Effect of Tracheal Intubation on the Morphology of Photoplethysmographic Pulse

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Abstract

Photoplethysmogram (PPG) of pulse wave has been proposed for analgesia monitoring recently with most attentions paid to its magnitude and little attention to its morphology. Therefore, effect of nociceptive stimuli on the morphology of PPG was studied using a morphological parameter named area ratio (AR). Fifty patients, ASA I or II, scheduled for laparoscopy surgery under general anaesthesia were enrolled. They were anaesthetized using propofol and remifentanil, and their PPG signals were recorded. Tracheal intubation was used as a nociceptive stimulus. Off-line analysis showed that the morphology of PPG was influenced by the intubation. The AR increased during intubation and returned to the initial level. Its distributions before intubation (0.687±0.153) and during intubation (0.862 ± 0.125) were very highly significantly different (P<0.001) according to the Wilcoxon signed rank test. The results indicated that the morphology of PPG could be influenced by stimuli and also had potential for analgesia monitoring as the magnitude of PPG.

1. Introduction

General anaesthesia mainly includes three components: hypnosis, analgesia and immobilization [1]. Accurate measurement of depth of general anaesthesia, which can be used for guiding delivery of anaesthetics, is the key to achieve an ideal general anesthesia. For monitoring the hypnotic depth, several indicators have been introduced such as Bispectral Index (BIS), auditory evoked potentials (AEPs) and Entropy [2]. However, monitoring analgesia is still a challenge, and rare subjective indicators are available yet. Traditionally, clinical signs, like heart rate, blood pressure, movement and muscle tension are used to assess analgesia subjectively. The modern indexes, BIS or middle latency AEPs, were of little relevance with stimuli and couldn't be used for monitoring analgesia either [3].

To overcome the challenge, some efforts have been made recently. Photoplethysmogram (PPG), which was used during anaesthesia mainly for monitoring blood oxygen before, has been discovered new potential application in analgesia monitoring during general anaesthesia. The magnitude of PPG was studied mostly and several parameters were extracted to measure the depth of analgesia during general anesthesia [4]. Such parameters as PPG amplitude (PPGA), PPG notch amplitude (PPGN), PPG area and PPG maximum derivative have showed significant differences between pre and post stimulation periods [5], indicating they responds to nociceptive stimuli. PPGA has been recently integrated with heart beat interval into an objective index named surgical stress index (SSI), or surgical pleth index, to monitor and guide analgesia [6-10].

However, morphology of PPG, which also contain rich information about the total vascular system, or neural system in other words, was neglected, and few parameters of morphology has been proposed. Therefore, this preliminary study was designed to investigate effect of nociceptive stimuli on the morphology of PPG. A parameter named area ratio was used to describe the morphology and its variation resulted by tracheal intubation during general anaesthesia was studied.

2. Methods

2.1. Patients and study plan

The present study was approved by the local Research Ethics Committee of School of Medicine, Zhejiang University and written informed consents were obtained from all patients who were participated in this study. A total of 50 patients, ASA I or II, scheduled for laparoscopy surgery under general anaesthesia were enrolled. Those with nervous system disease (e.g. neurological disorders, head injury, seizure disorders), chronic use of psychoactive medication or abuse of

alcohol or illicit drugs, and any clinical significant cardiovascular, renal, hepatic, or endocrinologic disorders were excluded from the study.

All patients received no premedication. In all patients, anaesthesia was induced with propfol and remifentanil via target-controlled infusion (TCI) pump (Orchestra Primea, Fresenius, France). Propofol was first administrated to achieve loss of conscious (LOC) indicated by BIS between 40 and 60. Remifentanil was then started to achieve and maintain different target effect-site concentration. Three minutes after the target concentration of remifentanil was achieved, tracheal intubations were performed. The concentration of remifentanil was maintained constant until 5 minutes after intubation and then adjusted according to the following surgical requirement.

A pulse-oximeter probe (DS-100A Durasensor, OxiMax, Nellcor Puritan Bennett Inc) was placed on the index finger of the non-dominant hand of every patient. PPG was record continuously with a sample rate of 250 Hz from anaesthesia induction to 5 minutes after intubation, and then was saved on computer for off-line analysis. The starting time or finishing time of PPG data was saved to calculate the time of every sample point. The exact times of drug administration, LOC and tracheal intubation during the anaesthesia were also noted on a sheet.

Avoid abbreviations and keep to one or two lines. Remember that the title should be easily understood when cited as a reference in another publication. Make sure the title is centered. Note use of capital letters.

2.2. Area ratio

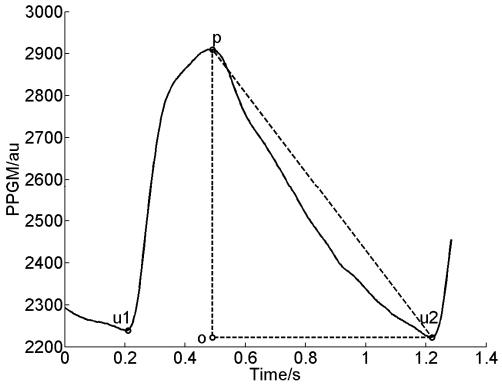

Figure 1. The schematic of area ratio. Area ratio was defined as ratio of the area of $\overset{\frown}{opu_2}$ and the area of Δopu_2. au is arbitrary unit.

The starting point (u1), peak point (p) and ending point (u2) of every period of PPG were detected automatically (Figure 1). The detection 1 minute before and 2 minutes after the onset of intubation was examined and any false was corrected artificially. Area ratio (*AR*) was proposed to describe the morphology of PPG, defined as

$$AR = \frac{area_{\overset{\frown}{opu_2}}}{area_{\Delta opu_2}}$$

in which $area_{\overset{\frown}{opu_2}}$ is the area under the curve of descending limb of PPG but above baseline, and $area_{\Delta opu_2}$ is the area of triangle (Figure 1).

As *PPGA* has been proposed as a good parameter of magnitude responding to stimulation [5], it was also calculated as reference.

2.3. Data filtering and comparison

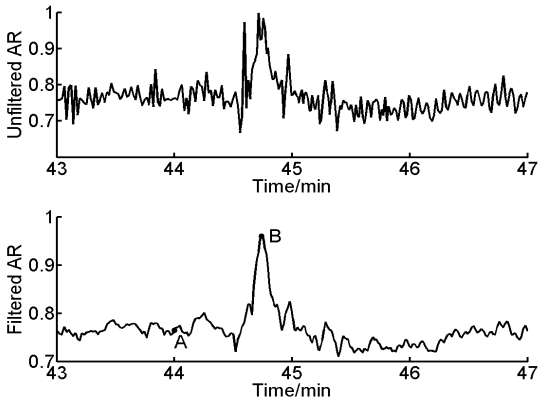

Figure 2. An example of unfiltered and filtered area ratio curve when intubation.

The initial curve of area ratio, as shown in the top figure of Figure 2, is not smooth, and was filtered with weighted moving average method. The filtered area ratio during intubation is shown in bottom figure of Figure 3. The filtered curve is smoother than the top one, and the time shift is only 1.6 seconds.

In some studies, the mean values of parameters several minutes before and after intubation were used for comparison. Differently in this study, points A and B as shown in the bottom figure of Figure 2 were used. Point A represents the average value 1 minute before intubation, but point B was the point where maximal variation appeared during intubation.

2.4. Statistics

The values of parameters before and during intubation were compared using the Wilcoxon signed rank test to estimate their response to intubation. The statistics were performed using the software SPSS for Windows v 16.0 (SPSS Inc., Chicago, IL, USA), and $P<0.001$ was considered statistically significant.

3. Results

A total of 50 patients were enrolled and 3 patients were excluded for too many artefacts during intubation. The demography of the patients was shown in Table 1.

Table 1. Characteristics of population in study. Values are mean (SD).

Gender	30 women, 17 men
Age(yr)	40.2 (11.5)
Weight(kg)	58.5 (8.0)
Height(cm)	164.7 (7.9)

An example of the morphology of PPG in a patient is shown in Figure 3. The morphology is quite different before and during intubation.

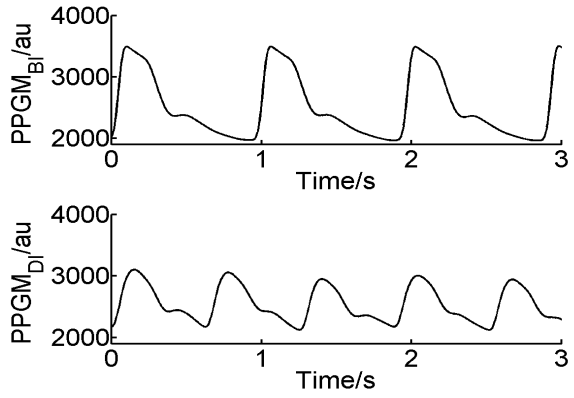

Figure 3. The comparison of waveform before and during intubation. *PPGM* is the magnitude of PPG in arbitrary units (au). BI denotes before intubation while DI denotes during intubation.

According to the Wilcoxon signed rank test, the distribution of both *AR* and *PPGA* during intubation was significantly different from the distribution before intubation (P<0.001)(Table 2).

Table 2. The distribution of *AR* and *PPGA*. Values are mean (SD).

	AR	PPGA(au)
Pre-intubation	0.687(0.153)	662(312)
Duri-Intubation	0.862(0.125)	335(218)
P-Values	P<0.001	P<0.001

The normalized *AR* and *PPGA* near the time of intubation are shown in Figure 4. AR_{norm} also responded to tracheal intubation, but in a different way from $PPGA_{norm}$. AR_{norm} increased when intubation was started, while $PPGA_{norm}$ decreased.

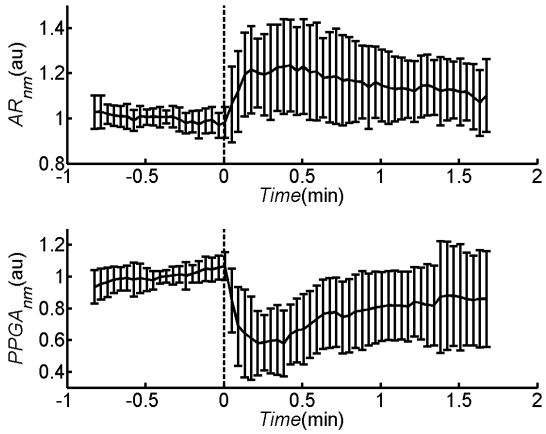

Figure 4. The errorbar of AR_{norm} and $PPGA_{\mathrm{norm}}$ in all patients. Both *AR* and *PPGA* were normalized by dividing the values before intubation. Tracheal intubation was supposed to be started at 0 min.

4. Discussion

Nociceptive stimulations like tracheal intubation to a patient during general anaesthesisa will stimulate neural system and resulting in the haemodynamic response of vasoconstriction. Vasoconstriction suppresses the magnitude of PPG. As shown in Figure 6, *PPGA* decreased when intubation was started. It was consistent with other studies [5,11,12]. On the other hand, as blood flows in vascular system, the vasomotor activities will alter the morphology of PPG. Therefore, the morphology of PPG is another way indicating vasomotor activities. The results showed that *AR* increased when a patient was stimulated. It could be explained by the increase of vascular resistance resulted by vasoconstriction. The increase of vascular resistance made the PPG decay more difficultly, and the curve $\overset{\frown}{pu_2}$ was more close to, or even above the line $\overline{pu_2}$. Therefore, *AR* increased (Figure 3).

PPG detects the local peripheral blood volume, usually fingers, and any factor influencing the local perfusion will alter the amplitude of PPG. To reduce these influencing factors, crystalloid solution infusions or a warming blanket were used to achieve maximal pulse amplitude in some studies [7, 9, 12, 13]. The morphology of PPG is influenced by the whole vascular system, of which local peripheral vessel is only a small part. Only factors influencing the whole vascular system like neural system, which can be stimulated by nociceptive stimulations, can change the morphology of PPG. Therefore, morphology of PPG is more specific to stimulations in theory. Meanwhile, as maximal magnitude is not necessary for morphology, crystalloid solution infusions or a warming blanket is not required. It is more convenient in detection.

In this study, two single points before and during intubation was used for comparison. As the points were from the filtered curve, they also represented mean values of initial curve. This method for choosing data was similar to other studies in a certain sense, and the same result for PPGA was achieved. If there had been no significant difference for PPGA and AR between before and during intubation, the value of point B would have been larger and smaller randomly than the value of point A, and P-value would have not been smaller than 0.001. Furthermore, for future application in continuous monitoring, a single point representing instantaneous value will generate quick response. Therefore, the method for choosing data for comparison in the study was reasonable.

There were also some limitations in our study. First, the initial curve of AR was not smooth enough for direct usage, and filtering was required. Second, large variability existed in AR among different patients, which could be resulted by different individual physiological statuses and pharmacodynamic influences of different concentrations of remifentanil. The effect of remifentanil on AR was important, but was not studied in this preliminary study. Meanwhile, the detailed comparison between PPGA and AR was also not carried out.

In conclusion, this preliminary study proposed area ratio for describing the morphology of PPG. AR responded to tracheal intubation during general anaesthesia, indicating the morphology of PPG also was affected by nociceptive stimuli besides the magnitude of PPG.

Acknowledgements

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