Effect of Oxygen Concentration Reduction on Photoplethysmographic Waveform Characteristics

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Abstract

This paper aims to find out the difference of human photoplehysmography (PPG) morphological parameter K between in normal oxygen concentration regions and in low oxygen level environments. We implemented an experiment with a normobaric hypoxic chamber which generalized low oxygen level environment of 13.4% (equivalent to the altitude of 3600 m). The experiment contained two sections—10 minutes short exposure and a night of sleep. Fingertip PPG signal was recorded in the whole process. We carried out a comparative analysis for each subject in normal and hypoxic conditions. Result showed that the average K values in normoxic environment and hypoxic conditions for short exposure were 0.3456 and 0.3861 respectively, and for sleep were 0.3081 and 0.3419 respectively. Significance level p were both less than 0.05. Variations of PPG waveform parameter K reflect the changed peripheral vascular resistance. In hypoxic environment, the raised K value tallied with the physiological mechanism that hypoxic exposure increases peripheral vascular resistance. And this phenomenon happened since the beginning of hypoxia and could last for at least a night.

1. Introduction

The Photoplehysmography (PPG) is a non-invasive optical biological monitoring technique that uses photoelectric sensors to detect the different intensity of reflected light after absorption by human blood and tissues, and to record the changes of blood vessel volume during the cardiac cycle [1]. Close connections exist between the variation of PPG waveform and the function changes of the cardiovascular system. Now there are many researches and practical applications on acquiring heart rate (HR), blood pressure (BP), oxygen saturation or evaluating cardiac output, blood volume, hypertension and other cardiovascular risk factors by PPG [2][3].

Low oxygen environment can make cardiovascular automatic nervous system change. The decreased peripheral oxygen saturation (SpO_2) actuates sympathetic nerves and weakens parasympathetic nerves [5][6]. When transferred to hypoxic environment, the content of red blood cells (RBC) and hemoglobin (Hb) increases significantly [7][8] which raise blood viscosity and even cause thrombosis.

The changes of oxygen level, air pressure, exercise and age have an influence on the PPG waveform [4][9]. When people first enter the high altitude regions, physiological indicators change significantly. There have been many researches on the variation regularities of traditional physiological features such as ECG, electroencephalogram (EEG), respiration, SpO_2 and maximal oxygen uptake (VO_2max) [5][6][7], but we can hardly find report on the variation rules of PPG waveform in hypoxic conditions. In the present paper, a classical PPG waveform parameter K was investigated experimentally in two conditions: short time hypoxic exposure and hypoxic sleep. The comparison in normal and low oxygen content environments may expand some new observations in hypoxic conditions.

2. Materials

2.1. Subjects

Eight young and healthy male subjects (21.2±1.7 years old, 64.6±5.8 kg, 173.1±5.2 cm) attended the experiment. They were not over one day's stay at altitude >3000 m in the past 6 months, born at altitude >1000 m, smokers, suffering from severe respiratory or cardiopulmonary diseases. Pungent drinks, medicine and intense physical exercise 24 hours before the experiment are not allowed. The experiment was approved by Ethics Committee of Southeast University, China. All the subjects were well informed of the aim and risks of the experiment and they all signed the informed consent before the study.

2.2. Experimental design and data acquisition

This experiment was carried out in a simulated normobaric hypoxic chamber. The oxygen concentration was reduced by an automatic nitrogen flow valve and maintained at 13.4%±0.2% (equivalent to the altitude of 3600 m). The experiment contains two sections. The first one is short time hypoxic exposure: the subjects were demanded lying in the bunks outside the chamber (about 65m above sea level) for 10 minutes, and then they entered into the hypoxic chamber lying in the bunks for another 10 minutes. The second section is hypoxic sleep: the subjects were required to sleep in the chamber for a night at normal oxygen content and for another night at low oxygen content of 13.4%±0.2%. PPG signals were recorded throughout the experiment by a portal sensor with a fingerstall (Prince-100A, Creative Industry Co. Ltd., Beijing, China). The subjects were asked to cover the same finger throughout the experiment and not move their fingers in the fingerstall during the first section. The sampling rate was 200Hz. The temperature and humidity both inside and outside the chamber were maintained the same.

3. Methods

With the PPG waveform, we first extracted critical characteristic points on PPG wave. As shown in Figure 1, we recognized the onset (Q_O) and the apex (Q_a) by the method developed in [10]. Then manual correction was implemented after that. The parameter K value is defined as follows [11]. The coordinate values of Q_a and Q_O are (T_a, P_a) and (T_o, P_o) respectively. $P(t)$ is the expression of PPG wave. The average value of the pulse pressure, which is also the mean height of the wave is

$$P_m = \frac{1}{T}\int_{T_0}^{T_e} P(t)dt$$

K value is defined as

$$K = \frac{P_m - P_o}{P_a - P_o}$$

4. Results

We calculated the mean value of parameter K based on the corrected characteristic points of each cardiac cycle in normoxic and hypoxic environment respectively. The comparison results are shown in Table 1 and Table 2 and Figure 2. Paired *t*–test was applied for the comparison of K value between the two environments. The data are presented as means±standard deviation. The average K value in normoxic and hypoxic conditions for short exposure are 0.3456 and 0.3861 respectively, and for sleep are 0.3081 and 0.3419 respectively. Significance level p are both less than 0.05. No matter in short time exposure or the whole sleep, K values are larger in hypoxic environment than in normal oxygen content condition for almost all subjects.

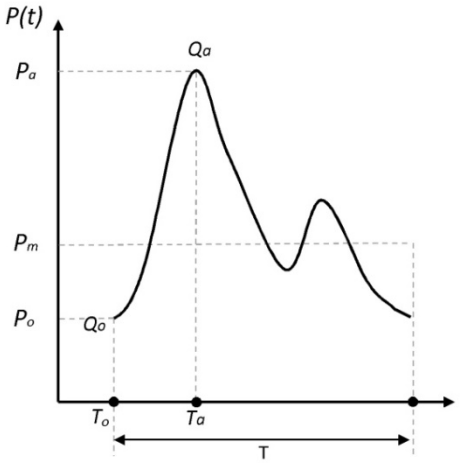

Figure 1 Graphical representation of critical points and time intervals in a beat of PPG wave, necessary to compute PPG morphological parameter K. (Q_O: the onset point; Q_a: the apex; T: cardiac cycle.)

Table 1 Comparison result of PPG morphological parameter K (means±SD) in short time exposure under normoxic and normobaric hypoxic environment for each subject

Subject No.	K in Normoxia	K in Hypoxia
1	0.3573±0.0213	0.3789±0.0605
2	0.3354±0.0229	0.3813±0.0243
3	0.3804±0.0295	0.4025±0.0430
4	0.3483±0.0580	0.3615±0.0617
5	0.3509±0.0715	0.3879±0.0421
6	0.2977±0.0332	0.3872±0.0307
7	0.3227±0.0345	0.3897±0.0367
8	0.3722±0.0318	0.3996±0.0416
Average value	0.3456	0.3861 (p<0.01)

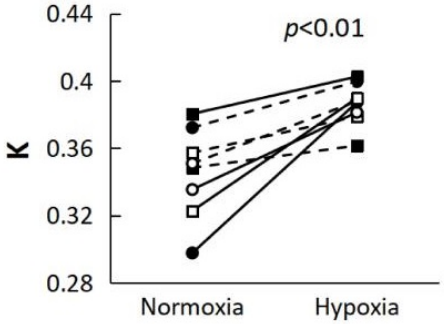

Figure 2 Difference of K value in normoxic and hypoxic environment

Table 2 Comparison result of PPG morphological parameter K (means±SD) in the whole sleep under normoxic and normobaric hypoxic conditions for each subject

Subject No.	K in Normoxia	K in Hypoxia
1	0.3024±0.0403	0.3015±0.1027
2	0.3164±0.0388	0.3381±0.0383
3	0.2923±0.0494	0.3274±0.0707
4	0.2807±0.0659	0.3392±0.0991
5	0.3076±0.1037	0.3221±0.0673
6	0.2766±0.0425	0.3427±0.0704
7	0.3353±0.0571	0.34±0.0748
8	0.3535±0.0423	0.4243±0.057
Average value	0.3081	0.3419 ($p<0.05$)

5. Discussion and conclusion

In the present work, we mainly investigated the difference of the PPG morphological parameter K between normoxic and normobaric hypoxic environment. Our research did some work to fills in the gaps in PPG morphological studies for hypoxic exposure and provides a potential observation technique for oxygen deficit.

The variation of PPG morphological parameter reflects the changes in cardiovascular functions. Morphological parameters of PPG behave an observation of the variations in vascular resistance, elasticity of vascular wall and blood viscosity. Previous studies reveal that the value of K is positively correlated with peripheral vascular resistance [11]. When the external oxygen concentration decreases, the content of RBC and Hb will increase rapidly, resulting in increased blood viscosity and increased peripheral vascular resistance. In this experiment, we obtained the result of raised K value, which is coincident with this physiological mechanism. Meanwhile, K is larger both in hypoxic short exposure and the whole sleep which Indicates that changes of peripheral vascular resistance happens as soon as the subjects step into the hypoxic environment and remain constant for a whole night.

Limited by the finance and experimental conditions, the number of recruited subjects in this study was small. Despite that some consistent conclusions were reached, it is uncertain whether they are generalizable to the wider population. Meanwhile, the physiological foundation of the changes of PPG morphological parameters in hypoxic environment is not well understood, and researches in this area is still scarce. The experimental site of this study is normobaric hypoxic chamber, and our conclusion would be more convincing to be verified in the real hypobaric hypoxic plateau environment. If the methods and conclusions of our study being checked and verified in wider population, it may potentially provide a more comfortable and non-invasive approach to observe and evaluate the variations of human peripheral vascular resistance and other physiological indicators in hypoxic conditions.

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