Comparison of Time-Domain Short-Term Heart Interval Variability Analysis Using a Wrist-Worn Heart Rate Monitor and the Conventional Electrocardiogram

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Background: *Wrist-worn heart rate monitors have not been extensively validated for heart rate variability analysis. The purpose of this study was to compare time-domain variability of heart interval series (R-Ri) recorded by the Polar S810 monitor (Polar Electro Oy, Kempele, Finland) and the conventional electrocardiogram (ECG).*

Methods: *Agreement was verified between variability indices of 5-minute R-Ri simultaneously recorded by both devices and processed by unique software, from 33 subjects aged 18 to 42 years, normal or with different clinical conditions, in rest supine and active standing. ECG minus Polar differences were quantified by the Bland-Altman analysis, and tested by the one-sample t-test or Wilcoxon test.*

Results: *In the supine position, the Polar overestimates ($P < 0.0001$) the absolute and percentage mean or median of the number (−2.00; −0.49%) and mean of R-Ri (–1.85 ms; –0.20%) and pNN50 (−2.20%; −8.68%), and underestimates the standard deviation (SDNN) (0.32 ms; 0.59%) ($P = 0.08$; $P = 0.02$) and root mean square successive difference (RMSSD) (0.90 ms; 1.56%) ($P = 0.0008$; $P < 0.0001$). The coefficient of variation (CV) showed null difference. On standing, differences were overestimated for the number (−2.61 intervals; −0.64%) and mean of R-Ri (−0.70 ms; −0.09%), and underestimated for rMSSD (1.70 ms; 10.84%) ($P < 0.0001$ to < 0.02). The SDNN, CV, and pNN50 indices did not show differences ($P = 0.12$ to 0.73).*

Conclusions: *The Polar S810 monitor was feasible and reliable for recording short-term R-R interval series, showing excellent agreement with the ECG in providing the time-domain indexes of heart interval variability with differences functionally not relevant. The CV showed the higher agreement in both postures, and the SDNN and pNN50 in the standing posture. (PACE 2009; 32:43–51)*

wrist-worn heart rate monitor*, *Polar monitor*, *exercise practice*, *heart rate variability*, *cardiac autonomic function

Introduction

Time- and frequency-domain variability analysis of spontaneous short- or long-term heart interval series is a recently introduced tool widely employed for simple, noninvasive, and sensitive evaluation of cardiac autonomic modulation in different functional and clinical conditions.[1–7] Time series of heart interval of variable duration may be continuously obtained by means of a 24-hour dynamic electrocardiogram (ECG)-registering device (Holter system) and offline processed and analyzed for variability. However, the Holter system is not appropriate for heart interval recording during body movements as in many exercise activities and sports, considering the limited stability, fidelity, and stationarity of the signal imposed by different noise influences. Furthermore, the Holter system has restrictions for long-lasting ambulatory registration of ECG signal and also for analysis of long-term heart interval variability, since it does not permit to control the experimental conditions.[2,4,8] Even for stable rest situations, the high cost and operational complexity of this instrument restricts their extensive use in a practical manner. Alternatively, short-term heart interval variability is usually evaluated, employing 5-minute time series obtained from conventional electrocardiograms and processed by dedicated software.[2,4,5]

Alternative devices for acquisition and momentary variability analysis of R-R interval series would be advantageous in ambulatory conditions where the Holter monitoring and the ECG cannot be employed with reliability and practicability, as in field studies and sports. Devices with potential reliability, accuracy, simplicity, and low cost for such use are the third-generation wrist portable heart rate monitors, which are commonly

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Received June 5, 2008; revised August 11, 2008; accepted September 9, 2008.

employed for monitoring heart rate out of the laboratory setting or during situations associated with body movements such as practice of exercise, physical training and conditioning, or athletic competitions.[9–16] Even in long-lasting or in rest situations or in laboratory conditions these instruments can be convenient alternatives. However, only a few studies employed wrist-worn heart rate monitors for heart interval variability analysis,[15–18] and the reliability of these devices to accurately record and process R-R interval series for such analysis should be yet extensively tested.

The trademarked Polar S810 (Polar Electro Oy, Kempele, Finland) third-generation model is a worldwide available wrist-worn heart rate monitor, which supports recording and processing of R-R intervals for heart rate change measures and beat-to-beat variability analysis, as additional functions to the chronometric ones. Accuracy and reliability of heart rate measurement by this monitor were proven to be very high,[9,17,19] around 89% to 98% in steady-state conditions[14,20] and in situations of transient movement and in challenging environment conditions.[12]

In this work we comparatively analyzed the short-term variability in the time domain of the same heart interval series simultaneously recorded by the Polar S810 monitor and by the conventional ECG from subjects with different clinical conditions. The aim was to test, under stable rest laboratory conditions in the supine and standing positions, the accuracy and feasibility of the Polar monitor as an alternative suitable device to ECG, for employment in evaluation of cardiac autonomic function based on the heart interval variability analysis.

Subjects and Methods

Study Group

A group of 33 consecutively recruited volunteers (15 men and 18 women) aged 18 to 42 years (mean ± SD, 26.1 ± 7.8) were included in this study. We intentionally selected subjects with several clinical, anthropometrical, and physical conditions in order to compose a heterogeneous sample to evaluate the measures from the Polar monitor and ECG in a possible wide range of heart interval variability. Diagnostic of the conditions was based on clinical data and 12-lead electrocardiogram. Subjects with suspicion of alterations were submitted to the thorax X-ray and Doppler echocardiogram. Twenty-five (76%) were healthy subjects with no clinically identifiable alteration. Eight subjects (24%) show some isolated or associated abnormal manifestation that potentially can influence the heart rate variability, including obesity (6%), intense emotional stress (3%), mitral valve prolapse (6%), bicuspid aortic valve stenosis plus stenosis of brachiocephalic trunk and superior mesenteric artery (3%), Chagas' disease (3%), and asthma (3%). From the total of subjects, 20 (61%) were sedentary and 13 (39%) were active in accordance with the Portuguese version-IPAQ criteria (International Physical Activity Questionnaire).[21] None subject reported tobacco use or was using any drug and all had eventual alcohol and stimulant drinks, tea, or coffee intake.

The study protocol was approved by the University of Brasilia Faculty of Health Sciences Ethics Committee on Human Research and each volunteer signed an informed consent term to participate. The authors declare no conflict of interest in general and in the use of the Polar heart rate monitor.

Experimental Protocol

The experimental sessions were conduced between 8 am and 12 pm and the same observer tested all subjects, which come from their routine activity, about 2 to 4 hours after a recommended light breakfast. All were instructed to avoid intaking stimulant beverages, tea, and coffee; exercising; and smoking in the 12 hours previous to the examination. Initially, the subjects were submitted to a complete clinical evaluation and obtention of 12-lead electrocardiogram, in a quiet clinical research room ambient temperature (22–28°C). After 10–15 minutes in the rest supine position, a continuous 5-minute R-R interval series was simultaneously and synchronically recorded by an electrocardiograph and by the Polar monitor. In sequence, the subjects were asked to actively stand up at bedside and, after 2 minutes in the active orthostatic position, a new 5-minute recording of R-R intervals was obtained by the two devices. Therefore, the series of R-R intervals recorded by the electrocardiograph and the Polar monitor were rigorously identical in duration and number of intervals. The electrocardiogram was recorded in the lead II at 25 mm/s under a sampling frequency of 250 Hz and signal filtering against 35 and 60 Hz noises. For the Polar recording, a receptor/transmitter belt was firmly fixed in the chest at the level of the lower third of the sternum in order to avoid mechanical and breath movement interferences and to propitiate better signal acquisition and transmission to the wrist receiver unit. During the recordings the subjects stayed breathing spontaneously and regularly and had their respiratory rate visually monitored and counted.

Heart Interval Variability Analysis

This analysis was performed as previously described[7] and according to the methodological

standards recommended by the Task Force on Heart Rate Variability.[2] The R-R intervals in the electrocardiographic tracings were manually measured only by one reader (LGGP) using a magnifying lens and employing a 5-ms precision electrocardiographic rule. For the Polar monitor, the series were automatically recorded by a receptor belt and captured and stored by a wrist sensor unit, and transferred by means an interface to a microcomputer for beat-to-beat heart interval changes processing by means of the incorporated software, being provided a periodogram and tabulated R-R intervals. Both recordings were directly inspected and visually checked offline on a beat-to-beat basis for confirmation of sinus rhythm and identification of nonsinusal beats, artifacts and stationarity. When eventually present, ectopic or other nonsinusal beats and its preceding and succeeding intervals were deleted from the two series recorded without adding new intervals.

Next, the R-R interval series derived from each ECG recording were sequentially digitized one-to-one and archived as a text file. The series obtained by the Polar monitor were directly transformed in text file. Both series were then transferred to a dedicated software developed and validated in our Cardiovascular Laboratory and the Department of Electrical Engineering of University of Brasilia, using the MATLAB version 5.03 platform (The MathWorks, Inc., Natick, MA, USA)[22] for processing and variability analysis. Before analysis, the tracing graphics of the R-R interval series plotted against the time of registering were again inspected and the residual spurious or outliers beats were removed. These beats were identically edited in the series derived from the electrocardiographic and Polar registering. The series eventually edited may be considered practically the original ones, with the percentage of intervals deleted up to 2.42% for the supine posture and 2.74% for standing. The series from which ectopic or other nonsinusal beats and outliers were removed were submitted to interpolation by the cubic splines method and then processed and analyzed. Considering that the R-R interval series were recorded with the subjects in stable rest conditions, without influence of any external interfering or noise factors, those qualified for analysis showed high stationarity as estimated by the percentage differences of the means and the standard deviations between each pair of three segments of the series.

The heart interval variability was quantified in time domain by means of different indices: the mean R-R interval; two overall variability indices markers of the sympathetic-parasympathetic combined modulation, which are the standard deviation (SDNN) and the coefficient of variation (CV: SDNN/mean R-R interval); and two instantaneous variability indices that are the percentage of successive R-R intervals greater than 50 ms (pNN50) and the square root of the mean squared differences of successive intervals (rMSSD), which reflects the rapid beat-to-beat parasympathetic modulation.[2,4,5,7,8]

Statistical Analysis

The indices of the heart interval variability based on the ECG and the Polar monitor recordings were compared estimating the absolute and the percentage differences between the individual values obtained from each device, employing the Bland-Altman method of agreement.[23] This statistical method plots the absolute or percentage difference between the same indices derived from the two R-R interval series recordings against the average of both indices for each subject. The mean differences between the pair of indices represent the bias or systematic relative error between the two recordings for the group of subjects, and the $\pm$ 1.96 SD of the mean differences is the range of agreement. If the differences within the limits of agreement are not relevant to cause functional or clinical discrepancies, then the Polar monitor can be used interchangeably with the ECG for R-R interval series recording and variability analysis.

For each time-domain index the distribution of the absolute and percentage differences between the pair-wised individual values derived from the ECG and the Polar recordings was tested for normality using the Kolmogorov-Smirnov, D'Agostino-Pearson, and Shapiro-Wilk tests. The sample of differences in at least two tests that showed a normal distribution were tested by the one-sample *t*-test, and those with a nonnormal distribution by the Wilcoxon signed-rank test, respectively, against a hypothetical mean or median value equal to zero (null difference between measures from the ECG and Polar). Bland-Altman analysis is not feasible for sample of differences nonnormally distributed and so not applied.[23]

The differences for each index, between the two methods of recordings, were considered statistically significant when a two-tailed P value was less than 5% ($P < 0.05$). Processing and analysis of the data employed the Prism® 4 for Windows (GraphPad Software, Inc., La Jolla, CA, USA) software package. The MedCalc® 9.0.1.1 (Frank Schoonjans, Mariakerke, Belgium) software was employed for the Bland-Altman agreement analysis and graphic design.

Results

The mean $\pm$ SD of the arterial pressure, heart rate, and respiratory rate obtained in the beginning of the experimental session were, respectively,

Table I.

Bland-Altman Analysis-Based Mean (Bias), Limits of Agreement (Mean ± 1.96 SD), and 95% Confidence Interval of Mean (95% CI) for the Absolute and Percentage Differences Normally Distributed, and Median of the Nonnormally Distributed Differences, of the Time-Domain Indices of 5-Minute Heart Interval Variability Provided by the ECG and Polar Monitor, in 33 Subjects in the Supine Position

	Mean Values		Absolute Difference (ECG Minus Polar)				Percentage Difference (ECG Minus Polar)			
	ECG Recording	Polar Recording	Mean or Median	Limits of Agreement	95% CI	P Value**	Mean or Median	Limits of Agreement	95% CI	P Value**
Number of R-Ri	318 ± 46	320 ± 46	−2.00*	–	–	<0.0001	−0.49*	–	–	<0.0001
Mean R-Ri (ms)	949 ± 141	951 ± 151	−1.85	−6.37 to 2.67	−2.67 to −1.03	<0.0001	−0.20	−0.67 to 0.27	−0.28 to −0.11	<0.0001
SDNN (ms)	61.2 ± 31.2	60.9 ± 32.7	0.32	−1.65 to 2.28	−0.04 to 0.67	0.08	0.59*	–	–	0.02
CV (%)	6.46 ± 3.20	6.42 ± 3.28	0.00*	–	–	0.05	0.00*	–	–	0.02
pNN50 (%)	30.1 ± 20.4	32.3 ± 20.9	−2.20	−5.53 to 1.13	−2.81 to −1.60	<0.0001	−8.68	−21.60 to 4.23	−11.02 to −6.35	<0.0001
rMSSD (ms)	60.4 ± 35.7	59.6 ± 36.5	0.90*	–	–	0.0008	1.56*	–	–	<0.0001

*Difference value as median. **P value from the one-sample *t*-test for differences normally distributed (mean) against hypothetical mean equal zero, or one-sample Wilcoxon signed-rank test for differences nonnormally distributed (median) against hypothetical median equal zero. A $P < 0.05$ denotes significant difference of heart interval variability index from R-R interval series recorded by the electrocardiogram and the Polar monitor. See *Subjects and Methods* for the definition of the time-domain indices of R-R interval variability.

Table II.

Bland-Altman Analysis-Based Mean (Bias), Limits of Agreement (Mean ± 1.96 SD), and 95% Confidence Interval of Mean (95% CI) for the Absolute and Percentage Differences Normally Distributed, and Median of the Nonnormally Distributed Differences of the Time-Domain Indices of 5-Minute Heart Interval Variability Provided by the ECG and Polar Monitor, in 33 Subjects in the Standing Position

	Mean Values		Absolute Difference (ECG Minus Polar)				Percentage Difference (ECG Minus Polar)			
	ECG Recording	Polar Recording	Mean or Median	Limits of Agreement	95% CI	P Value**	Mean or Median	Limits of Agreement	95% CI	P Value**
Number of R-Ri	404 ± 6.1	406 ± 6.1	−2.61	−7.70 to 2.48	−3.53 to −1.68	<0.0001	−0.64	−1.87 to 0.60	−0.86 to −0.41	<0.0001
Mean R-Ri (ms)	745 ± 116	746 ± 116	−0.70	−3.89 to 2.50	−1.27 to −0.12	<0.02	−0.09	−0.50 to 0.32	−0.16 to −0.01	0.02
SDNN (ms)	46.8 ± 12.3	46.6 ± 12.1	0.24	−1.47 to 1.96	−0.07 to 0.55	0.12	0.44	−3.86 to 4.73	−0.34 to 1.21	0.26
CV (%)	6.40 ± 1.92	6.37 ± 1.91	0.00*	–	–	0.37	0.00*	–	–	0.29
pNN50 (%)	4.10 ± 4.93	4.36 ± 5.63	0.01*	–	–	0.73	2.67*	–	–	0.51
rMSSD (ms)	24.5 ± 7.6	22.3 ± 7.9	1.70*	–	–	<0.0001	10.84	−4.74 to 26.43	8.02 to 13.66	<0.0001

*Difference value as median. **P value from the one-sample *t*-test for differences normally distributed (mean) against hypothetical mean equal zero, or one-sample Wilcoxon signed-rank test for differences nonnormally distributed (median) against hypothetical median equal zero. A $P < 0.05$ denotes significant difference of heart interval variability index from R-R interval series recorded by the electrocardiogram and the Polar monitor.
See *Subjects and Methods* for the definition of the time-domain indices of R-R interval variability.

104.4 ± 9.7/65.2 ± 7.2 mmHg (range: 90–110/50–82 mmHg), 63.1 ± 8.5 bpm (45–80 bpm), and 14.9 ± 3.8 ripm (6–20 ripm). The body index mass was 23.3 ± 4.3 kg/m^2 (17.9–37.4 kg/m^2).

Tables I and II show, respectively, for the supine and standing positions, the mean or median values of the indices from the variability analyses based on R-R interval series recorded by the electrocardiogram and the Polar monitor, and the Bland-Altman' analysis of agreement between the indices derived from the two recordings.

In the supine position, the normally or non-normally distributed absolute and percentage differences between the ECG- and Polar-derived indices were significant ($P < 0.0001$ to 0.05) or showed a borderline significance for the SDNN absolute difference ($P = 0.08$). Thus, an absolute or percentage bias or systematic relative error was observed between the variability of R-R intervals recorded by the ECG and Polar monitor. The Polar monitor overestimates the number (medians: −2.00; −0.49%) and the mean (means: −1.85 ms; −0.20%) of R-R intervals and the pNN50 (means: −2.20%; −8.68%), and underestimates the SDNN (means: 0.32 ms; 0.59%) and the rMSSD (medians: 0.90 ms; 1.56%) indices. The CV showed null difference. The absolute limits of agreement indicate that the mean R-R, SDNN, and pNN50 values from the Polar may be as much as, respectively, 6.37 ms, 1.65 ms, and 5.53% below or 2.67 ms, 2.28 ms, and 1.13% above the respective values from the ECG recording. The percentage ranges of agreement were −0.67 to 0.27% ms for the mean R-R, and −21.60 to 4.23% for pNN50.

In the standing position, the absolute or percentage differences between the ECG- and Polar-derived indices were significant ($P < 0.0001$ to <0.02), demonstrating a systematic relative error, only for the number and mean of R-R intervals and rMSSD. The Polar monitor significantly overestimates the number (means: −2.61; 0.64%) and the mean (means: −0.70 ms; −0.09%) of R-R intervals, and underestimates only the rMSSD (medians: 1.70 ms; 10.84%) index. The absolute limits of agreement indicate that the number and mean of R-R intervals from the Polar may be significantly as much as, respectively, 7.70, 3.89 ms below or 2.48, 2.50 ms above the respective values from the ECG recording. The significant percentage ranges of agreement between the two recordings were −1.87 to 0.60 for the number of R-R intervals, −0.50 to 0.32 ms for mean R-R, and −4.74 to 26.43 ms for rMSSD.

The CV was the most accurate index, showing null median difference, in both the supine and standing positions. Other indices with high accuracy, which showed no significant difference

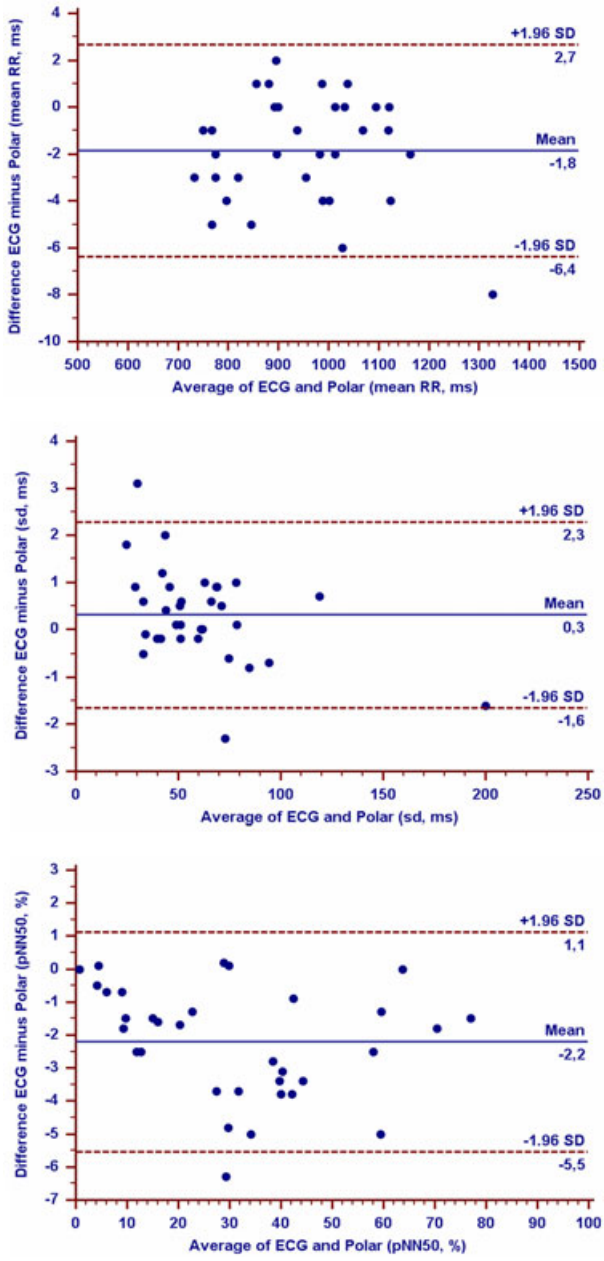

Figure 1. *Bland-Altman plots of agreement and normally distributed differences for the time-domain indices—mean (above), standard deviation (middle), and pNN50% (below), of the 5-minute variability analysis of R-R interval series derived from ECG and Polar monitor recordings obtained of 33 subjects in rest supine position. The plots show the average of ECG and Polar indices values plotted against the ECG minus Polar mean differences (bias or systematic relative error) (solid horizontal line) and the agreement limits (mean ± 1.96 SD) (dashed line) for the two devices. The functionally not-relevant over- or underestimated differences shown by the Polar monitor can bee seen.*

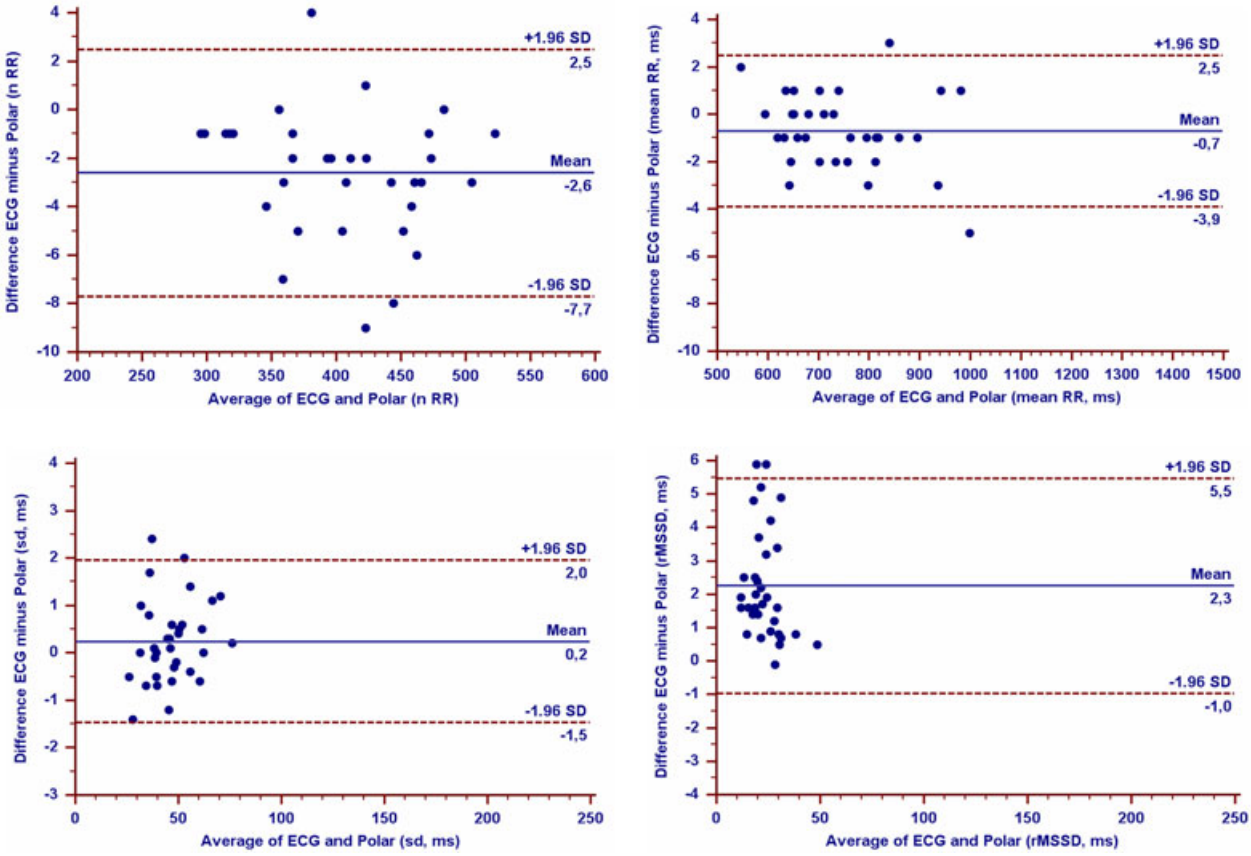

Figure 2. *Bland-Altman plots of agreement and normally distributed differences for the time-domain indices—number and mean (above), and SDNN and rMSSD (below), of the 5-minute variability analysis of R-R interval series derived from ECG and Polar monitor recordings obtained of 33 subjects in the standing position. Agreement variables and differences in the plots and comments in legend, as in Figure 1.*

($P = 0.12$ to 0.73), were the SDNN and pNN50 in the standing position.

Figures 1 and 2 depict the Bland-Altman plots of agreement and normally distributed differences between the time-domain indices from the variability analysis based on the Polar monitor and the ECG for each one of the 33 individuals in the supine and standing positions.

Discussion

In the last decades, the study of the short- or long-term cardiovascular variability under different physiological and pathophysiological conditions has awakened great interest and experienced considerable development, in parallel with the emergence of digital signal processing devices.[1,24–27] Conventional tests of acute heart rate responses associated with arterial pressure changes[28–31] and, more recently, linear and nonlinear analysis of short- or long-term heart rate variability in time and frequency domain, have been widely employed to evaluate the cardiac autonomic function and sympathovagal balance in normal sedentary and athlete subjects[4,8,27,28,32–37] and in a great variety of clinical conditions[4,5] in the rest supine and standing positions.

Also, studies of the relationship between exercise practice and athletic activity and heart rate dynamics have gained crescent interest to better understanding of functional aspects involving the cardiac autonomic modulation in these situations.[8,34,37,38–43] Various studies have recognized heart rate variability as expressing cardiac autonomic function to represent an important and independent predictor of cardiovascular events and global morbidity and mortality.[2,5,44,45]

In the sports and exercise domain, the search for practical and accurate alternative devices or tools for evaluating the short- and long-term cardiovascular autonomic regulation is a very important achievement. Several devices have been developed to augment the precision in functional

analysis, involving performance and safety, as the large variety of heart rate monitors, mainly the practical and low-cost worldwide employed wrist-worn models. Use of these monitors with accurate acquisition of R-R interval series is a very recent acquisition, but until now few were explored for studying the heart rate variability in conditions where other usual devices are not feasible, such as those implicating free movement or dynamic physical activity in exercise and sports practice. Although the most popular heart rate monitors are widely employed to measure heart rate,[9–12,16,19,20,46,47] they yet require validation for reliability in acquisition and variability analysis of R-R interval series.

In this work we aimed to further evaluate the possibility of a new use of the Polar S810 model of wrist-worn heart rate monitor available and extensively employed worldwide, validating this monitor model for heart rate variability analysis previously conducted with other models.[15–18] Our findings show that this model of Polar monitor is very practical and feasible for recording R-R interval series for variability analysis when compared to the same R-R interval series recorded by conventional ECG and processed by the same software. More than to test a specific Polar monitor model, this analysis proves the high sensitivity of a worldwide employed monitor model in detecting R-R interval series with similar precision to that of the ECG.

An excellent agreement was verified between the majority of the time-domain indices of heart interval variability analysis of R-R interval series from the ECG and Polar recordings, particularly in the supine position, although some indices were discretely but significantly underestimated and others were overestimated, in the sense that there were systematic differences when using the Polar monitor. Considering that the differences within the limits of agreement (mean $\pm$ 1.96 SD) were not functionally or clinically important, the two methods for recording R-R interval series may be used interchangeably. Thus, the Polar monitor would be an adequate alternative for heart interval variability analysis in conditions where the use of conventional ECG or the Holter system cannot be feasible or reliable.

Our data cannot be compared with those from others studies that used heart rate monitors, since the models employed, the experimental protocols, technical aspects of the processing of signals, and analysis of the data were all different. However, when compared with studies that employed similar model of monitor,[15–18,20] our results confirm the reliability and feasibility of the Polar S810, although there are differences in the experimental design and data analysis. Differently from analysis that compared the acquisition of R-R interval series based on a QRS detector with the series based on the Holter,[48,49] in this work we validate the Polar monitor for acquisition and processing R-R interval series in comparison with the same series obtained synchronically with the conventional ECG. Furthermore, those authors compared the Polar QRS detector with the Holter system for heart rate variability analysis in 24 hours of recording, showing good equivalence of results. Other studies involving validation of Polar monitors were made to test their reproducibility and precision to measure heart rate variability, which approved the validity of different models in comparison with the ECG or the Holter system.[9–11,16,18,46,47] A study of the Polar monitor to verify its internal consistency and computer interface for heart rate acquisition and processing concluded that the heart rate obtained were exactly the same, when evaluated by this monitor and by the computer after data transmission by means of their proper interface.[50] Therefore, we can suppose that in our study, the interface used for data transmission between the wrist device and the computer did not influence the results.

The heterogeneity of the sample of subjects we have examined, which suggests that the reliability of the Polar monitor is extensible to distinctive clinical and anthropometric conditions associated with a wide range of different sympathovagal balance, should be emphasized. Meaningful comparison between two or more devices requires that the measures provided should be of wide range in order to test the cardiac autonomic modulation in variable functional spectrum, including exercise. This work, however, has a limitation since it does not consider the comparison between the heart interval variability measurements provided by the two devices during an exercise activity. But, the comparison performed only in the rest condition is previously necessary for the expected comparison during the exercise, in order to verify the validity of the Polar monitor for to evaluate the heart rate variability in this condition, where it is widely employed.

In conclusion, heart interval variability analysis based on R-R interval series obtained by automated acquisition from the Polar S810 monitor was reliable and feasible, being comparable with high grade of agreement, to the analysis based on series recorded by the conventional ECG and processed by unique software. Although the differences between the two devices were statistically significant, with over- or underestimation of the index values when using the Polar monitor, they were very small and without functional relevance.

Therefore, the Polar monitor evaluated can be considered an excellent alternative device for acquisition and processing short-term R-R interval series for variability analysis in time domain, both in the supine and standing positions. The Polar heart rate monitor opens new perspectives for investigation of heart rate variability, either in a laboratory setting or in field studies or sports and exercise practice.

Acknowledgments: The authors gratefully acknowledge the technical assistance of Ms. Maria da Graça Souza and Mr. João Ronaldo de Andrade Rocha, and Mr. Fabiano Girardi Correia as scholarship from PIBIC/CNPq/UnB Program at the Cardiovascular Laboratory. The skillful assistance of Ms. Suiara Pereira Teixeira in the experimental protocol, Dr. Daniel França Vasconcelos in echocardiographic examination, and Prof. Maria Imaculada Muniz-Junqueira and Dr. Adriana Lofrano-Porto in reviewing the English language is also greatly appreciated.

References

1. Stein PK, Bosner MS, Kleiger RE, Conger BM. Heart rate variability: A measure of cardiac autonomic tonus. Am Heart J 1994; 127:1376–1381.
2. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: Standards of measurement, physiological interpretation and clinical use. Circulation 1996; 93:1043–1065.
3. Eckberg DL. Physiological basis for human autonomic rhythms. Ann Med 2000; 32:341–349.
4. Pumprla J, Howorka K, Groves D, Chester M, Nolan J. Functional assessment of heart rate variability: Physiological basis and practical applications. Int J Cardiol 2002; 84:1–14.
5. Kleiger RE, Stein PK, Bigger JT Jr. Heart rate variability: Measurement and clinical utility. Ann Noninvasive Electrocardiol 2005; 10:88–101.
6. Malliani A. Heart rate variability: From bench to bedside. Eur J Inter Med 2005; 16:12–20.
7. Correia D, Junqueira LF Jr, Molina RJ, Prata A. Cardiac autonomic modulation evaluated by heart interval variability is unaltered but subtly widespread in the indeterminate Chagas' disease. Pacing Clin Electrophysiol 2007; 30:772–780.
8. Aubert AE, Seps B, Beckers F. Heart rate variability in athletes. Sports Med 2003; 33:889–919.
9. Léger L, Thivièrge M. Heart rate monitors: Validity, stability and functionality. Phys Sportsmed 1988; 16:143–151.
10. Godsen R, Carroll T, Stones S. How well does the Polar Vantage XL heart rate monitor estimate actual heart rate? Med Sci Sports Exerc 1991; 23(Suppl):S14.
11. Gretebeck RJ, Montoye JJ, Ballor D, Montoye AP. Comment on heart rate recording in field studies. J Sports Med Phys Fitness 1991; 31:629–631.
12. Moore AD Jr, Lee SMC, Greenisen MC, Bishop P. Validity of a heart rate monitor during work in the laboratory and on the space shuttle. Am Ind Hyg Assoc J 1997; 58:299–301.
13. Laukkanen R, Virtanen P. Heart rate monitors: State of the art. J Sports Sci 1998; 16:3–7.
14. Boudet G, Chamoux A. Heart rate monitors and abnormal heart rhythm detection. Arch Physiol Biochem 2000; 108:371–379.
15. Radespiel-Troger M, Rauh R, Mahlke C, Gottschalk T, Muck-Weymann M. Agreement of two different methods for measurement of heart rate variability. Clin Auton Res 2003; 13:99–102.
16. Kingsley M, Lewis MJ, Marson RE. Comparison of Polar 810s and an ambulatory ECG system for RR interval measurement during progressive exercise. Int J Sports Med 2005; 26:39–44.
17. Marchant-Forde RM, Marlin DJ, Marchant-Forde JN. Validation of a cardiac monitor for measuring heart rate variability in adult female pigs: Accuracy, artifacts and editing. Physiol Behav 2004; 80:449–458.
18. Gamelin FX, Berthoin S, Bosquet L. Validity of the polar S810 heart rate monitor to measure R-R intervals at rest. Med Sci Sports Exerc 2006; 38:887–893.
19. Kinnunen H, Heikkila I. The timming accuracy of the Polar Vantage NV heart rate monitor. J Sports Sci 1998; 16:S107–S110.
20. Boudet G, Chamoux A. Ability of new heart rate monitors to measure normal and abnormal heart rate. J Sports Med Phys Fitness 2001; 41:546–553.
21. Pardini R, Matsudo S, Araújo T, Matsudo V, Andrade E, Braggion G, Andrade D, et al. Validação do questionário internacional de nível de atividade física (IPAQ—versão 6): Estudo piloto em adultos jovens brasileiros. Rev Bras Ciênc Mov 2001; 9:45–51.
22. Carvalho JLA, Rocha AF, Nascimento FAO, Souza-Neto J, Junqueira LF Jr. Development of a Matlab software for analysis of heart rate variability. In: Baozong Y, Xiaofang T (eds.): 6th International Conference on Signal Processing Proceedings, Vol. II. Beijing, IEEE Press, 2002, pp. 1488–1491.
23. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; 1:301–310.
24. Sayers BM. Analysis of heart rate variability. Ergonomics 1973; 16:17–32.
25. Appel ML, Berger RD, Saul JP, Smith JM, Cohen RJ. Beat-to-beat variability in cardiovascular variables: Noise or music? J Am Coll Cardiol 1989; 14:1139–1148.
26. Malliani A, Lombardi F, Pagani M, Cerutti S. Clinical exploration of the autonomic nervous system by means of electrocardiography. Ann N Y Acad Sci 1990; 601:234–246.
27. Malik M, Camm J. Components of heart rate variability—what they really mean and what we really measure. Am J Cardiol 1993; 72:821–822.
28. Eckberg DL. Parasympathetic cardiovascular control in human disease: A critical review of methods and results. Am J Physiol 1980; 239:H581–H593.
29. Ewing DJ, Martyn CN, Young RJ, Clarke BF. The value of cardiovascular autonomic function tests: 10 years experience in diabetes. Diabetes Care 1985; 18:491–498.
30. Gallo L Jr, Maciel BC, Marin-Neto JA, Martins LEB. Sympathetic and parasympathetic changes in heart rate control during dynamic exercise induced by endurance training in man. Braz J Med Biol Res 1989; 22:631–643.
31. Junqueira LF Jr, Soares JD. Impaired autonomic control of heart interval changes to Valsalva manoeuvre in Chagas' disease without overt manifestation. Auton Neurosci 2002; 97:59–67.
32. Eckberg DL. Sympathovagal balance: A critical appraisal. Circulation 1997; 96:3224–3232.
33. Hayano J, Sakakibara Y, Yamada A, Yamada M, Mukai S, Fujinami T, Yokoyama K, et al. Accuracy of assessment of cardiac vagal tone by heart rate variability in normal subjects. Am J Cardiol 1991; 67:199–204.
34. Dixon EM, Kamath MV, McCartney N, Fallen EL. Neural regulation of heart rate variability in endurance athletes and sedentary controls. Cardiovasc Res 1992; 26:713–719.
35. Malliani A, Pagani M, Furlan R, Guzzetti S, Lucini D, Montano N, Cerutti S, et al. Individual recognition by heart rate variability of two different autonomic profiles related to postures. Circulation 1997; 96:4143–4145.
36. Malliani A, Pagani M, Montano N, Mela GS. Sympathovagal balance: A reappraisal. Circulation 1998; 98:2640–2643.
37. Iellamo F. Neural mechanisms of cardiovascular regulation during exercise. Auton Neurosci 2001; 90:66–75.
38. Boutcher SH, Stein P. Association between heart rate variability and training response in sedentary middle-aged men. Eur J Appl Physiol 1995; 70:75–80.
39. Furlan R, Piazza S, Dell'Orto S, Gentile E, Cerutti S, Pagani M, Malliani A. Early and late effects of exercise and athletic training on neural mechanisms controlling heart rate. Cardiovas Res 1993; 27:482–488.
40. Gallo L Jr, Maciel BC, Marin-Neto JA, Martins LEB, Lima-Filho EC, Golfetti R, Chancon MPT, et al. Control of heart rate during exercise in health and disease. Braz J Med Biol Res 1995; 28:1179–1184.
41. Tulppo M, Mäkikallio TH, Airaksinen JKE, Huikuri HV. Quantitative beat-to-beat analysis of heart rate dynamics during exercise. Am J Physiol 1996; 271:H244–H252.

42. Tulppo MP, Mäkikallio TH, Seppänen T, Laukkanen RT, Huikuri HV. Vagal modulation of heart rate during exercise: Effects of age and physical fitness. Am J Physiol 1998; 274:H424–H429.
43. Uusitano ALT, Laitinen T, Väisänen SB, Länsimies E, Rauramaa R. Effects of endurance training on heart rate and blood pressure variability. Clin Physiol Funct Imaging 2002; 22:173–179.
44. Tsuji H, Larson MG, Venditti JR, Manders ES, Evans JC, Feldman CL, Levy D. Impact of reduced heart rate variability on risk for cardiac events. Framingham Heart Study. Circulation 1996; 94:2850–2855.
45. Kors JA, Swenne CA, Greiser KH. Cardiovascular disease, risk factors, and heart rate variability in the general population. J Electrocardiol 2007; 40:S19–S21.
46. Thivièrge M, Léger L. Critical review of heart rate monitors. Can Assoc Health Phys Educ Recreational J 1989; 55:26–31.
47. Seaward BL, Sleamaker RH, McAuliffe T, Clapp JF. The precision and accuracy of a portable heart rate monitor. Biom Instrum Technol 1990; 24:37–41.
48. Loimaala A, Sievänen H, Laukkanen R, Pärkkä J, Vuori I, Huikuri HV. Accuracy of a novel real-time microprocessor QRS-detector for heart rate variability assessment. Clin Physiol 1999; 19: 84–88.
49. Tapanainen JM, Seppänen T, Laukkanen R, Loimaala A, Huikuri HV. Significance of the accuracy of RR interval detection for the analysis of new dynamical measures of heart rate variability. Ann Noninvasive Electrocardiol 1999; 4:10–18.
50. Carrol T, Godsen R, Tangeman C. The Polar Vantage XL heart rate monitor: An analysis of its internal consistency and computer interface. Med Sci Sports Exerc 1991; 23:S14.