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MIDDLE LATENCY AUDUTORY EVOKED RESPONSE FOR MONITORING DEPTH OF ANESTHESIA USING FUZZY LOGIC SYSTEM

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ABSTRACT

The depth of anesthesia is generally considered adequate if the patient neither moves in response to surgical stimulus nor shows any signs of autonomic reflexes. So the measuring of depth of anesthesia is very important because it helps the anesthetist to monitor the anesthetic state of the patient from the start of giving the anesthetic drugs up to the patient awareness and helps him to control the required amounts of the anesthetic drugs during the surgery. The middle latency auditory evoked response (MLAER) was seemed to be the most promising measure of DOA, which is independent of the agent being used; the monitoring of DOA is complex and dependent on many factors, which vary between patients and operating procedures. Fuzzy set theory can be adapted for handling complex and inexact knowledge (DOA). This paradigm seems to be suitable for medical process, since it depends upon expert experiences which are not precisely quantifiable such as patients' subjective sensations, interpretation of clinical signs and effects of instrumental accuracy.
The aim of this paper is to extract significant features from the processed auditory evoked response (AER) signal using ARX model which, describing the changes in amplitudes and latencies of MLAER waves and merging together using fuzzy logic to create a reliable index for DOA every 30 sec.

KEY WORDS

Middle latency auditory evoked response (MLAER), depth of anesthesia (DOA), autoregressive with exogenous input (ARX model), fuzzy logic system (FLS), and auditory evoked response (AER).

Introduction

General anesthesia implies the loss of all sensation throughout the whole body and is associated with unconsciousness. General anesthesia is defined as irregular descending depression of the nervous system. A sensory evoked potential is the electrical activity that is elicited in a nervous pathway by a sensory stimulus [1]. When a sensory stimulus such as an auditory click or a light flash is applied to a subject, information about the stimulus is translated by the relevant sensory organ into a sequence of action potentials, which are then transmitted through a nervous pathway to CNS [2]. The signal used for measuring DOA should show graded changes with anesthetic concentration similar changes for different agent, appropriate changes with surgical event, and

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indicate awareness [3]. The above criteria have been used to examine the suitability of a various evoked potential for the signal used for measuring DOA.
The auditory evoked response (AER) has been tested with above criteria in mind, thus having validated the MLAER as a suitable measure of DOA [4].Monitoring of DOA is complex, and dependent on many factors which vary between patients and operating procedures. However, anesthetists in operating theater can monitor and manage patient very well based on their experience and knowledge. In many circumstances where decisions have to be made the facts are far from precise. A method that can be adapted for handling inexact facts is the fuzzy set theory [5]. This paradigm seems to be suitable for medical process.

Digital signal processing of MLAER

The auditory evoked response was selected for investigation because it directly assesses the functioning of the central nervous system, the target for anesthetic action, and it tests the sensory pathway that is the first to recover on return of consciousness from anesthesia. It has been established that all anesthetic drugs produce graded, dose-related changes in the amplitude and latency of waves in the range 16-85 ms. These changes can be reversed by surgical stimulation These waves (i.e. MLAER waves), therefore appear to reflect the balance between anesthetic concentration and surgical stimulation (the depth of anesthesia), and the AER technique thus promises to provide the anesthetist with a much needed monitoring aid.

The structure of the system for digital signal processing of AER is shown in fig. (1). It is focused on measuring the AER data, which can be input on-line/off-line to the system for improving the signal-to-noise ratio of the AER signal. Here, the system processes the AER signal from off-line AER data. The raw AER data of an epoch of 120 ms were recorded from patients, who were undergoing surface body and abdominal surgery during anesthesia with propofol, using the AER device. The conventional averaging technique is applied to the recorded raw AER data for a small number of sweeps (192 sweeps) to enhance the AER signal and making it visible using the AVG program. This value of 192 sweeps was deemed to be small enough to assume that the AER signal and EEG noise are stationary during the time taken to acquire those 192 sweeps. The averaged signals are filtered by low pass filter (LPF) and high pass fitter (HPF). The HPF frequency is set to 25 Hz because much of the MLAER power is above 20 Hz whereas most of the raw EEG power is below 20 Hz. The LPF is set to be 125 Hz because little of the MLAER power is above 100 Hz The output of these filters is smoothed and has a good S/N by using moving average filter with window of 5 samples, which is suitable for medical processing. The output of the moving average filter passes through the ARX model which overcomes the drawbacks of averaging and increases the signal-to-noise ratio to monitor the dynamic parameters of AER (changes in amplitudes and latencies of waves). In order to test the performance of the ARX model, a simulated MLAER was obtained in the following way.

The case study was based on the data file called AX-7485.The AER data (0-120 ms) of an old patient (64 years) during an operation. These data were recorded during an operation under anesthesia with propofol at the hospital using the AER device. The raw data was averaged (192 sweeps) using the average program to enhance the MLAER and then applied the filter technique to smooth the signal and increase its S/N. The raw AER data is shown in fig. (2-a), the averaged AER signal is shown in Fig. (2-b), and the output of the ARX model is shown in Fig. (2-c). A comparison between the input and the output signals of the DSP system is shown in Fig. (2-d) to show the increasing in the S/N.

Features extracting from MLAER

The MLAER contains 3-positive waves (P_a, P_b, P_c).The amplitudes (magnitudes) and phases (latencies) of these waves are considered to be the main parameters for measuring the anesthetic depth. The appearance of the 3-waves indicates inadequate anesthesia (i.e. awareness) while the appearance of the 2-waves (P_a, P_b) indicates moderate anesthesia. The further depression of the wave P_a (i.e. more decrease in amplitude and increase in latency) indicates surgical anesthesia while flat MLAER (i.e. the 3-positive waves disappear) indicates a deeper level of anesthesia than is necessary [6].

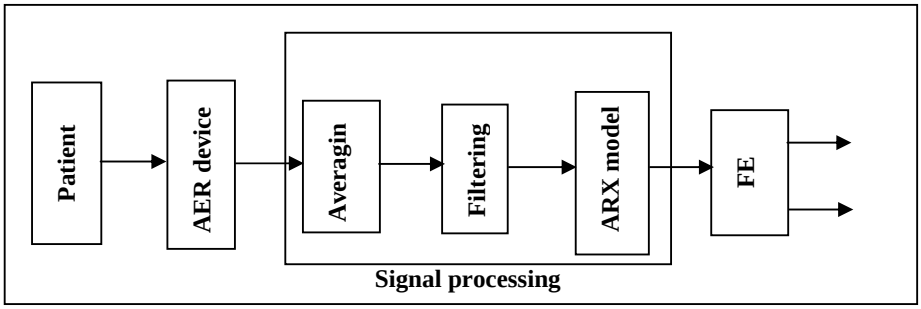

Fig.1. the structure of the system for digital signal processing of AER

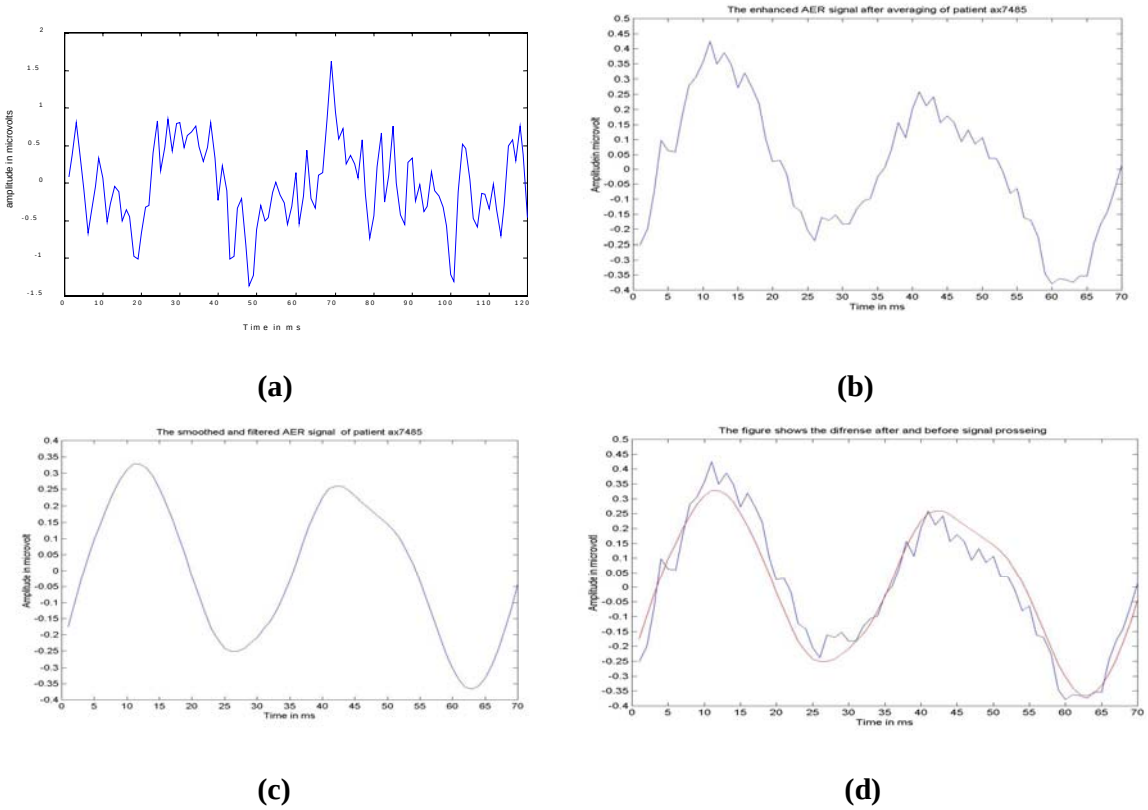

Fig.2. show the changes of AER a) the raw AER data of patient AX7485 from AER device b) the enhanced AER signal after averaging, c) the output signal from ARX model, d) the comparison between signals in (b) and (c).

To observe the changes in the 3-positive waves, the AER window for analysis was chosen to be 16-85 ms. it was found experimentally that in the model of ARX. the sum of modulus of the coefficients of polynomial A(z)($\sum|A|$),the dominant pole location (T_d) and the average power of the noise-free output Y_h ($P_a(Y_h)$) describes the changes in amplitudes and latencies of the MLAER waves relating to the depth of anesthesia. The $\sum|A|$ and T_d are obtained from the parameters of the ARX model, while $P_a(Y_h)$ is obtained from the filtered output of the model. The $\sum|A|$ and $P_a(Y_h)$ represent the average of the amplitudes of the 3-positive waves while the(T_d) represents the latency of wave P_b with respect to wave P_a (i.e. the main period).

The above three factors are calculated by the following procedure:

1) Prepare the reference signal u (base line of AER) as the conventional averaging of 1000-2000 sweeps (i.e. 3-6 min. average) during a silent period before induction of anesthesia.
2) Calculate the average of the signal (192 sweeps, i.e. 30 Seconds) after the start of the induction phase and filtering technique.
3) Compute the output of the ARX model with the optimum order (n =12, m =11, d =7).
4) Calculate the $\sum|A|$ by the following equation:

$$\sum|A| = 1 + \sum_{i=1}^{n}|a| \qquad (1)$$

5) Compute the poles of the model
6) Determine the complex pole with minimum angle α (i.e. dominant pole)
7) Compute the main period Td by the following steps:
   a) Calculate the dominant frequency ω by the following equation:

$$\omega\,\tau = \alpha \qquad (2)$$

   Where: α is the minimum angle of the complex poles in radians and τ is the sampling time (τ= 1 ms because the sampling rate equals 1 KHz)
   b) Compute the main period Td in ms by the following equation:

$$T_d = \frac{2\pi}{\omega} = \frac{360}{\alpha} \qquad (3)$$

8) Compute the noise-free output Yh.

9) Calculate the average power of Yh by the following equation:

$$Pa(Yh) = \frac{\sum_{r=16}^{85}(Sr)^2}{70} \qquad (4)$$

Where Sr is the value of the r-th sample of Yh

Validation of the extracted factors

From the literature review described before we are satisfied that the MLAER shows promise for measuring the DOA. To clinically evaluate the three factors ($\sum|A|$, T_d, $P_a(Y_h)$) derived from the MLAER the AER data were recorded from 4 patients, who were undergoing body surface surgery, during intravenous anesthesia via propofol in Hospital. At the same time, the propofol concentration (PC) was measured one minute before stopping of propofol and every minute after the stopping of propofol (i.e. during the recovery phase). The AER data corresponding to the period of measuring the PC were selected from the AER data files of the 4 patients. These AER data were

processed using the digital signal processing technique as mentioned above. The numerical indices ($\sum|A|$,T_d,$P_a(Y_h)$) over the window l6-85 ms, which include the MLAER, were derived every 30 second. These indices were used to facilitate tracking the changes in the MLAER according to the changes in propofol concentration during time recovery phase. The three indices and PC were plotted versus the recovery time as shown in fig. (3).

The changes in the above three factors $\sum|A|$, T_d and $P_a(Y_h)$ with different PC, during the recovery phase were examined. It was found that the $\sum|A|$, and $P_a(Y_h)$, values were increasing when the PC values were decreasing. However, the T_d values decreasing when PC values were decreasing. This result confirms that the $\sum|A|$, and $P_a(Y_h)$, reflected the change in magnitude and T_d reflects the changes in latencies of the MLAER waves during anesthesia, the three factors detected the awareness (i.e. eye opening) successfully as shown from Fig. (3).and the anesthetist's experiments for detecting the awareness using the clinical signs.

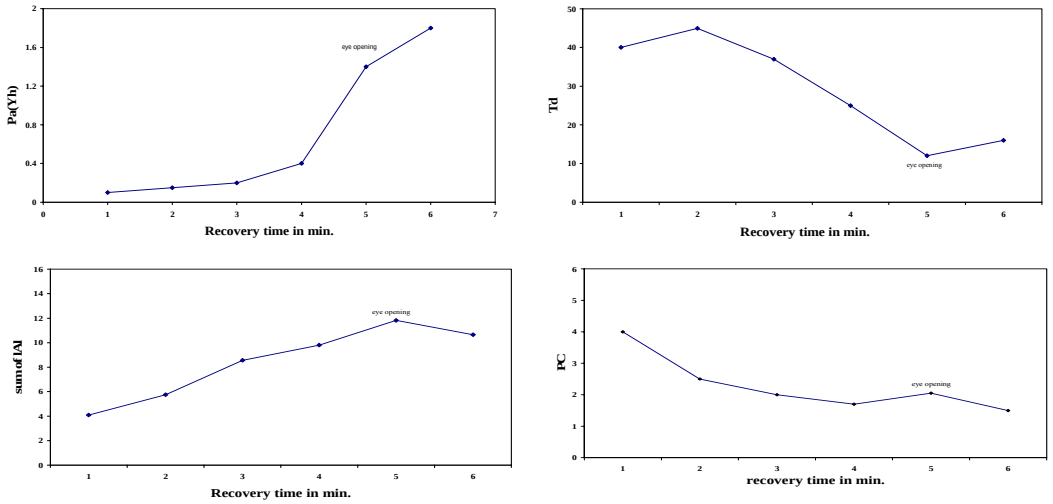

Fig.3. The changes of PC, T_d, $\sum|A|$ and $P_a(Y_h)$ every one minute During the recovery phase of the patient

The proposed System for monitoring depth of anesthesia

The structure of the system for monitoring DOA is show in fig. (4).It is focused on measuring the AER data which can be input on-line/ off-line to the system for interpreting the DOA. In this paper, the system estimates the DOA from off-line AER data. As described before a digital signal processing technique was carried out to smooth the MLAER and improve the signal to noise ratio (S/N). Furthermore, feature extraction (FE) was implemented to extract the factors (i.e. $P_a(Y_h)$, and Td) describing the changes in amplitudes and latencies of MLAER waves every 30 seconds. The above two factors have been merged together using fuzzy logic system to create a reliable index for DOA every 30 seconds. The rules come from anesthetists experience, the merging $P_a(Y_h)$ and Td, where the $P_a(Y_h)$ is the dominant factor, provides estimates for DOA. The output of the monitoring system has values from 90 to 500 for the three states of anesthesia , where anesthetic light (AL) is DOA less than 200, anesthetic OK (AO) is DOA between 200 and 400 and anesthetic deep (AD) is DOA greater than 400. the state of AO is divided to three levels: anesthetic (max-ok) where DOA is

between 320 and 400, anesthetic (ok) where DOA is between 260 and 320, and anesthetic (min-ok) where DOA is between 200 and 260.

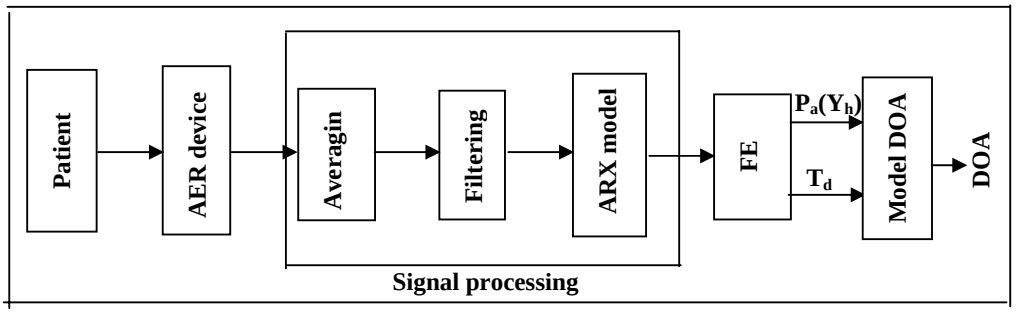

Fig.4. the structure of the system for monitoring depth of anesthesia

Clinical results

The method of monitoring the DOA mentioned above was applied to clinical trails for 12 patients. These cases who where undergoing body surface and abdominal surgery were studied, with respect to AER during intravenous anesthesia via propofol. The off-line results of interpreting the DOA were successful. They are assessed by discussion with anesthetists and found to be acceptable. The results of one clinical trail is shown in fig. (5) to demonstrate the performance of the numerical index derived from AER (i.e.DOA) as a reliable assessment for monitor the DOA every 30 seconds during anesthesia with propofol. In this result the DOA increased following induction. It decreased slightly at the intubation. The index mostly remained in the state of anesthetic (ok) especially in the state of (max-ok), and never went into the state of anesthetic light or deep. The index returned to the low level when anesthesia was reversed.

The index showed appropriate changes with the surgical events. Graded change with anesthetic concentration, and indicate awareness (i.e. eye open) this indicates adequate clinical anesthesia for all studied cases. Furthermore, this matched the interpretation of anesthetic depth via anesthetists experience using clinical signs.

Conclusions

The AER changes seen were compatible with valid DOA measurement. The AER index (i.e. DOA) reflected the changes in amplitudes and latencies of MLAER waves due to drug concentration and surgical stimulation in a way that might be expected in routine anesthesia practice. So the DOA has been validated as a reliable assessment of anesthetic depth during anesthesia with propofol.

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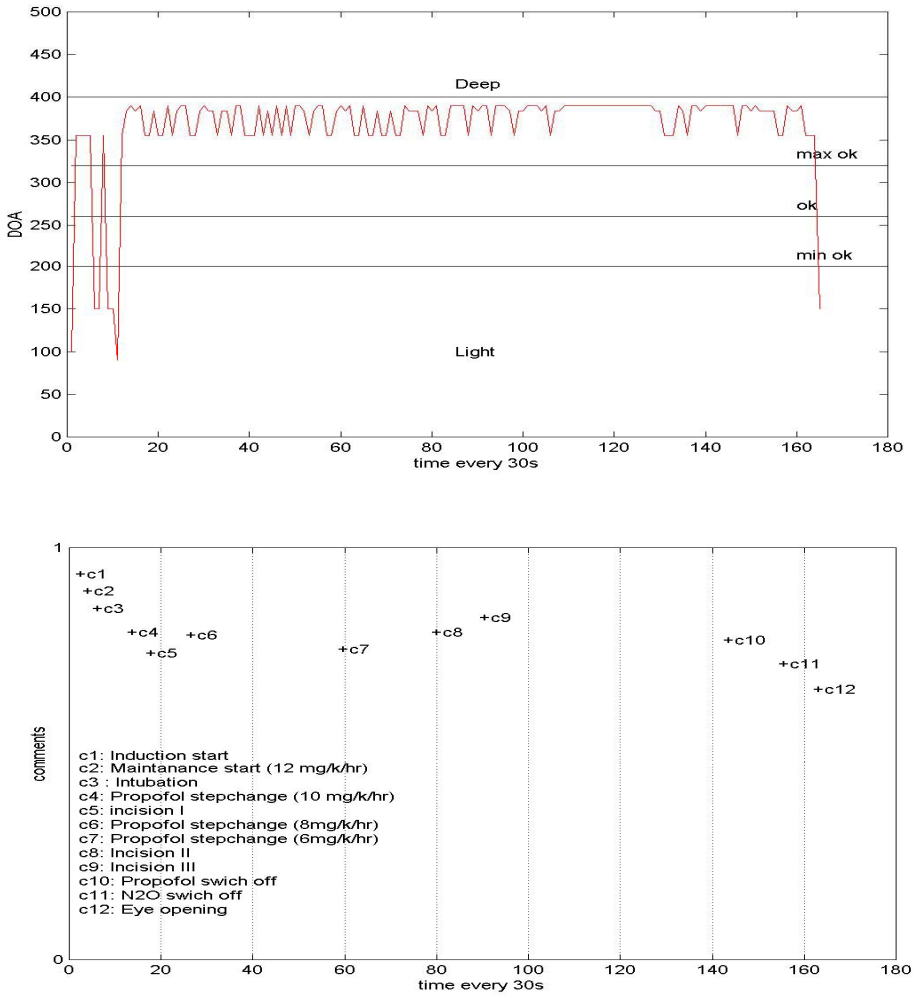

Fig.5.The results of interpreting the DOA of patient CP5138. a) DOA b) Comments from anesthetists