Analysing Effect of Heart Rate and Age on Radial Artery Pressure Derived Systolic and Diastolic Durations in Healthy Adults

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Abstract

The measurements of cardiac systolic duration (SD) and diastolic duration (DD) have been well accepted as helpful tools for evaluating the cardiac functionality. In clinical practice, SD and DD are generally measured using echocardiography or heart sound signals. Recent studies have seen the attempts of approximating SD and DD by electrocardiogram (ECG) derived QT and TQ intervals, as well as radial artery pressure (RAP) derived foot-to-notch and notch-to-foot intervals. However, to the best of knowledge, there lacks deep elucidations on their performance when used as surrogate SD and DD data. We investigated the RAP-derived SD, DD, and ratio of SD to DD (S/D), to heart rate (HR) and age in healthy adults. Sixty healthy subjects were enrolled and their ECG and RAP signals were simultaneously recorded. The SD and DD were extracted automatically from RAP with the aid of the acceleration RAP. The HR was calculated using the RR interval extracted from ECG. Their mean values of 10 cardiac cycles were used in the analysis. Results demonstrated a negative linear relationship between SD and HR, a negative nonlinear relationship between DD and HR, and a positive linear relationship between S/D and HR (all $p < 0.001$). *In addition, age did not suggest statistically significant relation with those RAP derived parameters. Our results were in common with previous publications, confirming that the RAP derived foot-to-notch and notch-to-foot intervals are good surrogates for the cardiac systolic and diastolic durations.*

1. Introduction

Systole and diastole are fundamental periods of the cardiac cycle. Friedberg et al. demonstrated that children with different types of heart failure are characterized by a prolongation of left ventricular systole and an abnormal shortening of diastole [1, 2]. This loss of diastolic time was subsequently investigated in patients with exercise-induced diastolic dysfunction [3] as well as patients with exercise-induced pulmonary hypertension [4]. Those publications also showed potential of a global index, ratio of the systolic to diastolic duration (S/D), in the assessment of the heart functionality [1-4].

Aiming at establishing normal values for this S/D index, Sarnari et al. studied it in a large sample of normal children using Doppler flow signals [5]. On the other hand, Gemignani et al. investigated the effect of exercise stress test on the systolic and diastolic durations and S/D. To obtain the systolic and diastolic durations during exercise, they developed a heart sound monitoring system with a transcutaneous accelerometer sensor and defined them from the heart sound signals [6]. In addition to the Doppler and heart sound methods, ECG and radial artery pressure (RAP) signals have also been used to determine the systolic and diastolic durations. Imam et al. used the ECG-derived QT and TQ intervals as surrogate systolic and diastolic durations, and demonstrated the performance of QT/TQ ratio in the detection of cardiac autonomic neuropathy in diabetes [7]. In our previous studies, we used the foot-to-notch and notch-to-foot intervals, which was derived from RAP signal to estimate the systolic and diastolic duration, and showed the nonlinear beat-to-beat coupling between the cardiac cycle and the notch-to-foot interval [8, 9]. However, although the Q and T waves in ECG, as well as the systolic foot and diastolic notch in RAP, have well-defined physiological meanings, further elucidations are still required to determine whether they can be used in approximating the Doppler or heart sound defined systolic and diastolic intervals.

In this study, our main objective was to investigate the relation of RAP derived systolic and diastolic durations in healthy adults with heart rate and age.

2. Methods

2.1. Subjects and protocol

Sixty healthy subjects were studied. They were taken from one of our previous clinical trials with a view to assess the cardiovascular functioning by jointly analysing

Table 1. Physiological characteristics.

Variables	Value	Range
No. (M/F)	60 (28/32)	-
Age (years)	50 ± 15	23- 72
BMI (kg/m^2)	23 ± 3	17- 30
SBP (mmHg)	110 ± 13	83-129
DBP (mmHg)	75 ± 9	58- 89

BMI body mass index, *DBP* diastolic blood pressure, *No*. number, *SBP* systolic blood pressure. Value is expressed as number (male/female) or mean ± SD. Range is expressed as min-max.

the common non-invasive physiological signals including ECG, heart sound and RAP. The ethical approval was obtained from the Qilu Hospital of Shandong University. Table 1 shows the physiological characteristics of studied subjects.

Measurements were undertaken in a quite temperature controlled clinical measurement room (25 ± 3 °C) at the Qilu Hospital of Shandong University, by a Cardiovascular Function Detection device (CV FD–I) produced by Huiyironggong Tech. Co. Ltd., Jinan, China. Each subjects lay supine on a measurement bed for a 10 min rest period before the formal recording to allow cardiovascular stabilization. A piezoresistive sensor was attached to the left wrist to acquire the RAP signal. ECG electrodes were attached to the right wrist and the right and left ankles to acquire a standard limb lead-II ECG. Both signals were recorded at a sampling frequency of 1,000 Hz. Subjects were told to breathe regularly and gently during the whole measurement.

2.2. RAP-derived systolic and diastolic duration

The acceleration signal of RAP was firstly constructed, and used as a reference for the extraction of systolic feet and diastolic notches [10]. The correspondence between the feature points in RAP and in acceleration RAP signals was demonstrated in Figure 1. Customized program was designed by the MATLAB platform (Ver. R2014b, Mathworks, MA, USA) to facilitate the extraction. The systolic duration (SD) was defined as the interval from the systolic foot to the diastolic notch of the same cardiac cycle, and the diastolic duration (DD) as the interval from the diastolic notch to the systolic foot of the subsequent cardiac cycle. The mean values of SD and DD, respectively, of the first 10 cardiac cycles in each RAP recording were used in the following analyses.

2.3. Heart rate

The heart rate (HR) was estimated by the consecutive RR intervals in ECG recording. Firstly, we detected the R-peak locations in the ECG automatically using a template matching approach [11]. RR intervals of the first 10 cardiac cycles in each ECG recording were then averaged to obtain an estimation of HR.

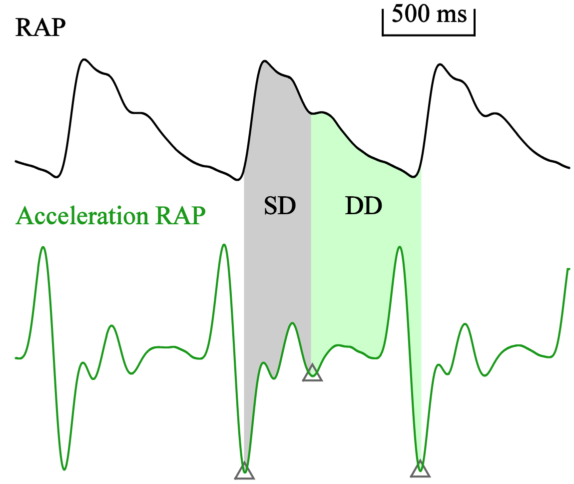

Figure 1. Schematic diagram for the extraction of systolic duration (SD) and diastolic duration (DD) with the help of acceleration radial artery pressure (RAP) signal.

2.4. Statistical analysis

The SPSS software (Ver. 20.0, IBM, USA) was used for the statistical analysis. Relationships were evaluated between the RAP derived SD, DD, S/D parameters and HR, age, respectively, using univariate regression analysis. Statistical significance was accepted at $p < 0.05$.

3. Results

We reported the cardiac intervals (including the SD and DD) in milliseconds, S/D as decimal fractions, and HR in beats per minute (bpm).

In the 60 healthy adults, their mean age was 50 ± 15 years (range, 23-72 years) (Table 1). The mean HR was 67 ± 8 bpm (range, 50-95 bpm), the averaged SD and DD were 353 ± 19 ms (range, 309-397 ms) and 558 ± 100 ms (range, 316-823 ms), respectively. The mean S/D was

Table 2. Averaged HR and cardiac intervals.

Variables	Value	Range
HR (bpm)	67 ± 8	50-95
SD (ms)	353 ± 19	309-397
DD (ms)	558 ± 100	316-823
S/D	0.65 ± 0.11	0.43-1.00

HR heart rate, *SD* systolic duration, *DD* diastolic duration, *S/D* ratio of the systolic to diastolic duration. Value is expressed as mean ± SD. Range is expressed as min-max.

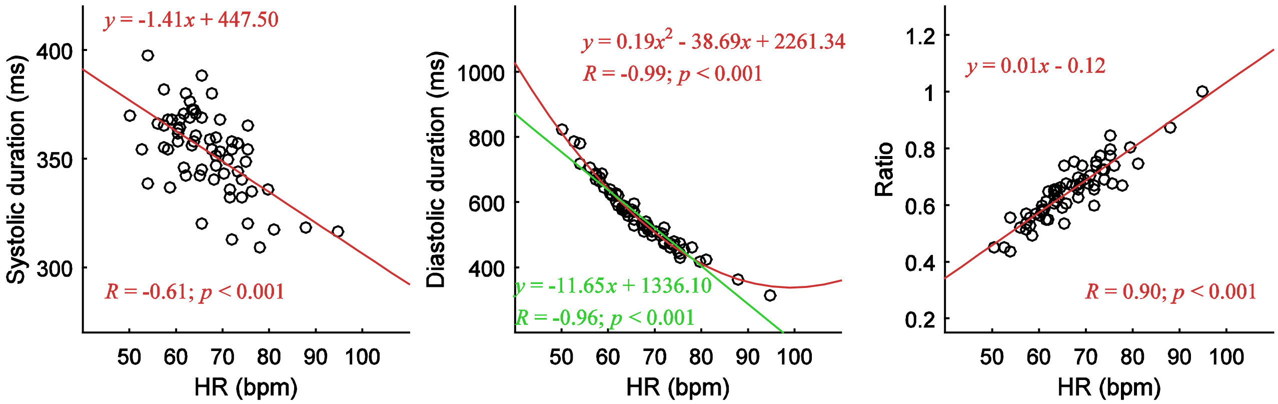

Figure 2. RAP-derived systolic duration, diastolic duration, and S/D ratio are shown as a function of HR.

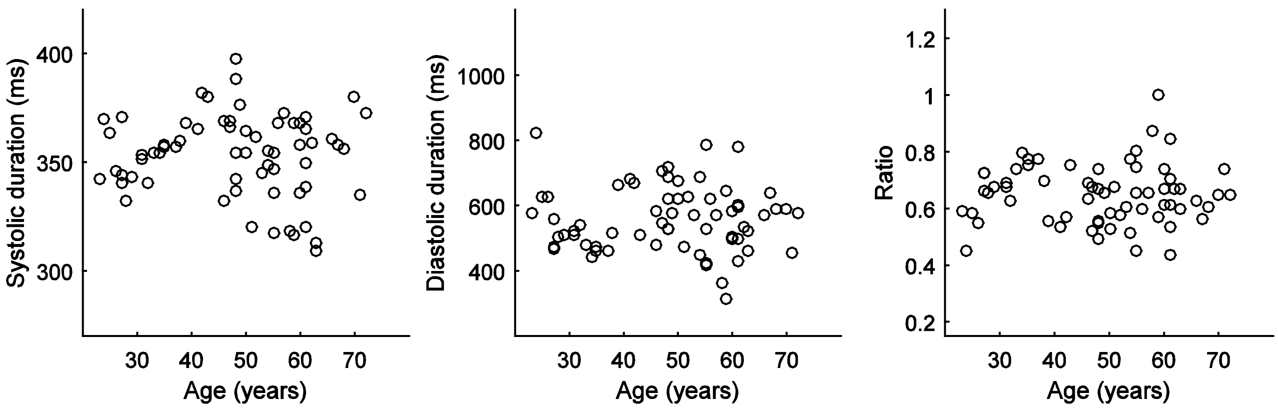

Figure 3. RAP-derived systolic duration, diastolic duration, and S/D ratio with respect to ages.

0.65 ± 0.11 (range, 0.43-1.00) (Table 2).

The relationships of RAP derived SD, DD, and S/D parameters to HR are demonstrated in Figure 2. The SD showed a negative linear relationship to HR increase ($SD = -1.41HR + 447.50$, $R = -0.61$, $p < 0.001$). The DD showed a negative nonlinear relationship to HR increase ($DD = 0.19HR^2 - 38.69HR + 2261.34$, $R = -0.99$, $p < 0.001$), although a linear fit also worked ($DD = -11.65HR + 1336.10$, $R = -0.96$, $p < 0.001$). However, with a quadric fit there was an improvement on the fitting error (from 26.67 in linear fit decreased to 16.21 in quadric fit, as suggested by the SPSS). The S/D correlated positively with HR ($S/D = 0.01HR - 0.12$, $R = 0.90$, $p < 0.01$).

Age did not demonstrate relationships with all three parameters – RAP derived SD, DD, and S/D, as shown in Figure 3.

4. Discussion

The concept of measuring the systolic and diastolic durations to evaluate cardiac functionality has been validated using both the M-mode echocardiography [1, 4, 5] and heart sound signals [3, 6]. Those studies provided a simple yet very potential clinical index, ratio of systolic to diastolic duration (S/D), which would be elevated in cardiac dysfunction.

Some more recent publications used ECG derived QT and TQ intervals, or RAP derived foot-to-notch and notch-to-foot intervals, as surrogates of physiological systolic and diastolic durations [7-9]. Their measurements, compared with especially echocardiography, are simple, which thus allows this valuable S/D index implemented in novel household intelligent medical devices. However, both above approximating methods may not represent the true cardiac systolic and diastolic durations. For example, QT interval in ECG represents the depolarization and repolarization periods of the ventricle, whereas the foot-to-notch interval in RAP reveals the left ventricle ejection time. But they have indeed direct correlations with the true systolic and diastolic durations. Since previous studies have demonstrated certain relations of systolic and diastolic durations as well as S/D ratio to heart rate and age [5, 6], the surrogate intervals should reveal similar results.

In this study, we analyzed the relation of RAP-derived SD, DD, and S/D parameters to HR and age. Results showed negative relationships of SD and DD to HR, whereas a positive relationship of S/D to HR (all $p < 0.001$, see Figure 2). Besides, the correlation between DD and HR was found nonlinear and as a result a quadric regression improved the fitting error compared with the linear regression. However, age did not demonstrate statistically significant relations with any of the three parameters. The results are in common with the previous publications [5, 6], confirming that the RAP derived foot-to-notch and notch-to-foot intervals may be good surrogate intervals for cardiac systolic and diastolic durations. In addition, the nonlinear relation between DD and HR suggests that a nonlinear coupling analysis between them may be of merit for revealing the cardiac functioning [8, 9].

Study limitations: The RAP waveform may be distorted with arterial stiffness e.g., the early reflection wave may superimpose the forward wave during systole in subjects with arteriosclerosis, and will consequently shift the notch in a complicate way [12]. Therefore, simple acceleration signal may not provide accurate reference for the extraction of systolic feet and diastolic notches. Liu et al. developed a Gaussian fitting method to approximate the waveform by three Gaussian functions which allows a more robust extraction of both forward and reflection waves [13]. Through this method, the systolic and diastolic durations probably can be defined more accurately.

5. Conclusion

The RAP derived foot-to-notch and notch-to-foot intervals were used as a surrogate systolic and diastolic durations in the present study. The relations of those RAP derived SD, DD, and S/D parameters to HR and age were investigated. Results demonstrated: i) a negative linear relationship between SD and HR; ii) a negative nonlinear relationship between DD and HR; and iii) a positive linear relationship between S/D and HR. Age did not reveal statistically significant relationship with any of the three parameters. Our results indicate that the RAP derived cardiac intervals could be a good surrogate for the cardiac systolic and diastolic durations.

Acknowledgements

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