The Acceleration Plethysmography System as a New Physiological Technology for Evaluating Autonomic Modulations

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ABSTRACT

It is commonly known that autonomic modulations are caused by depression, fatal arrhythmia, and vascular disease. This may lead to be an urgent need of a reliable physiological technology to evaluate autonomic modulations. The specific purpose of the current study is to examine the possibility of whether the Acceleration Plethysmography (APG) system can become a new useful tool to measure autonomic modulations. We verified the heart rate variability (HRV) analysis by APG whether it can be used as same as by the ECG. The HRV is interpreted from the a-a interval (Taa) on APG waves. We assembled the simultaneous measurement system of APG and ECG, examined the identities of the R-R interval (TRR) of ECG and the Taa of APG in six subjects of 22-60 old, and then compared variables in frequency domains of HRV by both APG and ECG. The results showed a close correspondence of the Taa and the TRR. Furthermore, when the regression formula was set as Taa=C*TRR, the coefficient of determination was merely 0.1-0.2%, and the coefficient of variation of HRV was merely 0.1-0.2%, and the LF/HF ratio as 0.1-0.4. If we carefully interpret the results of the frequency analysis, the APG system can be a useful objective methodology to evaluate autonomic modulations. Because of its simplicity in usage, it is expected to be employed in the occupational health or primary care.

Key Words: Acceleration Plethysmography, Autonomic Modulation, Frequency Analysis, Heart Rate Variability, Mental Stress

INTRODUCTION

Recent problems in Japanese occupational health are mental disease, vascular disease, and diabetes caused by long working hours or an irregular lifestyle.1-3 It is known that autonomic modulations by mental stress cause depression, fatal arrhythmia, and vascular disease.4-6 Moreover, it is also known that diabetes amalgamates the autonomic disturbance.7 From such a socio-medical background, a reliable physiological technology to evaluate autonomic modulations is in urgent need.

The Electrocardiography (ECG) has been used as a tool for estimating autonomic modulations by analyzing the heart rate variability (HRV). Recently, we have been investigating an application of the acceleration plethysmography (APG) for analyzing the HRV. The APG system has three advantages: Firstly, its simplicity in that the waveforms can be measured on one finger in the sitting position for a short time. Secondly, the APG system is equipped with the software of frequency analysis.8 Thirdly, the system can simultaneously offer the information of stiffness of arteries.9,10

Originally, the prototype of APG machine was developed in Japan about 20 years ago, however, the physiological significance of APG was not noticed. Takada H et al. proposed the evaluation method to offer information of arteriosclerosis by APG in 2002.10 On the basis of this theory, the APG system consisting of a new APG machine with remarkably good reproducibility of waveforms was produced. The APG system evolved to the type that is able to measure HRV in 2004.8 However, as the system was developed merely three years ago, the research works relating to the HRV by using the APG system are few. The findings of the actual experience of the system are even fewer.

Therefore, we attempted to verify the HRV analysis by APG whether it can be used as same as by the ECG. The HRV is interpreted from the R-R interval (TRR) on ECG waves, and on the other hand, from the a-a interval (Taa) on APG waves. We examined the identities of the TRR of ECG and the Taa of APG, and compared the results of frequency analysis of HRV by APG and ECG. The purpose of this study is to examine whether the APG system can become a new tool useful in the health management of occupational health, or in the primary care.

MATERIALS AND METHODS

1. Subjects and statistical analyses

The subjects of this study are six volunteers who have agreed to participate in this study. The subjects were three males (23, 48 and 56 years old respectively) and three females (22, 34 and 60 years old respectively). They were explained about the research, and submitted the documents of agreement.

First, we assembled the simultaneous measurement system which measures APG and ECG. The waveforms of ECG
and APG were recorded 100 beats simultaneously in the sitting position, and data of both consecutive Taa of APG wave and TRR of ECG wave were obtained. For each subject, the coefficient of variation of HRV (CV) was calculated from the consecutive Taa and consecutive TRR. The scatter chart of the Taa and the TRR was drawn for each subject, and the relationship was analyzed by the regression analysis. The coefficient of determination, when the regression formula was set as Taa = C*TRR (with C as approximately unity), was obtained.

Frequency analyses were executed with respect to Taa and TRR for each subject. The Maximum Entropy Method (MEM) was adopted for frequency analysis. The resolution ability of spectrum was set as 0.001 Hz. During the analysis, the re-sampling was not executed. Power spectra are quantified at 0.02–0.15 Hz as the low frequency range (LF element), and at 0.15–0.5 Hz as the high frequency range (HF element). From the power spectra, the variables in frequency domains such as total power, the proportion of HF power (LF%), the proportion of HF power (HF%), and the ratio of LF power and HF power (LF/HF ratio) were obtained.

2. The simultaneous measurement system of APG and ECG

The simultaneous measurement system comprises a personal computer, four channel data logger, an ECG amplifier, an APG machine, and ECG terminals. We used ARTETT (U-MEDICA, Inc. Co) to measure the APG waves (Fig. 1). The center wavelength is 940 nm, and the output maximum amplitude is ±3.3 V.

The block chart of the device was shown in Fig. 2. In the system, two amplified analog signals from APG and ECG are converted into digital signals by the sampling rate of 1,000 Samples/Sec. The time difference between the analog and the digital conversion of input is less than 0.1 msec. Digital signals are input to the host personal computer by USB. Resolution ability is 10 bit/3.3 V. As to the APG input, amplification rate of alternated current is 100 times, and the cutoff frequency is about 20 Hz. The time constant of the direct current cut is about 1.5 seconds. As to ECG input, amplification rate of alternated current is about 2,000 times, and the cutoff frequency is about 24 Hz. The time constant of direct current cut is about 1.5 seconds. The output is conformed of “Abstract Control Model” that can be operated through USB of Ver1.0 and of Ver2.0. As for digital filter processing, the differentiation filter of cutting high frequency region has zero points on 50 Hz and 60 Hz. The integrated cut frequency of APG is approximately 15 Hz, and that of the ECG is 20 Hz.

The attached software can display two kinds of waves which are APG waves and ECG waves from two channels as shown in Fig. 3. This leads to an automatic formation of the output files in the computer in the forms of the time position of the a-wave of APG, the a-a intervals, the time position of...
the R-wave of ECG, and the R-R intervals. These files were then read by the frequency analysis program.

3. APG waveform

An APG wave is the second derivative of the capacity pulse wave. A waveform has five element waves. These are the positive a-wave, the negative b-wave, the positive c-wave, the negative d-wave, and the positive e-wave (Fig. 3). The a-peak and the e-peak correspond respectively to the starting point, and the aortic notch of the original wave. Therefore, an APG wave is a waveform of systolic of heart. The interval of the a-wave is called the a-a interval (Taa). The heart rate is interpreted from Taa. It is also known that APG waveform varies according to aging. Hence, the information relating to the aging of the blood vessel is offered by waveform patterns.[9],[10]

RESULTS

Figure 3 shows an apparent delay of the APG to the ECG of approximately 200 msec. This is because the APG is the wave of cardiac systole. Figure 4 shows the correspondence of the Taa and the TRR for each subject. The Taa and the TRR were closely corresponding. Figure 4 also shows the regression of the Taa with the TRR with the regression formula. When the regression formula was set as Taa=C*TRR, the coefficient of regression (C) was 1.0002, 1.0001, 0.9997, 1.0000, 0.9999, 1.0001, respectively; and the coefficient of determination was 0.9901, 0.9892, 0.9968, 0.9740, 0.9676, 0.9677, respectively for each subject (p<0.01).

The results of frequency analysis by APG or ECG were shown in Table 1. As for the difference between APG and ECG, CV% was 0.1-0.2%, and the LF/HF ratio as 0.1-0.4.

DISCUSSION

As shown in the results, the Taa of APG wave showed the high regression with the TRR of ECG wave. The coefficient of determination of the regression formula for each subject was nearly 1.0, and the coefficient of variation of HRV measured by APG was almost the same as the one by ECG. Moreover, both results of frequency analysis by APG and by ECG were very close. Therefore, we consider it appropriate to use the APG system instead of the ECG in order to measure HRV, and to estimate autonomic modulations. There has been no ECG system equipped with the frequency analysis program. Thus, the APG system has potential for analyzing autonomic modulations as a simple and reliable method. However, the results of the frequency analysis should be interpreted carefully.

It is known that LF and HF elements in frequency domains increase or decrease due to emotional or physical environment. The HF element increases by splashing cold water on the face, sleeping, or by deep breathing.[11],[12] Therefore, it is considered that vagal activity influences chiefly the HF element. On the other hand, the LF element increases by inclination to 90 degrees, by physical activities, or mental stress.[11],[13] The LF element is considered to reflect sympathetic nerve activity and partially parasympathetic activity. The LF/HF ratio which is the ratio of LF and HF element emphasizes autonomic balance. The LF% and the HF% are used as an index of autonomic modulations.

To evaluate autonomic modulations, the problem is that the standard value of such variables in frequency domains has not been established yet. Therefore, we should observe changes of variables carefully to estimate autonomic modulations. Moreover, when we refer to a previous research, it is also necessary to notice whether the measurement was done in the sitting, or supine position. Generally, it is difficult to know the mental stress level, though mental stress deeply relates to fatal arrhythmia, or depression. However, if we carefully interpret the results of the frequency analysis, the APG system can lead to be a useful objective method to evaluate mental stress. Moreover, it might be useful also for following up the lifestyle-related disease such as diabetics. Further investigation is required to apply this method for health management in the occupational health, or the primary care.
Fig. 4 The results that were shown as the corresponding of Taa of APG and TRR of ECG by the regression analysis.

Table 1 Comparison of APG and ECG with respect to variables in frequency domains.

<table>
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<tr>
<th>ID</th>
<th>Sex</th>
<th>Age (y.o)</th>
<th>Heart rate</th>
<th>CV (%)</th>
<th>LF%</th>
<th>HF%</th>
<th>LF/HF</th>
<th>Total power (ms²)</th>
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Note. APG: acceleration plethysmography, ECG: electrocardiography, CV: coefficient of variation of heart rate variability, LF%: the proportion of power in the low frequency domains of heart rate variability, HF%: the proportion of power in the high frequency domains of heart rate variability, LF/HF: the ratio of LF power and HF power.
ACKNOWLEDGEMENTS

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REFERENCES