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EXPERIMENTAL TECHNIQUES TO MEASURE HYPNOTIC LEVELS DURING SURGERY

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Abstract

The administration of anesthetics during a surgical procedure has been done historically in a manual way with the anesthesiologist deciding what amounts and at what rates to use. Over the last few decades there has been a rapid increase in the automation of many medical areas including anesthesiology, with that increased level of automation have also appeared new ways to measure the level of sedation in patients. Historically, one of the most frequently index used has been the BIS, which has proven rather reliable as an indicator. More recently, another index called PSI has attracted interest of practitioners. In this article a comparison of these two indexes was performed. Data recording BIS and PSI values from surgical operations for several patients were collected and analyzed. The results seem to indicate that it is to be expected that in 95% of the cases the correlation between the BIS and PSI index will be at least 0.6866.

Keywords: propofol, anesthesia, control, monitoring. hypnosis.

1 INTRODUCTION

An essential part of any surgical procedure is monitoring the level of sedation in patients. This monitoring has been traditionally done manually by the anesthesiologist. Over the last few decades technology has developed quickly allowing nowadays for an increased level in automation in the monitoring system (Bibian 2001, 2003) [1], [2]. While these automation techniques are very promising it is critical to ensure that they operate in a reliable and robust way.

There are three major components to take into account when analyzing the anesthetic process (Mendez 20015) [11]:

1) Hypnosis
2) Analgesia
3) Muscular relaxation

This paper focuses on the monitoring of the hypnotic component. The most common index to monitor hypnotic state is the Bispectral Index (BIS), obtained from the EEG signal (Mayo 1950) [9], (Masseri 2011) [10], (Zikov 2002) [10]. However, new alternatives are arising to BIS. This work analyses one of this alternatives, the Patient State Index (PSI). The aim is to evaluate its performance to be used as a reliable measure in a closed-loop control system.

The paper begins with describing the basics concepts of anesthesia monitoring. Then, the methods used in the study are presented. In the next section the main results derived from this study is exposed. The paper ends with a summary of the main conclusions.

2 MONITORING ANESTHESIA

2.1 THE BISPECTRAL INDEX (BIS)

Hypnosis refers to the degree of consciousness during the intervention. Analgesia refers to the level of pain perceived by the patient. One of the issues facing faced in anesthesiology is that the level of hypnosis cannot be measured directly. A way of going around this problem is finding indirect measures to quantify the level of sedation. This is done in practice by using techniques such as bispectral electroencephalographic (EEG) techniques (Coppens 2011) [4], (Martin 2013) [8], (Morley 2000)

[12], (Soehle 2008) [12]. These are typically non-invasive techniques that rely on electrodes placed in the head (no surgery required). These electrodes are able to detect the electrical signals generated by the brain, which have been shown to correlate well with the level of hypnosis of a patient. In this topic there is ample literature. For instance, (Twite 2005) [19] funded that “BIS monitor may be a valid and useful monitor of the level of sedation of children”. An index (BIS) is created with the signal obtained. This index range is from 0 to 100 with the 100 level representing fully awake person while a 0 level representing no signal received. A typical BIS level for a patient undergoing surgery is in the 40 to 60 range. The traditional process of sedation during surgery starts with the administration of a relatively large amount of anesthetic, such as propofol (Goudra 2014) [7], 9 (Rigouzzo 2010) [13],(Shangguan 2006) [14], (Schnider 1998) [16], (Schutter 2000) [17], (Schwilden 1989) [18], that brings the patient down from a high BIS level (awake) to a lower BIS level, typically in the 40 to 60 range (sedated). After this initial stage the amount of anesthetic administered to the patient is decreased to just the necessary level to keep the patient within the sedation range. This ongoing monitoring continues until all the surgical procedures are done. When the surgeon has finished all the required procedures the administration of the anesthetic stops and the patient recovers gradually consciousness.

There are multiple chemical compounds with anesthetic applications. As previously mentioned, propofol (2,6-diisopropylphenol) is a frequently used intravenous anesthetic for surgical procedures. It is sometimes referred by its commercial name Diprivan. Its chemical formula is [(CH3)2CH]2C6H3OH and its anesthetic effect is due to its interaction with the receptor GABAA. According to some studies, the concentration level of propofol in plasma correlates well with the level of sedation of the patient (Florez 2008) [8]. Propofol was the anesthetic used in all the patients in this study.

2.2 THE PATIENT STATE INDEX (PSI)

Besides BIS there are other commercially available approaches to obtain the level of sedation of a patient. For instance, a SEDline electroencephalograph tool can be used to generate a patient state index (PSI), which is also believed to relate to the degree of sedation. This is a relatively new technique. One of the obvious questions to answer when analyzing a new technology is comparing its results with the results from the existing technology and hence a comparison between the BIS and PSI index was performed in this article. Some articles have used simultaneously the BIS and PSI index. For instance, (Chawla 2009) [3] analyzed terminal patients at the “end of life care protocol” and found a transitory spike using both, the BIS and PSI indexes.

The PSI approach has some benefits compared to PSI. For instance, the PSI sensor gives bilateral information, something that the BIS sensor is not designed to do. Also, the PSI system has lower costs than the BIS.

3 METHODS

BIS and PSI time data series for 15 patients that underwent surgery at the Hospital Universitario de Canarias were collected. The patients had different types of surgeries and they were all sedated using propofol. To control the analgesic state of the patient, remifentanil was administered continuously during the surgery. No changes in the initial infusion dose of remifentanil is applied unless necessary due to patients in the patient state. To achieve neuromuscular blockade, rucuronium id administered at the beginning of the surgery. Induction is reached with a manual bolus of propofol. After induction, the continuous infusion of propofol is started.

The PSI measurement was recorded using a BIS Vista monitor from the company Aspect Medical Systems. For the PSI signal SEDline monitor was used. The PSI and BIS equipment were both connected to the same computer and the internal clock of that computer was used as the reference to synchronize the signals. The frequency of the data for the BIS and PSI signals was not identical. The equipment generated PSI data every second and BSI data every 5 seconds. The data was synchronized using 5 second intervals.

Figure 1. Surgical setting (Mendez 2016)

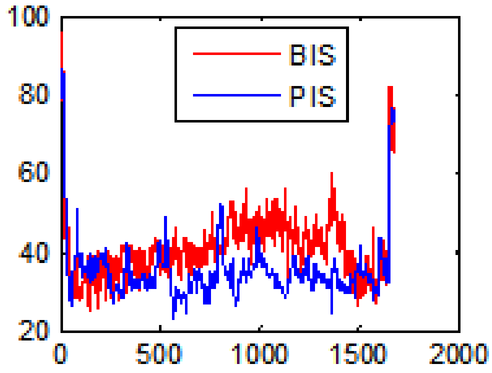

Figure 2. BIS vs PSI signal for a patient

Of the 15 patients 12 were men. The age range from the patients was from 27 to 74 and the weight range was from 60 kg to 115 kg. There were no enough data (only 3 female patients) to determine if gender had an impact on the correlation results between the BIS and the PSI signals. The average of the mean for all the patients (BIS –PIS) was 7.482.

Table 1. Patients characteristics

Patients	
Men	12
Women	3
Max weight	115 kg
Mean weight	82 kg
Min weight	60 kg
Max age	74
Mean age	60
Min age	27

4 RESULTS

A correlation analysis between the two signals (BIS and PSI) for all patients was performed. The correlation analysis was done in Matlab. The histogram for the correlations is shown in figure 2. Another approach followed was to subtract the PSI signal for the BIS signal (figure 3).

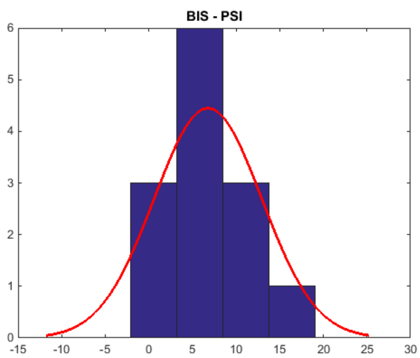

Figure 2. Correlations for BIS vs PIS (15 patients)

A Lillie test was performed at a 5% significance level to determine if the correlation data follows a normal distribution. At that significance level the hypothesis that the correlation data follow a normal distribution cannot be rejected. Given that the data, according to the Lillie test, follows a normal distribution it is relatively straightforward to build a confidence interval for the value of the mean. The confidence interval, at a 5% significance level, is [0.6866, 0.8337]. Table 4 summarizes the statistical results of the signal analysis.

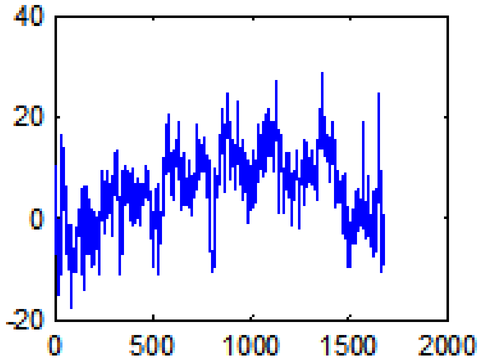

Figure 3. BIS – PSI signal for a patient

4.2 LAGS BETWEEN THE SIGNALS

A sample cross correlation analysis was performed to determine if there were lags between the signals (see figure 4). All the calculations were performed in Matlab. The results indicate that in 13 out of the 15 cases there were no lag issues between the BIS and PSI signals. Lag issues can arise from synchronization issues between the data from the two equipments (mitigated by using the clock in the same computer) and by lags intrinsic to the equipment and process itself.

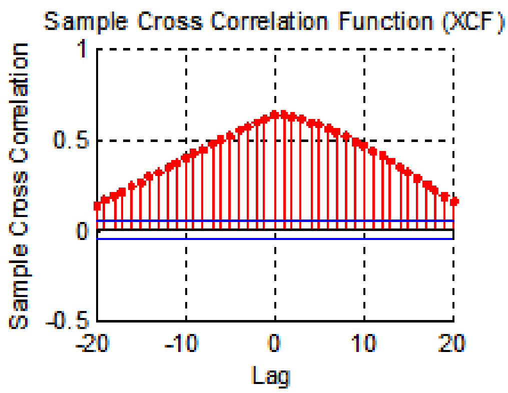

Figure 4. Lag analysis for a patient

Table 4. BIS-PSI correlation data for individual patients

Patient	Correlation of BIS & PSI	(BIS – PSI) Mean	(BIS – PSI) STD
1	0.6362	5.7145	7.7145
2	0.5000	11.2791	7.3000
3	0.6092	-1.3073	13.2893
4	0.7226	6.9638	7.6023
5	0.7188	19.0468	8.4341
6	0.7315	-2.1080	13.1384
7	0.6951	7.4352	11.2507
8	0.8617	3.3973	9.6542
9	0.9022	-1.2865	6.9696
10	0.5481	12.8667	17.0017
11	0.9617	6.3997	8.0195
12	0.8952	8.0446	8.0163
13	0.7985	10.7215	6.8475
14	0.8914	12.4909	6.6526
15	0.9303	12.5773	6.1637
Average	0.7602	7.4824	

5 CONCLUSIONS

The results indicates that, for the patients analyzed, there is some relationship between the BIS and PSI time series. On average, in 95% of the cases the correlation will be at least 0.6866 (the confidence interval at a 5% significance level is from 0.6866 to 0.8337). The time series created by subtracting the PSI from the BSI had a mean statistically different from zero at a 5% significance (with the confidence level from 4.4389 to 10.5259) perhaps indicating that there could be some calibrating differences between the two indexes.

The importance of this study is also related to its application to the design of a closed-loop control system to control the level of unconsciousness of the patient using Patient State Index as a feedback variable. Most of existing closed-loop approaches are based in BIS signal and although they have demonstrated good performance, this new index can also be included and the exhaustive information provided by the monitor can potentially improve the existing proposals.

Future work

One of the limitations of this article is that it analysis only 15 patients. It would be interesting to repeat the analysis in the future with a larger data pool and check the consistency of the results.

Acknowledgements

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References

1. Bibian St, Ries Craig, Huzmezan Mihai, Dumont Guy. 2003. Clinical anesthesia and control engineering: terminology, concepts and issues. European control conference.
2. Bibian S, Zikov T. 2001. Estimation of the anesthetic depth using wavelet analysis of electroencephalogram. Engineering in medicine and biology (IEE).
3. Chawla LS, Akst S, Junker C, Jacobs B, Seneff MG. 2009. Surges of electroencephalogram activity at the time of death: a case series. US National library of medicine national institutes of health
4. Coppens Marc, Eleveld Douglas, Proost Johannes.2011. An evaluation of using pharmacokinetic models to estimate pharmacodynamic parameters for propofol and bispectral index in children. The American society of anesthesiology. 115:83-93.
5. Florez Jesus, Armijo juan Antonio, Mediavilla Africa. 2008. Pag 572-573. Farmacologia humana. Quinta edicion. Elsevier Mandon

6. Gandhi M, Aweeka F. 2004. Sex differences in pharmacokinetics and pharmakidynamics. Annual review of pharmacology and toxicity.
7. Goudra B, Singh P, Samuel A, Cifuentes E. 2014. Prospective Comparison of Patient State Index (PSI) Between Propofol Sedation and Intravenous Conscious Sedation During Colonoscopy. American Society of Anesthesiologists
8. Martin-Mateos, Mendez JA.2013. Modeling propofol pharmacodynamics using BIS-guided anesthesia. Anaesthesia, 68,1132-1140
9. Mayo, Faulconer. 1950. Electroencephalographically controlled anesthesia in abdominal surgery. Journal of the American Medicla Association.
10. Masseri-Noori, McIvor D, Hsu F. 2011. Prospective comparison of global electroencephalogram to frontal Sedline electroencephalogram monitoring for the evaluation of intraoperative burst suppression during elective intracranial surgery. Proceedings of the 2011 annual meeting of the American Society of Anesthesiologists
11. Mendez Juan, Marrero Ayoze, Reboso Jose, Leaon Ana. May 2015. Adaptive fuzzy predictive controller for anesthesia delivery. Control engineering practice 46 (2016) 1-9
12. Morley D, Mainland P. 2000. Closed loop control of anesthesia: as assessment of bispectral index as the target control.
13. Rigouzzo Agnes, Servin Frederique, Constant Isabelle. 2010. Pharmacokinetic-Pharmacodynamic modeling of propofol in children.The American society of anesthesiology. 113: 343-52.
14. Shangguan W, Lian Q. 2006. Pharmacokinetics of a single bolus of propofol in Chinese children of different ages.
15. Soehle Martin, Ellerkman Richard, Gruge Matthias. 2008. Comparison between bispectral index and patient state index as measures of the electroencephalographic effects of sevoflurane
16. Schnider T, Minto CF. 1998. The influence of method of administration and covariates on the pharmacokinetics of propofol in adult volunteers,
17. Schutter J. 2000. Population pharmacokinetics of propofol for target-controlled infusion in the elderly.
18. Schwilden H, Stoeckel H. 1989. Close loop feedback control of propofol anesthesia by quantitative EEG analysis in humas, British Journal of Anesthesia.
19. Twite, Zuck J, Gralla J, Friessen RH. 2005. Correlation of the bispectral index monitor with the comfort scale in the pediatric intensive care unit. Pediatrical Critical Care Medicine; 6(6): 648-53
20 Zikov T. 2002. Monitoring the anesthetic-induced unconsciousness (hypnosis) using wavelet analysis of the electroencephalogram. The University of British Columbia.