Variability of the Systolic and Diastolic Electromechanical Periods in Healthy Subjects

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Abstract

Our aims were to assess: 1)the variability of the systolic and diastolic periods, estimated by the electromechanical interval measured from the R wave to the systolic peak of the pressure wave (RPre), and the interval from this peak to the next R wave (PreR), respectively; 2)the effect of two maneuvers on the variability of these periods. ECG, arterial pressure and respiration were recorded from 21 volunteers in three 5-min conditions: supine (S), controlled breathing (CB) and exercise (E). Spectral analysis of RR, RPre, PreR and respiration series was performed to obtain their high (HF) and low (LF) frequency components. Both LF and HF powers of PreR changed in parallel with those of RR intervals. The maneuvers did not affect the LF power of RPre interval (p>0.05) and had a minimal effect on the HF power; both components were much smaller than those of PreR in S and CB (p<0.001) but similar during E. The minimal and constant spectral powers of RPre interval and the highly variable components of PreR indicate that the cardiac autonomic modulation is expressed preferentially in the diastolic period rather than in the systolic one.

1. Introduction

The cardiac electric cycle has been divided into the atrioventricular conduction and ventricular repolarization intervals to perform the spectral analysis of their variability [1,2]. In line with this approach, in the present study we divided the RR interval into two complementary electromechanical intervals that roughly estimate the duration of the systolic and diastolic phases. We considered the electromechanical interval measured from the R wave to the systolic peak of the arterial pressure wave (RPre) as a systolic period index, and the interval from this peak to the next R wave (PreR) as a diastolic period index. This method combines widely used instrumentation with simple and reliable processing.

Recently, some authors [3] have obtained the pulse transit time (PTT) in the same way we computed the RPre period. PTT is a simple non-invasive measurement defined as the time it takes a pulse wave to travel between two arterial sites [4]. It has been suggested as an arterial pressure surrogate and has become a popular index of arterial stiffness [3]. However, there is not a unique procedure to measure PTT. Diverse instruments as well as various fiducial points have been used, resulting in a non-standardized indicator. The most common methodology computes PTT as the time between the R wave peak and the onset of the upstroke of the photoplethysmographic pulse [4,5]. The few studies that have assessed the PTT variability (PTTV) using spectral analysis have tried to validate its low frequency power (LF) as a sympathetic activity measure [5,6].

We were interested in comparing the variability of the systolic, diastolic and full cardiac cycle periods, and how this variability related to the cardiac autonomic changes produced by provocative maneuvers. Therefore, our aims were to assess: 1) the power spectra of the RPre, PreR and RR interval series, and 2) the effect of two maneuvers that modify the cardiac autonomic activity on the variability of these series.

2. Methods

2.1. Subjects

Twenty one healthy and sedentary subjects, 12 men and 9 women, were studied. Mean age, height and weight were 23.3 ± 1.8 years, 165.0 ± 8.0 cm and 61.2 ± 10.1 kg respectively. Health status of the subjects was evaluated by resting ECG, spirometry and clinical history. Their written informed consent was requested to participate.

2.2. Protocol

In a first visit to the laboratory the health status and anthropometric characteristics of the volunteers were evaluated, and in a second visit the experimental stage was carried on. Two 5 min long maneuvers inducing stationary heart rate states and opposite changes in the cardiac autonomic activity were performed [7]. These were: controlled breathing (CB) at 0.2 Hz, characterized for increasing heart rate variability (HRV) due to augmented vagal outflow; and a single bout of 100W cycle exercise (E), which elicits an important variability decrement via vagal withdrawal. Supine position (S) was considered the control state. ECG, non-invasive blood pressure and respiratory movements were recorded during each condition.

2.3. Recorded variables and signal acquisition

ECG was detected at the CM5 derivation using a bioelectric amplifier (Biopac Systems). None of the participants presented ectopic beats. Non-invasive blood pressure was measured by Finapres (Ohmeda). The respirogram was obtained by a stretching pneumograph (Nihon Kohden). ECG, blood pressure and respirogram signals were digitized at a sampling rate of 2 kHz via an acquisition and display system (Biopac Systems).

2.4. Data processing

Peak values of the R wave and the systolic point of the arterial pressure pulse were detected to compute the RPre, PreR and RR intervals. The first interval was defined as the time from the occurrence of the R wave to the systolic pressure, and the second one as the complementary time, i.e. from the systolic pressure to the next R wave (Fig. 1). Respiratory series were also obtained. The mean RR (M_{RR}), RPre (M_{RPre}) y PreR (M_{PreR}) intervals of each recording was calculated. The series were cubic-spline interpolated, resampled at 4 Hz and detrended. Power spectra of the series were computed using a Welch periodogram method. Power was integrated in two frequency bands, from 0.04 to 0.15 Hz to obtain the LF components of RPre (LF_{RPre}), PreR (LF_{PreR}) and RR (LF_{RR}) series, and from 0.15 to 0.4 Hz (extended to 1 Hz for E) to compute the high frequency (HF) components of RPre (HF_{RPre}), PreR (HF_{PreR}) and RR (HF_{RR}), all in absolute units. The square root of the ratios [5] of HF_{RPre} to HF_{RR} (HF_{RPre}/HF_{RR}) and of HF_{PreR} to HF_{RR} (HF_{PreR}/HF_{RR}) were calculated.

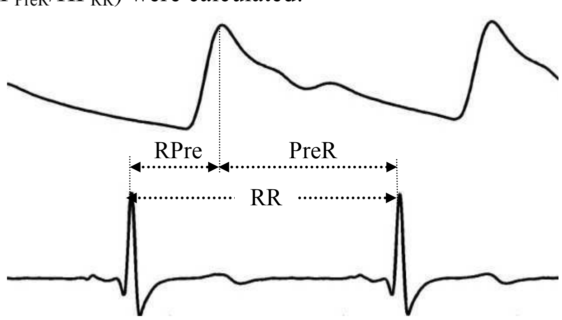

Figure 1. Division of RR interval into the complementary systolic and diastolic periods RPre and PreR.

2.5. Statistical analysis

Data were expressed as mean ± standard deviation. Inter- and intra-maneuvers differences among the spectral indexes derived from RR, RPre and PreR series were tested by ANOVA for repeated measures. Post-hoc pairwise comparisons were done by the Tukey test. Linear regressions and correlations among the pooled measures of the RPre, PreR and RR intervals were computed. Statistical significance was accepted at $p<0.05$.

3. Results

During S and CB conditions, M_{RPre} was around one-third of M_{RR}, but increased to almost one-half during E at the expense of a greater decrement of M_{RR} (Table 1).

Table 1. Mean±sd of the M_{RR}, M_{RPre}, M_{PreR} intervals and the M_{RPre}/M_{RR} ratio during the three conditions. N=21.

	Supine	Controlled Breathing	Exercise
M_{RPre} (ms)	270±17	276±19	194±14†
M_{PreR} (ms)	613±105	511±89†	214±35†
M_{RR} (ms)	885±111	790±91†	410±43†
M_{RPre}/M_{RR}	0.31±0.04	0.35±0.05	0.48±0.04†

†$p<0.001$ in relation to S.

Figure 2 shows a representative example of the RPre, PreR and RR interval series and their respective power spectra during the three conditions. While in S and CB the variability of the PreR and RR intervals series was very similar, the variability of RPre series was markedly reduced. In E, the variability of these three intervals was minimal (Fig. 2A). Spectra of PreR and RR were similar but HF_{PreR} power was slightly greater than the HF_{RR}. In S and CB, the spectra of RPre were so strikingly lower that were not visible, but in E the RPre and PreR spectra were superimposed (Fig. 2B). When the RPre spectra were magnified 100 times they showed a prominent HF power (Fig. 2C) associated to the respiratory spectra (Fig. 2D). In relation to S, mean HF_{RR} and HF_{PreR} powers increased in CB ($p<0.001$) and decreased drastically ($p<0.001$) in E (Table 2); mean values of both LF_{PreR} and LF_{RR} powers decreased in CB ($p<0.001$) and reduced further during E ($p<0.001$). During the three conditions, while the mean values of HF_{PreR} power were greater than those of HF_{RR} ($p<0.001$), as indicated by the HF_{PreR}/HF_{RR} ratio which reached a maximum value in E (Table 2), the means of LF_{PreR} and LF_{RR} powers were not different ($p>0.05$). In S and CB conditions both LF_{RPre} and HF_{RPre} were much lower than those of RR and PreR intervals ($p<0.001$). This difference was blunted during E. Means of LF_{RPre} power did not change across conditions ($p>0.05$) but HF_{RPre} power increased slightly during CB ($p<0.001$) and decreased subtly in E ($p<0.001$) in relation to S (Table 2).

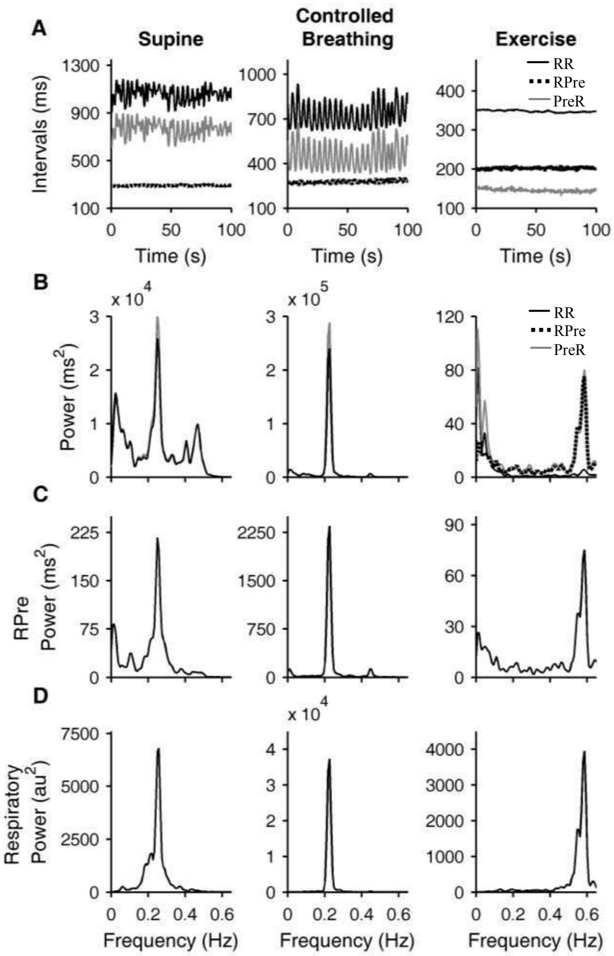

Figure 2. Typical example of (A) RPre, PreR and RR intervals time series, (B) their respective power spectra, (C) magnified RPre power spectra and (D) respiratory spectra, in the three conditions used.

Mean values of HF_{RPre} power were greater than those of LF_{RPre} in S and CB ($p<0.001$) and were not different during E ($p>0.05$).

Table 2. Mean ± sd of the spectral measures of RPre, PreR and RR intervals and the HF and LF powers of RPre and PreR ratios in the three conditions. N=21.

	Supine	Controlled Breathing	Exercise
HF_{RPre} (ms^2)	3±2*	15±7†*	1±0.5†
HF_{PreR} (ms^2)	473±372‡	1854±1263†‡	2±1†‡
HF_{RR} (ms^2)	420±339	1611±1205†	1±0.5†
HF_{RPre}/HF_{RR}	0.01±0.01	0.01±0.01	2.2±1.8
HF_{PreR}/HF_{RR}	1.14±0.05	1.19±0.15	3.1±2.0
LF_{RPre} (ms^2)	1±0.6*	1±0.4*	1±0.3*
LF_{PreR}(ms^2)	318±236	149±119†	4±4†
LF_{RR}(ms^2)	309±230	149±122†	4±4†

† p<0.001 in relation to supine; ‡ p<0.001 between PreR and RR; * p<0.001 between RPre and RR

While the pooled values of M_{PreR} were strongly correlated to M_{RR}, the correlation between M_{RPre} and M_{RR} was lower. The slope of the M_{RPre} vs. M_{RR} regression was less steep ($p<0.001$) than that of M_{PreR} vs. M_{RR} (Fig. 3).

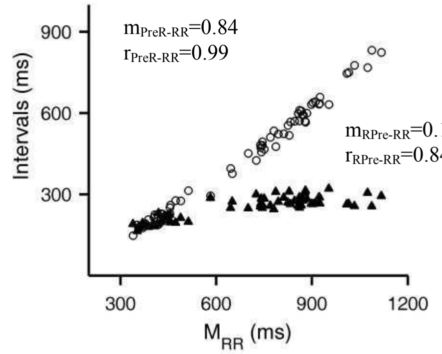

Figure 3. Relationships between M_{RPre} and M_{RR} (▲) and between M_{PreR} and M_{RR} (○). m_x=regression slope.

While the correlations between the spectral indexes of PreR and RR intervals were very strong, with slopes close to one, the regressions of RPre indexes had weaker correlations and flat slopes (Fig. 4).

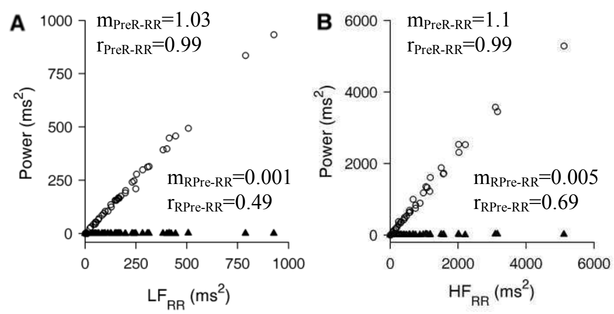

Figure 4. (A) Relations between LF_{RPre} and LF_{RR} (▲) and between LF_{PreR} and LF_{RR} (○). (B) Relations between HF_{RPre} and HF_{RR} (▲) and between HF_{PreR} and HF_{RR} (○). m_x=regression slope.

4. Discussion and conclusions

Our main finding is that RPre intervals have a minimal variability that remains constant in all conditions, in contrast with the high variability of PreR and RR intervals in S and CB, which is drastically reduced to magnitudes similar to those of RPre variability during E.

The similarity between the variability of the diastolic PreR interval and of RR intervals throughout the maneuvers is documented by the great resemblance of their power spectra (Fig. 2), the strong correlations between their indexes (Figs. 3-4) and the similarity of their LF components values (Table 2). These findings suggest that the diastolic period is flexible and that, due to its great ability to shorten and lengthen, it totally reflects the autonomic influence responsible of the adjustments of heart rate to the experimental conditions employed. In addition, the fact that HF_{PreR} was greater than HF_{RR}

component, most obviously during E, suggests an extra respiratory modulation probably exerted by a non-neural mechanism over the period between systolic pressures.

In contrast, RPre intervals remain relatively constant across the conditions, supported by the stable values of M_{RPre} and spectral measures (Tables 1-2), and the flat slopes and weak correlations between the RPre and RR indexes (Figs. 3-4). Also, the HF_{RPre}/HF_{RR} ratio is very small in S and CB but large during E, because this last maneuver drastically reduces HF powers of RR but does not alter those of RPre (Table 2). It is noteworthy that the HF_{RPre} power is greater than the LF_{RPre} power during S and CB conditions and of similar amplitude during E (Fig. 2C, Table 2). Therefore, the minimal variability of the RPre interval is determined almost exclusively by respiratory influence. These results suggest that the impact of the autonomic modulation on the systolic RPre interval is greatly reduced, probably due to the refractory period of the sinus node. This mechanism ensures the appropriate timing of the systolic electromechanical events by maintaining the relative constancy of RPre interval throughout different conditions.

Unlike Forester et al. [1], who analyzed the variability of the P wave-to-R wave and R wave-to-T wave intervals within the electric cardiac cycle, we divided each RR interval into two complementary intervals, using the systolic pressure as the reference point to derive the electromechanical intervals RPre and PreR. These intervals share two important characteristics: they provide rough estimates of the systolic and diastolic periods, and they are easy to detect and measure.

A better index of the electromechanical systole duration is the interval measured from the Q wave to the second heart sound (QS_2). This interval includes the preejection period and the left ventricular ejection time [8]. The diastolic interval would then be its complement. Therefore, the RPre interval can roughly estimate the electromechanical systole interval because it comprises the second part of the preejection period (leaving out the initial part of the depolarization) and the first part of the ejection (not considering the aortic valve closure), although it includes the vascular transit time. RPre and PTT have this last period in common.

We could not find any studies on the spectral analysis of the RPre and PreR intervals variability. However, since RPre is similar to PTT, we discuss the few studies that performed spectral analysis of PTTV. Ma and Zhang [4] concluded that PTTV is mainly caused by parasympathetic modulation. Tang et al. [5] reported an increase in LF power of the PTT series that might arise from an increase in LF pre-ejection period variability, as a result of an increased cardiac sympathetic activity in sepsis patients. Gil et al. [6] documented in apneic children that spectral indexes derived from PTTV reflect sympathetic changes more clearly than HRV. We disagree with these interpretations. The reduced spectral power of the RPre series suggests only a micromodulation from the autonomous nervous system on this interval. LF_{RPre} power does not change throughout the experimental conditions and its amplitude is lower or equal than that of the HF_{RPre} power even during exercise, suggesting that it does not indicate the sympathetic activity changes elicited by the maneuvers. Moreover, we consider that the micromodulation of the HF_{RPre} is caused by a non-neural respiratory effect. By analogy to the observed RPre behavior, we speculate that the reduced PTTV should not be affected by conditions associated to depressed HRV, like most cardiological diseases.

The markedly reduced and constant amplitude of both HF and LF powers of RPre series, and the highly variable spectral measures of PreR and RR intervals, indicate that the systolic period is relatively constant throughout the conditions, while the diastolic interval shows considerable flexibility. Hence, due to the cardiac electrical properties the autonomic modulation is expressed preferentially in the diastolic period rather than in the systolic one.

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