Performance of the Low Frequency Power of Pulse Pressure Variability as a Sympathetic Activity Measure during Supine Rest, Controlled Breathing, Standing and Exercise

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Abstract

In 28 healthy volunteers, we assessed the effects of 5-min maneuvers that provoke different sympathetic and respiratory activities (supine rest (SR), controlled breathing (CB), standing (S) and exercise (E)) on the instantaneous low (LF) and high frequency (HF) powers of pulse (LFPP, HFPP), systolic (LFSP, HFSP), and diastolic pressures (LFDP, HFDP), to associate physiological correlates to LF PP and HF PP, and to test the interchangeability of those of systolic and diastolic pressures. Except for LFDP in E, LF PP, LF SP and LF DP powers increased progressively from CB to SR, S and E. LFSP and HFSP powers were greater than LFDP and HFDP. Correlations of both LF PP and HF PP were greater with LFSP and HF SP. Instantaneous coherences of respiration with HF PP, HF SP and HF DP were greater than 0.76. Sympathetic modulation is greater in LF SP than in LF DP and is smaller in LF PP than the respiratory modulation in HFPP. LF PP adequately marks the progressive sympathetic increases evoked by the maneuvers, mainly due to its greater resemblance with LFSP. LF DP is not a satisfactory sympathetic index. LF SP and HF SP are not interchangeable with LFDP and HFDP respectively.

1. Introduction

Pulse pressure (PP) is considered a risk predictor of a wide variety of cardiovascular diseases, independent from systolic pressure (SP) and diastolic pressure (DP) [1]. Moreover, it has been found to be an index of arterial stiffening, pulse wave velocity and stroke volume magnitude [2, 3].

It has been reported that PP exhibits variability (PPV) and that its frequency spectrum presents components in the same standard low (LF) and high frequency (HF) bands as other cardiovascular variables [2]. The LF power of PPV (LFPP) has been associated with baroreflex sensitivity (BRS) [2], and its HF power (HFPP) has been related to respiration in ventilated patients [3].

After some evidence supporting the similarity between the frequency spectra of SP variability (SPV) and DP variability (DPV) was provided several decades ago [4], there were no further studies to corroborate it, and hence their spectral components have been used indistinctly, being referred to by the imprecise term “blood pressure variability” [5, 6]. Of the SPV and DPV spectral components, the most studied and used one is the LF power of SP (LFSP), which, by the available evidence, is considered a suitable noninvasive marker of sympathetic activity [7, 8].

It is still unclear if maneuvers that modify autonomic and respiratory activities affect the spectral powers of SPV and DPV similarly. Furthermore, given that PP series, which is formed by subtracting DP from SP series, presents a power spectrum, SPV and DPV must therefore be necessarily different. Considering these notions, we examined: 1) the effects of four maneuvers that elicit different respiratory and sympathetic activity levels on the spectral powers of PPV, SPV and DPV, and 2) the relations among them and with measures of heart rate variability (HRV).

2. Methods

2.1. Subjects

Twenty-eight healthy, normotensive, nonsmoking and sedentary subjects, 16 male and 12 female, were studied. Mean age, height and weight were 22.5±2.2 years, 164±8 cm and 60.4±10.3 kg respectively. Their written informed consent was requested to participate.

2.2. Protocol

Volunteers visited the laboratory twice. The first time, their health status and anthropometric variables were evaluated, and in the second visit the experimental stage was carried out. The 5-min-long maneuvers employed to induce specific changes in the sympathetic and respiratory activities were: supine rest (SR) with spontaneous breathing as control condition; postural change from SR to standing position (S); lying with
controlled breathing (CB) at 0.2 Hz with tidal volume of about 1.5 liters, and one bout of 100W cycling exercise (E). Resting periods between maneuvers were 5 min long.

2.3. Signal recording and acquisition

ECG was detected at the CM5 bipolar lead using a bioelectric amplifier (Biopac Systems). Noninvasive arterial pressure (AP) was measured by Finapres (Ohmeda). The respirogram (Res) was obtained with a stretching pneumograph (Nihon Kohden). ECG, AP and Res signals were digitized at a sampling rate of 1 kHz via an acquisition and display system (Biopac Systems).

2.4. Data processing

R-wave peaks, SP and DP values were detected from ECG and AP waveforms respectively to form the corresponding time series. DP series were beat-by-beat subtracted from SP series to generate the PP series. All time series, including Res, were cubic-spline interpolated, resampled at 4 Hz and separated into levels (RR L, SP L, DP L and PP L) and oscillations by the smoothness priors method with a cutoff frequency of 0.03Hz. Time-frequency spectra of the oscillations series, estimated with the smoothed pseudo-Wigner-Ville distribution, were integrated to compute their LF (LFRR, LFDPP and LF Res) and HF powers (HFRR, HFS, HFDPP and HFRes). Time-frequency coherences of HFSCL with HFP, HFS and HFDPP were obtained. Coherences greater than 0.5 were considered significant. Indexes dynamics were ensemble-averaged for visualization, and were segmented into 50-s epochs for statistical purposes.

2.5. Statistical analysis

Data are expressed as mean ± SD. Inter- and intra-maneuver indexes differences were tested by ANOVA for repeated measures. Post-hoc pairwise comparisons were performed by the Tukey test. Pooled means of the 50-s segments of the indexes dynamics of the four maneuvers were used to compute linear regressions and correlations for each subject. Statistical significance was accepted at p<0.05.

3. Results

In relation to SR (Fig.1): lnHFRR power was maximal in CB and gradually decreased in S and E (p<0.001); RR L progressively decreased in CB, S and E (p<0.001); SP L, DP L and PP L increased in E condition (p<0.001); and respiratory frequency (RF) decreased in CB (p<0.001) and increased progressively in S and E (p<0.001).

In the time-frequency spectra of PPV and SPV, the LF power gradually rose in S and E, becoming maximal in the latter, but that of DPV did not. The HF power was different for each pressure series in each condition and greatest in E (Fig. 2).

Fig. 1. Pooled means±SD of the dynamics of: a) lnHFRR, b) RR L, c) SP L, d) DP L, e) PP L and f) RF during the four maneuvers. *p<0.001 vs. SR, control condition.

Important fluctuations of instantaneous power were noticeable in both frequency bands in each maneuver.

In all maneuvers, pooled means of the LF powers dynamics of the three pressures were different (p<0.001), greatest for LFS, intermediate for LFDPP (around half of LFS power), and smallest for LFPP, except for SR, in which LFDPP and LFPP were similar (Fig. 3). In relation to SR, mean values of LF powers of the three pressures decreased in CB (p<0.01) and increased progressively in
S and E conditions (p<0.001), except LFDP in E (Fig. 3).

In CB, S and E conditions, HFSP power was greater (p<0.03) than HFPP, and this component was in turn greater (p<0.015) than HFDP (Fig. 3). In SR condition, only HFSP was greater (p<0.001) than HFDP. HF powers of the three pressures were maximal in E. Except in CB, LFSP power was greater (p<0.001) than HFSP. LFDP was greater (p<0.009) than HFDP in SR and S. HFPP was greater (p<0.001) than LFPP in CB, S and E.

While the mean correlation of LFPP with LFSP was 0.88±0.06 (Fig. 5a), its correlations with LFDP (Fig. 5b), lnHFRR and RRl, ranged from -0.60 to 0.73. The correlations of HFPP with HFSP and HFDP ranged from 0.79 to 0.84 (Fig. 5 c-d). While HFSP-HFDP correlation was 0.72±0.33, LFSP-LFDP correlation was 0.92±0.04.

In the four maneuvers, pooled means of the time-frequency coherences of HFRes with HFSP ranged from 0.92 to 0.96 and with HFPP and HFDP ranged from 0.76 to 0.96 (Fig. 4).

The progressive sympathetic activity increase and vagal withdrawal elicited by CB, SR, S, and E, were indicated by lnHFRR and RRl, and the different respiratory activities were reflected in RF (Fig. 1).

The few studies that have performed spectral analysis of PPV associated LFPP with BRS in subjects in supine position [2], and HFPP with respiratory activity in mechanically ventilated patients [3]. These studies did not assess the close relation among the spectra of the three pressures series; specifically, they did not deal with the

4. Discussion

This study establishes that, in healthy subjects, the time-frequency distributions (TFD) of SP and DP series are not interchangeable, and those of their difference, the PP series, are associated to sympathetic and respiratory activities. These notions are supported by the following findings: 1) LFPP, LFSP and LFDP powers increased progressively from a minimum in CB to SR, then S and to a maximum in E, except for LFDP in E, being the LFSP powers nearly double those of LFDP, and those of LFPP the smallest. 2) Correlation of LFPP with LFSP was very strong, and with LFDP, lnHFRR and RRl were lower. 3) HFSP was greater than HFDP in all maneuvers, and HFPP power was of intermediate value. Similarly, coherences with HFRes were very high for HFSP and smaller for HFPP and HFDP. 4) HPFP-HFSP correlation was strong and greater than HFPP-HFDP. HFSP-HFDP correlation was lower than that of LFSP-LFDP.

Fig. 3. Ensemble averages and pooled means±SD of instantaneous dynamics of LF and HF powers of SP (thin line), DP (dotted line) and PP (thick line) in: CB (a and b), SR (c and d), S (e and f) and E (g and h). *p<0.01 vs SR, †p<0.001 vs. LFPP, ‡p<0.015 vs. HFDP.

In the four maneuvers, pooled means of the time-frequency coherences of HFRes with HFSP were greater than 0.92, with HFPP ranged from 0.86 to 0.96 and with HFDP ranged from 0.76 to 0.96 (Fig. 4).

Fig. 4. Ensemble averages of (a) HFRes-HFPP and (b) HFRes-HFDP time-frequency coherences obtained in: SR (thin dotted line), CB (thin solid line), S (thick solid line) and E (thick dotted line).

Fig. 5. Individual (black lines) and mean (thick grey lines) linear regressions of: a) LFPP vs. LFSP, b) LF PP vs. LFDP, c) HFPP vs. HFSP, d) HFPP vs. HFDP powers.
notion that, for PPV to present a meaningful power spectrum, SPV and DPV must be different. Moreover, it has not been clearly established how different the spectra of SPV and DPV are from one another. Based on fragile evidence, a prestigious study established that they were similar [4], and subsequently LF SP and LF DP powers have been indistinctly employed as sympathetic markers, the former more frequently than the latter [5].

In our study, in response to all maneuvers, both LF and HF powers of SPV are around double those of DPV; therefore, their differences necessarily generate the LF and HF powers of PPV. To the best of our knowledge, this is the first study to: 1) explore the effects of sympathetic maneuvers on the TFD of PPV, associating the sympathetic activity to its LF power and the respiratory influence to its HF power as physiological correlates, and, in consequence 2) document the non-interchangeability of the TFD of SPV and DPV.

LF SP power is an adequate noninvasive sympathetic marker with enough supporting evidence published [6, 8]. In contrast, the evidence that supports the performance of LF PP as sympathetic activity marker is rare. Our finding that LF SP power is around two times larger than LF DP indicates that the sympathetic activation elicited by the maneuvers affect SPV and DPV differently. The greater increments of LF SP and its better correlation with LF PP during the maneuvers, suggest that LF PP is more influenced by LF SP than by LF DP power. While both LF SP and LF PP powers discriminated the progressively raising sympathetic activation in CB, SR, S and E, LF DP was unable to indicate the greater sympathetic activation provoked by E (Fig. 3); therefore, its performance as sympathetic activity marker is not acceptable. The similar performance of LF PP and LF SP, and their moderate correlation with HRV measures, which disagrees with the reported lack of correlation [2], support that LF PP is a suitable noninvasive index of sympathetic activity.

Our findings that HF SP is greater than HF PP and this is in turn greater than HF DP (Fig. 3) disagree with the reported results [2]. Their different coherences with HF Res, together with the diverse correlations between HF PP, HF SP and HF DP, suggest that HF power of each pressure is influenced differently by Res, with a greater effect in SPV than in DPV. That the respiratory effect on the three pressures is maximal in E and prominent in S, the maneuvers that course with minimal vagal modulation, suggest that it is mechanically mediated. While in SR and CB, the respiratory effect may also be produced by vagal modulation, which is maximal in the last maneuver (Fig. 1). Thus, the physiological correlate of the resulting HF PP power must be the respiratory activity, mediated by both vagal and mechanical effects. The greater powers and correlations of LF SP and LF DP than those of HF SP and HF DP suggest that the sympathetic modulatory effect is greater and more uniform than the respiratory one, and that it is the main source of variability for SP and DP (Fig. 5). In contrast, the result that HF PP is greater than LF PP in all maneuvers suggests that respiratory activity is the main source of PPV.

In conclusion, the sympathetic and respiratory activities elicited by the maneuvers provoke a modulation nearly double in SPV than in DPV, yielding the PPV. The progressive sympathetic increases evoked by the maneuvers, estimated by HF SP power and RR L, are adequately marked by LF PP, mainly due to its greater resemblance with LF SP than with LF DP. The performance of LF DP as sympathetic index is not adequate. The respiratory modulation, mechanical and vagally mediated and indicated by the HF powers, affects the three pressures series differently. Furthermore, it is smaller than the sympathetic modulation in SPV and DPV but greater in PPV. Thus, LF SP and HF SP are not interchangeable with LF DP and HF DP powers respectively.

References


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