheduled for neurosurgical procedures were studied during induction of general anesthesia. Patients were monitored according to the American Society of Anesthesiologists (ASA) standards. BIS was also monitored in all patients. A XP-Quattro sensor was applied to the forehead and ASPECT A2000 or VISTA monitors were used. BIS and EMG were recorded every 5 seconds using Rugloop software. Anesthesia was induced with Remifentanil (an opioid analgesic) and Propofol (an hypnotic) administered intra-venously by Target Controlled Infusion (TCI) using Rugloop software and Asena pumps. During induction, LOC was determined as the moment when patients failed to open their eyes following name calling and a tap on the forehead at every 15 seconds. The moment of LOC was recorded for every patient.

BIS and EMG values collected during induction were analyzed, as well as the moment of LOC. In order to find another possible indicator of consciousness on the BIS and EMG signals, the moment when a significant fall in BIS and EMG values occurred was assessed. Both signals were processed using Matlab®. First, a moving average filter of 11 samples was applied to the acquired signals aiming to smooth them, and afterwards its first derivative was analyzed. The minimum derivative value corresponds to the abrupt fall observed in the signals.

Once the falls were detected, we defined two new variables: the difference of time between LOC clinical detection and the moment when the falls in BIS and EMG occurred (δ_{BIS} and δ_{EMG} respectively).

3.2 Results

We studied 69 patients of both genders; age was 51.5±14.7 years, height was 164.1±9.9 cm and weight was 69.7±13.3 kg. The patients underwent cranial or spinal surgeries.

BIS at LOC was 69,52±15,86 and EMG at LOC was 42,04±7,60 dB (table 1). Typical tracings for BIS and EMG trends during induction are shown in figure 1.

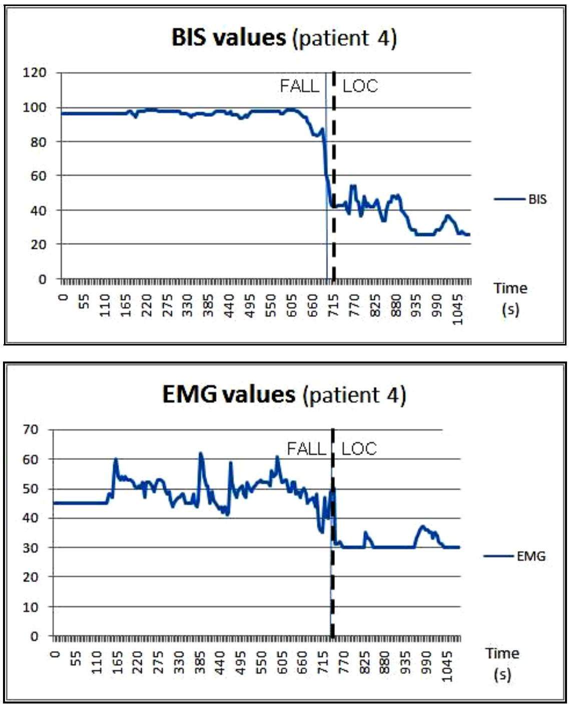

Figure 1: Example of BIS and EMG trends during induction. The moment of LOC (dashed line) and of the abrupt fall (straight line) are also indicated.

Table 1: Obtained values for EMG and BIS at LOC, and for the difference of time between the moment of LOC and the detected falls.

	Mean	Standard Deviation
BIS	69.52	15.86
EMG (dB)	42.04	7.60
δ_{BIS} (s)	-0.79	34.45
δ_{EMG} (s)	4.47	25.9

The difference of time between LOC clinical detection and the moment when the falls occurred was -0,79±34,45 seconds for BIS and 4,47±25,9 seconds for EMG (see table1). The fall detection failed in 4 cases with BIS (5,7%) and 12 with EMG (17,39%) because no abrupt fall clearly associated with LOC existed in those cases (figure 2). The statistical distribution of both variables is shown in figure 3.

No significant correlation was found between the new variables (δ_{BIS} and δ_{EMG}) and patient data, such as age, sex, body mass index and the amount of hypnotic administered until LOC. However, a significant relationship was found between the values of BIS at LOC and the difference of time between LOC and BIS fall's detection (figure 4).

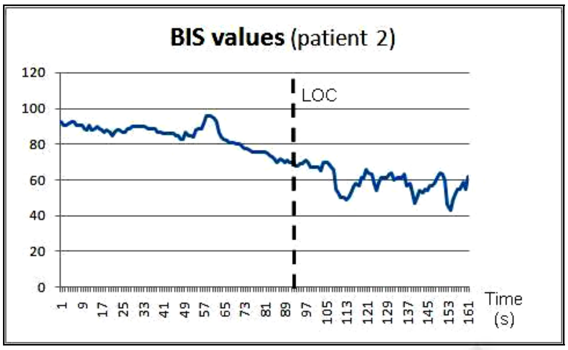

Figure 2: BIS trend during induction and moment of LOC in patient number 2: an abrupt fall in BIS cannot be clearly identified.

Using a regression linear model, as shown in figure 4, we confirmed the existence of a relationship, with a *P* significance value lower than 10^{-8}. No similar conclusion was obtained for EMG signals and their abrupt fall.

3.3 Discussion

Some authors have previously reported BIS values at the moment of LOC: BIS values in the transition from consciousness to unconsciousness were: 78±14 (mean±standard deviation) (Tesniere, Billard, 2003); 82±10 (Kreuer et al., 2004) ; 73±18 (White et al., 2006). Not only the BIS values at LOC were quite different, but also a high standard deviation was observed. Our results also show a high standard deviation. This can be due to an existing inter-subject variability or to a lack of ability of BIS to reflect LOC. We investigated the possibility that patients' characteristics could influence BIS or EMG performance to detect LOC, however, the fact none of the demographic patient data showed significant relationship with values at LOC suggests that BIS or EMG do not perform well in this setting. Therefore, it seems that there is not a BIS or EMG value associated to loss of consciousness.

The values obtained for the difference of time between the moment of LOC and the abrupt fall in BIS and EMG signals also show a very high standard deviation. Again, this can be due to inter-subject variability. Furthermore, precise fall detection in EMG signals failed in 17,39% of the cases. Our finding that high values of BIS at LOC correspond to negative δ values (LOC detection occurs before the abrupt fall) and low values are associated to positive δ values (LOC detection occurs after the abrupt fall), although interesting, has no clinical application for the real time detection of LOC using data derived from the BIS signal.

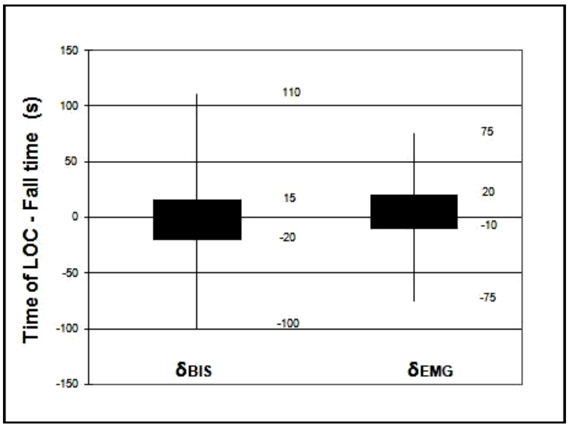

Figure 3: Boxplot of the difference of time between LOC and the BIS fall, and LOC and the EMG fall. For each variable, values for maximum, third quartile, first quartile and minimum are shown.

4 CONCLUSIONS

The BIS index provides useful information about hypnotic state, but not about LOC detection; transition from consciousness to unconsciousness cannot be identified by the index value. We can detect the moment when an abrupt fall in BIS (and EMG) in most patients occurs, but it is usually different from the moment of LOC. Our results suggest that neither BIS nor EMG derivatives can be used to determine the moment of LOC with precision. Clinical signs are not ideal for LOC detection. Clinical assessment of LOC is not accurate, consistent or precise: different criteria turn up into different LOC detections, and clinical signs are not continuously checked.

We can conclude from this study that BIS index does not reflect LOC: the index value does not have any direct relation with the transition from consciousness to unconsciousness, and the BIS fall can only be identified using future values, so it is not a useful tool in real-time scenarios and has no clinical use to guide anesthesia induction.

No existing technique can detect the moment of LOC with precision and without interfering with a smooth induction or independently of patient's cooperation. We can approximately know when LOC occurs, but small errors in its identification can turn into over or under doses that can have deleterious effects for patients undergoing general anesthesia.

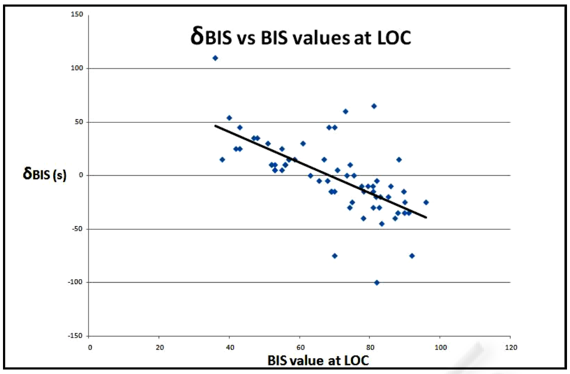

Figure 4: Linear regression model for the difference of the time between LOC and BIS fall and BIS values at LOC (significance $P < 10^{-8}$).

More precision in LOC detection is also an important step for automated anesthesia delivery systems. The closed-loop systems developed until now are controlled by the index value (e.g. BIS), and the majority of them can only be used during anesthesia maintenance (Liu et al., 2007). A proper LOC detection would allow the development of closed-loop systems able to deal with inter-subject variability and to be used also during induction.

Further work should be done in this area in order to find a reliable, objective and rigorous method of LOC detection for both improving patient safety and new automated anesthesia delivery systems.

ACKNOWLEDGEMENTS

This work was supported by Fundação para a Ciência e Tecnologia (FCT), as being part of the project PTDC/EEA-ACR/75454/2006.

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