ORIGINAL ARTICLES

An Evaluation Method for Heart Rate Variability, by Using Acceleration Plethysmography

Haruko TAKADA¹; Kazuo OKINO²; and Yumiko NIWA³

¹College of Medical Engineering, Suzuka University of Medical and Science, ²Research Section, U-medica Inc. Co., and ³Clinical Examination, Meitetsu Hospital

ABSTRACT

Objects We have recently developed a new type of acceleration plethysmography (APG) machine and software. This APG system functions to indicate heart rate variability, by using the coefficient of the variation of the a-a intervals (CVaa%). We tried to evaluate the validity of the APG system to estimate heart rate variability, instead of using ECG.

Methods We simultaneously recorded an ECG and an APG by using a 2-channel APG system. We examined the difference between the a-a intervals (Taa) of an APG and the R-R interval of an ECG. Next, APG waveforms of 121 healthy people and 26 diabetics were recorded, and the mean CVaa% in each age category for healthy people and diabetics were calculated.

Results 1) All differences between the Taa and the R-R interval were within 10 msec., and the multiple correlation coefficient was 0.999175. 2) The mean CVaa% was 0.2 to 1.5% bigger than the mean coefficient of the variation of the R-R intervals (CVRR%) in all age categories. 3) The mean CVaa% decreased by age. 4) In ages 40–60, mean CVaa% of diabetics was significantly lower than that of healthy people.

Conclusion The APG system is suitable to estimate heart rate variability. And, when we want to evaluate heart rate variability by CVaa% of an APG in stead of CVRR% of an ECG, a standard value of CVaa% in each age is necessary. The APG system has some possibilities for explanation of a mechanism of autonomic-nerve-related diseases.

Key Words Acceleration Plethysmography, Aging, Autonomic nerve, Diabetes, Heart rate variability

INTRODUCTION

We have recently developed a new APG system. The new APG machine is small like a “mouse”, and can be connected to a personal computer by USB port. We can easily measure APG waveforms from the fingertip of a subject in a sitting position. The software consists of three units to record, to measure and to analyze APG. When we record APG waveforms for 18 seconds by this system, it gives information about the degree of arteriosclerosis or “the relative vascular

age” automatically.^{[1], [2]}

This APG system also has another function. It gives information of heart rate variability, if we measure APG for two minutes. Heart rate variability can be estimated by the coefficient of the variation of the a-a intervals (CVaa%) of an APG.

The heart rate variability had been obtained by the coefficient of the variation of the R-R interval (CVRR%) of an ECG. This time, we examined the reliability of CVaa% as the index of heart rate variability. The purpose of this study is to evaluate the validity of the APG system to estimate heart rate variability, and to introduce the APG system as a system which would estimate autonomic nerve function instead of an ECG.

METHODS

Instrument

An APG machine named ARTETT (U-MEDICA, Inc. Co., Osaka) was used for this study (Fig. 1). ARTETT's sensor is an infrared sensor of the reflected type. The center wavelength is 940 nm, and the output maximum amplitude is ± 3.3 V in the amplification circuit. The time constant of the direct current cut is 1.5 seconds. The sampling frequency for the analog to digital exchange is 1,000 Hz, which corresponds to the standard of an ECG. The resolution ability is 3.23 mV/digit. ARTETT can be connected to a computer by USB Ver1.1. The USB cable is an A-B type whose length is 1.5 m. The filter treatment is done through the software. Power supply frequency removal rate is beyond 60 dB.

ARTETT is equipped with the measurement-and-analyzing software of waveforms. Using this software, an irregular pulse can be automatically removed, and all the a-a intervals (Taa) of waveforms can be measured automatically. The

Fig. 1 APG machine (ARTETT; U-medica, Inc., Co.).

Received: October 16, 2003

¹Address; College of Medical Engineering, Suzuka University of Medical and Science, 1001-1, Kishioka, Suzuka City, Mie, 510-0293 Japan. TEL: 81-593-83-9208 (ext. 2408), FAX: 81-593-83-9666, E-mail:

²Address; Research Section, U-medica Inc. Co., 5-5, Koubai-cho, Kita-ku, Osaka City, 530-0038 Japan. TEL: 81-6-4800-8626, FAX: 81-6-4800-8627

³Address; Clinical Examination, Meitetsu Hospital, 2-26-11, Sakou, Nishi-ku, Nagoya City, 451-8511 Japan. TEL: 81-52-551-6121

Fig. 5 The difference between the a-a interval and the R-R interval (msec.).

Fig. 6 The simple linear regression of the a-a interval and the R-R interval.

RESULTS

The Taa of an APG Waveform

Figure 2 shows three kinds of waves, which are the original wave (DPG), the first differential wave and the second differential wave (APG). An APG waveform has five element waves, which are the positive a-wave, the negative b-wave, the positive c-wave, the negative d-wave, and the positive e-wave. The interval from the a-peak to the next a-peak is called the

Fig. 7 The average of CVaa% in healthy people.

Note: *, $p<0.05$, **, $p<0.01$

Fig. 8 The average of CVaa% in the diabetics.

Taa. Figure 3 shows an ECG and an APG that were simultaneously recorded. The a-wave of APG appears with the fixed delay after the appearance of the R-wave of an ECG. Then, Fig. 4 is the graph where the first apex of the a-wave of APG aligns with the first apex of the R-wave of an ECG, by adjusting the time delay. It shows that the Taa of APG and the R-R interval on an ECG corresponds. It was also found that a T-wave's end corresponds to an e-wave's end. An APG waveform from the a-peak to an e-wave's end corresponds with the so-called systolic time of an ECG. Figure 5 is the difference between the Taa and the R-R interval. All the differences were within 10 msec. Figure 6 showed the simple linear regression of the a-a interval and the R-R interval. The multiple correlation coefficient was 0.999175. From the results, it was found that an ARTETT is a reliable machine whose sampling frequency is 1,000 Hz.

Table 1 Previous reports of the CVRR% of an ECG.

Age group	10 th.	20 th.	30 th.	40 th.	50 th.	60 th.	70 th.
Report 1	6.2%	6.0%	3.7%	3.2%	3.1%	2.8%	2.5%
Report 2		4.92%	4.02%	3.21%	2.8%	1.58%	

Note. Report 1: Souichirou Mothio: Aging and Disease, IYAKU Journal, p. 182, 1993
Report 2: Junko Fujimoto et al.: The Normality Reference Value of the Autonomic Nerve Function and a Standard Prediction-formula, by Using the Variation Coefficient of R-R Intervals on ECG. Diabetes 30: 167-173, 1987

The CVaa% in healthy persons

The mean CVaa% decreased by age as shown in Fig. 7. Each CVaa% in the age category was 5.4% with 1.00% of SD, 4.7% with 1.87% of SD, 4.3% with 1.34% of SD, 3.4% with 1.26% of SD, 3.1% with 1.49% of SD, and 2.2% with 1.23% of SD. It was clear that the heart rate variability became stable with aging.

Table 1 shows the mean CVRR% of an ECG in age categories in previous reports. As shown in Fig. 7, the mean CVaa% was bigger from 0.2 to 1.5% than the mean CVR-R% of an ECG in all age categories.

The CVaa% in diabetics

Comparing two groups of the healthy and the diabetics, as shown in Fig. 8, both in the age group of 40's and the 50's, mean CVaa% of the diabetics was significantly lower than that of healthy people ($p<0.01$; $p<0.05$; respectively). In the age group of 40's, the diabetics' mean CVaa% was 2.0% with 1.5% of SD. In the age group of 50's, the diabetics' mean CVaa% was 2.6% with 0.6% of SD.

On the other hand in the age groups of 30's, 60's and 70's, significant differences were not seen between diabetics and healthy persons. The diabetics' mean CVaa% was 3.1% with 0.2% of SD in the 30's age group, 2.7% with 1.4% of SD in the 60's age group, and 2.1% with 0.6% of SD in the 70's age group.

DISCUSSION

We proposed in this research a new method to know the heart rate variability with an APG system. Our new developing machine ARTETT uses the original filter-technology, and carries an analytic algorithm, which is well resistant to the changes in baseline and amplitude (In the patent application). The sampling time of ARTETT is 1,000 Hz, and the performance is trustworthy. Original waveform is reproduced faithfully without distortion (In the patent application).

We confirmed that the CVaa% which was derived from ARTETT is almost equal to CVRR% of an ECG. The difference between CVaa% and CVRR% in one person was so small we could ignore it. The multiple correlation coefficient was 0.999175, and the difference time was within 10 msec. It is easily understandable that 10 msec difference is too small to see, when we consider that one mark of the electrocardiogram's paper is 40 msec. Even so, the mean CVaa% would be 0.2 to 1.5% bigger than the mean CVRR% of an

ECG in all age categories (See Table 1 and Fig. 7). This difference is considered to be caused by breathing. The Breathing condition must be different in two different postures, which are the sleeping posture of an ECG and the sitting posture of an APG. As for other thinking, a sympatho-vagal balance would be different between the sitting posture and the sleeping posture. Therefore, at any rate, when we want to evaluate the heart rate variability by CVaa%, the standard value of CVaa% of each age category is necessary (See Fig. 7).

The significance of knowing the heart rate variability is great. It is said that the decrease in heart rate variability shows mainly in the inhibition of parasympathetic nerve function, although the impairment of the sympathetic nerve also associated with its decline.^[3] And, it is known that a decline of heart rate variability shows in aging, too.^{[4], [5]} If we can evaluate the heart rate variability properly, we can gain much information, for example, about circadian rhythm,^{[6], [7]} cardiac disorders,^{[3], [6], [8]} neurological disorders,^{[9], [10]} diabetic disorders,^{[11]-[13]} or aging.

In the diabetics of this study, too, the decline of heart rate variability appeared, whether they showed diabetic symptoms such as digestive dysfunction, difficulties in urination, orthostatic hypotension or orthostatic hypertension, or not. This was remarkably seen in the 40's and 50's age groups. Also in this study, we confirmed that heart rate variability presented as CVaa% became stable with aging. Thus, we could know heart rate variability very easily, and could evaluate it.

In conclusion, the introduced APG system in this study is suitable to estimate heart rate variability. And, when we want to evaluate heart rate variability by CVaa% of an APG instead of CVRR% of an ECG, a standard value of CVaa% in each age is necessary. The APG system has some possibilities for explanation of a mechanism of autonomic-nerve-related diseases.

REFERENCES

[1] Takada H: Proposal of Aging Score Method by Acceleration Plethysmography. Health Eval Prom 29: 855-861, 2002
[2] Takada H: Acceleration Plethysmography and Aging. KE-TSUATU 9: 1267-1272, 2002 (In Japanese)
[3] Gulli G, Gemin R, Pancera P, Menegatti G, Vassanelli C, Cevese A: Evidence of Parasympathetic Impairment with Cardiac Syndrome X. Cardiovas Res 52: 208-216, 2001
[4] Mothio S: Aging and Disease. IYAKU J. 1993, p. 182 (In

- Japanese)
- [5] Fujimoto J, et al.: The Normality Reference Value of the Autonomic Nerve Function and a Standard Prediction-formula, by Using the Variation Coefficient of R-R Intervals on ECG. *Diabetes* 30: 167-173, 1987 (In Japanese)
 - [6] Manolis AG, Katsivas A, Lazaris E, Kutsogeogis D, Lourvos N: Circadian Modulation of Ventricular Tachycardia Cycle Length Variability in ICD Patients with Dilated Cardiomyopathy. *Pacing Clin Electrophysiol* 20: 203-207, 1997
 - [7] Kageyama S: The Variety of R-R Intervals of ECG. *NAIKAGAKU* 55: 242-246, 1985 (In Japanese)
 - [8] Carney RM, et al.: Depression, Heart Rate Variability, and Acute Myocardial Infarction. *Circulation* 104: 2024-2028, 2001
 - [9] Goth T, Fukushima H, Sasaki G, Matsuo N, Takahashi T: Evaluation of Autonomic Nervous System Functions with Spectral Analysis of Heart Rate Variability in a Case of Tetanus. *Brain Dev* 23: 791-795, 2001
 - [10] Yang TF, et al.: Power Spectrum Analysis of Heart Rate Variability in Children with Epilepsy. *Childs Nerv Syst* 17: 602-606, 2001
 - [11] Wheeler T, Watkins PJ: Cardiac Denervation in Diabetes. *Br Med J* 4: 584-586, 1973
 - [12] De Angelis C, et al.: Modified Autonomic Balance in Offsprings of Diabetics Detected by Spectral Analysis of Heart Rate Variability. *Metabolism* 50: 1270-1274, 2001
 - [13] Yoshinari M, Wakisaka M, Nakamura U, Yoshioka M, Uchizono Y, Iwase M: Orthostatic Hypertension in Patients with Type 2 Diabetes. *Diabetes Care* 24: 1783-1786, 2001