Neural Control of Movement

Validity of the Polar V800 heart rate monitor for assessing cardiac autonomic control in individuals with spinal cord injury

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Abstract - Aim: Spinal cord injury (SCI) is associated with changes in cardiac autonomic control, that can be evaluated by heart rate variability (HRV), for which the electrocardiogram (ECG) is the gold standard. However, the use of ECG is limited to laboratory environments, and new tools are needed for this purpose and that can be applied in the routine monitoring of individuals with SCI. The present study aimed to investigate the validity of the Polar V800 heart rate monitor in assessing the cardiac autonomic control of individuals with SCI. **Methods:** Nineteen adult men with SCI (paraplegia n = 10; 44.5 ± 8.5 years and tetraplegia n = 9; 34.4 ± 7.5 years) participated in this cross-sectional study. The participants remained in the sitting position at rest for 10 min for the acquisition of the ECG and Polar V800 signals. The last 5-min window was used to count the beat-by-beat R-R interval series and then calculate the HRV indices (linear methods in the time and frequency domains). The study subgroups were compared, and the validity of the measurements generated with a heart rate monitor was determined using the intraclass correlation coefficient ($ICC_{2,1}$) and Bland-Altman graphs. **Results:** Agreement analyses for the R-R intervals, SDNN, rMSSD, PNN50, SD1, LF, HF, and LF: HF ratio tended to show reliability ranging from acceptable to excellent (ICC = 0.579-0.990; P = 0.043-0.001) and acceptably narrow limits of agreement within both the group with tetraplegia and the group with paraplegia. **Conclusion:** The Polar V800 heart rate monitor is a valid instrument for assessing HRV in individuals with paraplegia and tetraplegia.

Keywords: spinal cord injuries, rehabilitation, autonomic nervous system, heart rate determination.

Introduction

Spinal cord injury (SCI) in the upper segments (i.e. the cervical level and first thoracic vertebrae) is associated with changes in the functioning of the autonomic nervous system, in particular markedly reduced sympathetic activity[1-6]. Consequently, cardiac autonomic control is affected, increasing the risk of cardiovascular events in this population[7-9]. The repercussions vary according to the level and severity of the injury, and the higher the injury, the greater the changes and the risks[3,8,10-12].

Changes in cardiac autonomic control can be investigated by analysing heart rate variability (HRV). HRV is a non-invasive, easy-to-apply method that reflects beat-to-beat changes in heart rate (HR) and shows the influence of the sympathetic and parasympathetic nervous system on heart rhythm and can be used as a diagnostic indicator in individuals with SCI[13-16]. HRV is obtained by the variation of both instantaneous HR and R-R intervals within the cardiac cycle, which can be recorded by electrocardiogram (ECG), the gold-standard method for this measurement[17], or by a heart rate monitor, a more practical and affordable alternative to the ECG that also enables measurement of R-R intervals in the field[18-20]. Several studies have demonstrated the validity of using the instruments such as Polar's heart rate monitors for the evaluation of cardiac autonomic control in healthy populations[21-26], as well as in specific populations, such as adolescents with obesity[27] and children[28].

To the best of our knowledge, however, no study has investigated the validity of heart rate monitor for short-term HRV measures in individuals with SCI. Taking into account that the agreement of HRV indices performed by

these methods (e.g. ECG *vs*. Polar's heart rate monitors) appears to rely on population characteristics[23], it would be important to investigate the accuracy of HRV indices obtained by heart rate monitor compared to the gold-standard method for this measurement. Thus, the main purpose of the present study was to investigate the level of agreement between HRV indices in time and frequency domains derived from the Polar V800 monitor *vs*. ECG in individuals with SCI.

Method

Study design and sample

This was a cross-sectional observational study with nineteen adults with SCI divided into two groups: paraplegia (SCI between the first thoracic vertebra and second lumbar vertebra; n = 10) and tetraplegia (SCI between the fourth and seventh cervical vertebrae; n = 9). All participants signed an informed consent form, and the study was submitted to and approved by the institutional research ethics committee (CAAE 10519917.9.0000.5259).

The participants were recruited from sports associations by the principal investigator using a nonprobabilistic (convenience) sampling. The inclusion criteria were as follows: men, age ≥ 18 years, presence of tetraplegia or paraplegia, stable clinical condition for at least three months, and engagement in recreational sports (wheelchair rugby in the case of tetraplegics and wheelchair basketball in the case of paraplegics) for at least six months. The exclusion criteria were a diagnosis of cardiovascular disease and the use of drugs that could affect the heart rate response, such as beta-adrenergic blockers and antiarrhythmic agents. The sample size was calculated considering an alpha of 5%, power of 80%, and minimally accepted reliability of 0.75[29,30], resulting in a minimal sample size of 10 participants per group.

Each participant visited the laboratory one time to undertake the following procedures: a) complete a preparticipation screening questionnaire for demographic profile and physical activity level (i.e., International Physical Activity Questionnaire, IPAQ-SF), b) to perform anthropometric measurements, and c) assessment of resting HRV. All procedures were conducted at approximately the same time of day (between 06:00 and 12:00 a.m.) to negate any effects of circadian variation.

Demographic characteristics

Demographic data and data on disability and sports practice were provided by the participants by completing a questionnaire. To characterize body composition, the following measurements were taken: height with the participants lying supine on a stretcher (CESCORF; 0.1 cm; Rio Grande do Sul - Brazil) and total body mass (Filizola ID-M300/5; 0.1 kg; Campo Grande - Brazil).

Physical activity level

The assessment of the individuals' level of physical activity was performed using the International Physical Activity Questionnaire (IPAQ-version 8) in its short form[31]. The individuals were classified into the following categories of physical activity: low, moderate, or high[32].

Assessment of heart rate variability indices

Participants were asked not to perform physical activity and not to drink alcohol or caffeinated beverages in the 24 hours preceding the evaluation, and not to smoke in the 12 hours preceding the evaluation. Before starting the recording, the participants were asked to empty their bladder to avoid possible changes in HRV[27]. In the laboratory, participants laid quietly for 10 min, after which the HRV was measured for 10 min in a sitting position using two devices - an ECG and a heart rate monitor - manually synchronized. The last 5 min of data were recorded as the HRV at rest. Participants were asked to refrain from moving and to breathe regularly during the evaluation.

To place the electrodes (3M; São Paulo, Brazil), body hair was shaved, and the corneal layer of the skin was removed with gauze, followed by asepsis with 70% alcohol. A conductive gel was applied for better electrical conduction at the skin-electrode interface. To avoid possible noise, micropore tape (Nexcare, 3 M; São Paulo, Brazil) was used to secure the electrodes after their placement.

For the continuous recording of ECG signals, an electrocardiograph (HW; ECG V6; Minas Gerais, Brazil) was used to record 12 simultaneous leads and 11 channels. The signals acquired by the ECG were transferred to a computer running the ErgoMET 13 software (HW Systems, Minas Gerais, Brazil) with a frequency of 1000 Hz and a time unit of 1 ms.

The Polar V800 heart rate monitor (Polar™, Kempele, Finland) was used with a Polar H7 chest strap placed on the participant's chest, with conductive gel being applied as stipulated in the manufacturer's instructions. The R-R interval signals were acquired with a 1-ms time unit and a frequency of 1000 Hz, then transferred to Polar-Flow software. The raw data of each participant was then downloaded into a PC in Excel file format and reviewed for manual inspection (i.e., R-R interval values with differences of more than 30% of the preceding R-R interval)[33]. Subsequently, the verification of the correction level selected within the graphical interface was performed using a customized algorithm from Kubios HRV Standard software (Biomedical Signal Analysis Group, Department of Applied Physics, University of Kuopio, Kuopio, Finland). For spectral analysis of R-R interval time series, data were processed using a Fast Fourier Transform. Continuous heart period series were corrected by the piecewise cubic spline interpolation method at the default rate of 4 Hz (adjustable). Using a window with

256 s (window overlap of 50%; adjustable), samples were smoothed prior to detrending, tapered using a Hanning window, and processed by Welch's periodogram method.

The indices obtained in the time and frequency domains were considered. The time-domain analysis consisted of measures of R-R intervals (average of all normal R-R intervals), the standard deviation of all normal R-R intervals recorded in a time interval (SDNN), root mean square of the differences between adjacent normal R-R intervals in a time interval (rMSSD), percentage of adjacent R-R intervals with a difference in duration greater than 50 ms (pNN50), and geometric indices, for which SD1 was used, a Poincaré plot component. In the frequency-domain, the power spectrum density function was integrated into the two classical frequency bands, as follows: 1) low-frequency band (LF: 0.04 to 0.15 Hz); and 2) high-frequency band (HF: 0.15 to 0.40 Hz). The HF was used as an index of vagal modulation, whereas LF was considered primarily as a representative of sympathetic nervous system influence[34,35]. The spectral values were expressed as normalized units (n.u.)[36]. The LF: HF ratio was adopted as a marker of sympathovagal balance.

Statistical analysis

All statistical analyses were completed using IBM SPSS Statistics 22 (SPSS Inc., Chicago, IL). Data were summarized using means and standard deviations (SD). Variables distribution were verified with Kolmogorov-Smirnov Test and all P-values were > 0.05, not rejecting the null hypothesis. Homogeneity of variances was assessed with Levene's Test and comparisons of numeric variables were performed with Student's t-test. For comparisons of nominal variables, Chi-square Test was applied. The agreement between the HRV indices obtained by the heart rate monitor and ECG was determined by calculating the intraclass correlation coefficient (ICC) and using the Bland-Altman graphical approach[37]. The ICC was calculated using an analysis of variance model with random effects (two-way random ANOVA) for analysis of the reliability (consistency) ($ICC_{2,1}$). ICC values were classified as follows: < 0.40: unacceptable; $0.40 \leq ICC \leq 0.75$: acceptable; and > 0.75: excellent[29,30]. The Bland-Altman plots were based on the differences between the values of each of the HRV indices considered in the study obtained by the ECG and by the heart rate monitor (Y-axis) and the mean of these values (X-axis). The lower limit was calculated as the mean of the differences $-1.96 \times$ (standard deviation of the differences), and the upper limit was calculated as the mean of the differences $+1.96 \times$ (standard deviation of the differences)[37]. Statistical significance for all null hypothesis significance tests was regarded as $P < 0.05$.

Results

The demographic characteristics of the study participants are shown in Table 1. Among the variables investigated, only age differed between groups ($t = -2.727$; $P = 0.014$). There was no significant difference between the tetraplegia and paraplegia groups in the time since injury ($t = 0.901$; $P = 0.380$). The individuals were classified in the following categories of physical activity in the group with tetraplegia: high (56%; n = 5), moderate (11%; n = 1), and low (33%; n = 3). In the group with paraplegia, individuals were classified as high (30%; n = 3), moderate (50%; n = 5) and low (20%; n = 2) ($P = 0.190$). The injury level of the participants was between T1-L2 in the group with paraplegia and C4-C7 in the group with tetraplegia.

Table 2 depicts data for resting HRV indices in the time and frequency domains derived from ECG vs. Polar V800 in paraplegia and tetraplegia groups. ICCs were classified as excellent (ranging from 0.798 to 0.990) and they were all statistically significant (P-values ranging from < 0.001 to 0.007) in both groups. The only exception was LF in the tetraplegia group which was classified as acceptable (ICC = 0.579 [−0.076; 0.886]; $P = 0.043$).

The limits of agreement and the distribution of the values found for each individual in the group with paraplegia and tetraplegia, according to the Bland-Altman graphical approach, are shown in Figures 1 and 2 for time and frequency domain HRV indices, respectively. In the paraplegia and tetraplegia groups, a bias was obtained for the R-R intervals (1.1% and 1.0%, respectively), SDNN (5% and 2.4%, respectively), rMSSD (11.4% and 3.4%, respectively), pNN50 (24.6% and 8.9%, respectively), SD1 (12.2% and 4.7%, respectively), total power (2.5% and 1.7%, respectively), LF (0.7% and 8.4%, respec-

Table 1 - Characteristics of the population.

Variables	Paraplegia (n = 10) Mean ± SD (range)	Tetraplegia (n = 09) Mean ± SD (range)	t-test	*P*-value
Age in years	44.5 ± 8.5 (25-53)	34.4 ± 7.5 (25-47)	−2.727	0.014
Years since injury	6 ± 7,6 (3-26)	13 ± 5,7 (4-24)	0,901	0.380
Height (cm)	175.1 ± 6.6 (164-184)	179.2 ± 5.7 (171-189)	1.618	0.124
Body mass (kg)	78.9 ± 15.3 (57.2-100.2)	67.7 ± 9.2 (50.7-80.1)	−1.921	0.072
IPAQ (minutes/week)	126.5 ± 47.4 (60-210)	192.2 ± 119.8 (40-390)	1.541	0.154

Table 2 - Mean ± SD values for resting heart rate variability indices derived from ECG *vs*. Polar V800 in paraplegia (n = 10) and tetraplegia (n = 9) groups.

Variables	Group	ECG	Polar V800	ECG-Polar V800 differences			$ICC_{(2,1)}$ [95%CI]	*P*-value
		Mean ± SD	Mean ± SD	Mean diff.	S_d	95% LoA		
Time domain								
R-R interval (ms)	paraplegia	902.9 ± 169.0	892.3 ± 166.6	10.7	35.4	−58.6, 79.9	0.978 [0.913; 0.994]	< 0.001
	tetraplegia	1003.0 ± 205.7	1021.7 ± 212.5	−18.7	59.5	−135.2, 97.9	0.960 [0.845; 0.991]	< 0.001
SDNN (ms)	paraplegia	49.1 ± 36.9	45.7 ± 35.5	3.4	10.9	−17.9, 24.8	0.956 [0.833; 0.989]	< 0.001
	tetraplegia	52.4 ± 36.5	50.0 ± 31.5	2.4	10.3	−17.7, 22.6	0.955 [0.816; 0.990]	< 0.001
rMSSD (ms)	paraplegia	43.2 ± 33.1	37.9 ± 32.3	5.3	16.9	−27.9, 38.5	0.867 [0.554; 0.965]	0.007
	tetraplegia	46.5 ± 35.9	46.1 ± 37.4	0.4	11.3	−21.7, 22.6	0.954 [0.810; 0.989]	< 0.001
pNN50 (%)	paraplegia	21.4 ± 23.9	17.6 ± 23.9	3.8	11.3	−18.5, 25.9	0.888 [0.615; 0.971]	0.003
	tetraplegia	18.8 ± 19.4	21.9 ± 25.5	−3.1	8.7	−20.2, 13.9	0.923 [0.700; 0.982]	0.001
SD1 (ms)	paraplegia	30.6 ± 23.5	26.8 ± 22.9	3.8	11.9	−19.6, 27.2	0.867 [0.555; 0.965]	0.007
	tetraplegia	33.0 ± 25.3	32.6 ± 26.5	0.4	7.9	−15.1, 16.0	0.954 [0.810; 0.989]	< 0.001
Frequency domain								
TP (ms^2)	paraplegia	3263.5 ± 4340.7	3113.9 ± 4339.8	149.6	808.2	−1434, 1734	0.983 [0.932; 0.996]	< 0.001
	tetraplegia	3519.1 ± 5013.4	3457.1 ± 4627.2	62	1382	−2647, 2771	0.959 [0.830; 0.991]	< 0.001
LF (n.u.)	paraplegia	60.5 ± 22.3	60.6 ± 22.1	−0.1	3.3	−6.5, 6.4	0.990 [0.960; 0.997]	0.001
	tetraplegia	62.1 ± 15.6	57.8 ± 19.6	4.3	16.9	−28.7, 37.4	0.579 [−0.076; 0.886]	0.043
HF (n.u.)	paraplegia	46.6 ± 16.2	44.6 ± 15.4	2.0	3.1	−4.1, 8.2	0.977 [0.892; 0.994]	< 0.001
	tetraplegia	46.1 ± 15.8	45.4 ± 15.7	0.7	6.9	−12.9, 14.3	0.911 [0.657; 0.979]	0.001
LF/HF ratio	paraplegia	1.5 ± 0.9	1.6 ± 1.0	−0.1	0.2	−0.5, 0.3	0.977 [0.916; 0.994]	< 0.001
	tetraplegia	1.5 ± 0.6	1.9 ± 1.9	−0.4	1.5	−3.3, 2.5	0.798 [0.321; 0.951]	0.004

ECG: electrocardiogram; Polar V800: cardiofrequencymeter system. Mean diff = mean difference between ECG *vs*. Polar V800; S_d = the standard deviation of the differences; LoA = 95% limits of agreement; $ICC_{(2,1)}$ [95%CI] = intraclass correlation coefficient and associated 95% confidence intervals. R-R interval = average of all normal R-R intervals; SDNN = standard deviation of all normal R-R intervals; rMSSD = square root of the sum of successive differences between adjacent normal R-R intervals squared; pNN50 = percentage of successive R-R intervals that differ by more than 50 ms; SD1 = Poincaré plot standard deviation perpendicular the line of identity; LF = low frequency component; HF = high frequency component; LF:HF ratio = sympathovagal balance.

tively), HF (4.3% and 2.2%, respectively), and LF:HF ratio (5.1% and 0.7%, respectively). In all the HRV indices, the individuals were within the acceptable limits of agreement, except for one participant of each group who was found outside the acceptable limits of agreement [paraplegia group (R-R interval, SDNN, rMSSD, pNN50, SD1, and total power); tetraplegia group (R-R interval, SDNN, LF, and LF/HF ratio)].

Discussion

This study aimed to investigate the validity of the Polar V800 heart rate monitor as an instrument for evaluating cardiac autonomic control in individuals with SCI. The main outcomes suggest that the Polar V800 seems to be a valid instrument, since most of the HRV indices investigated in both the time and frequency domains showed excellent or acceptable reliability, regardless of the level of the SCI. In addition, by the Bland-Altman approach, the values found in most of the evaluated individuals were within the acceptable limits of agreement.

To date, the evaluation of cardiac autonomic control has been the subject of many studies in recent years, including studies of different evaluation methods[21,22,24,25] of different populations[27,28] of its association with the incidence of sports injuries,[38] and of overtraining[39]. However, no study has investigated different methods of HRV analysis in individuals with SCI.

When comparing the results found in the present study with those of other studies conducted on individuals without SCI but with similar evaluation protocols (rest, recording of short-term R-R intervals, and use of a heart rate monitor), we found similar results, suggesting that heart rate monitors can be an alternative to the ECG[21,22,24-27].

In the present study, the HRV indices in the time domain measured by the Polar V800 monitor showed, for all indices and in both groups, excellent reliability (ICC ≥ 0.75) and statistical significance when compared with the ECG. A similar result was also found by Giles et al. (2016)[24], who observed high reliability (ICC = 1.0) in the SDNN, rMSSD, and pNN50 or the Polar V800 moni-

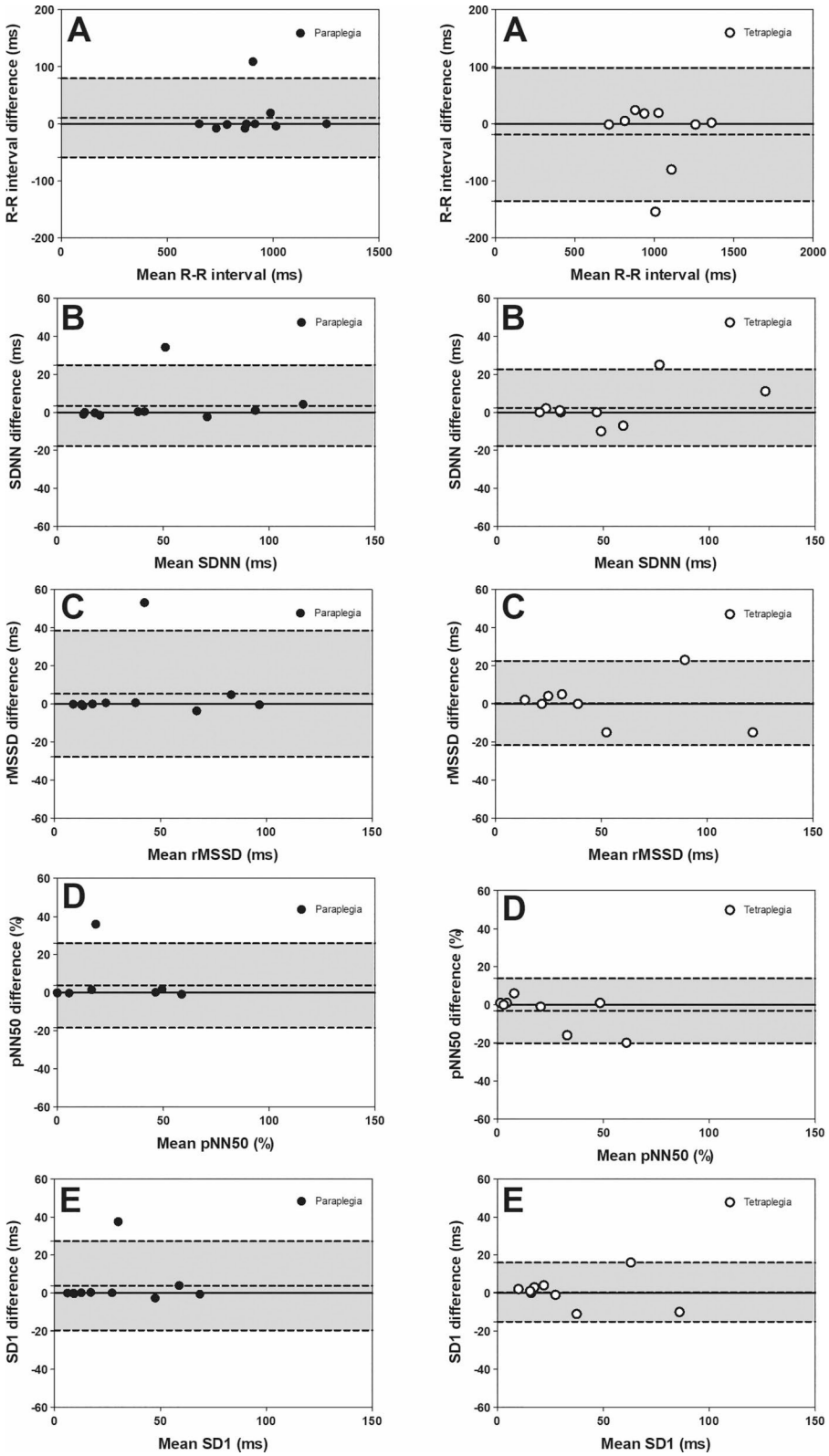

Figure 1 - Bland-Altman plot showing individual differences between HRV indices in time domain derived from ECG vs. Polar V800 in paraplegia (n = 10) and tetraplegia (n = 9) groups. The first and third horizontal dashed lines in each graph represent the 95% limits of agreement. S_d = standard deviation of the differences. (**A**) R-R interval = average of all normal R-R intervals; (**B**) SDNN = standard deviation of all normal R-R intervals; (**C**) rMSSD = square root of the sum of successive differences between adjacent normal R-R intervals squared; (**D**) pNN50 = percentage of successive R-R intervals that differ by more than 50 ms; (**E**) SD1 = Poincaré plot standard deviation perpendicular the line of identity.

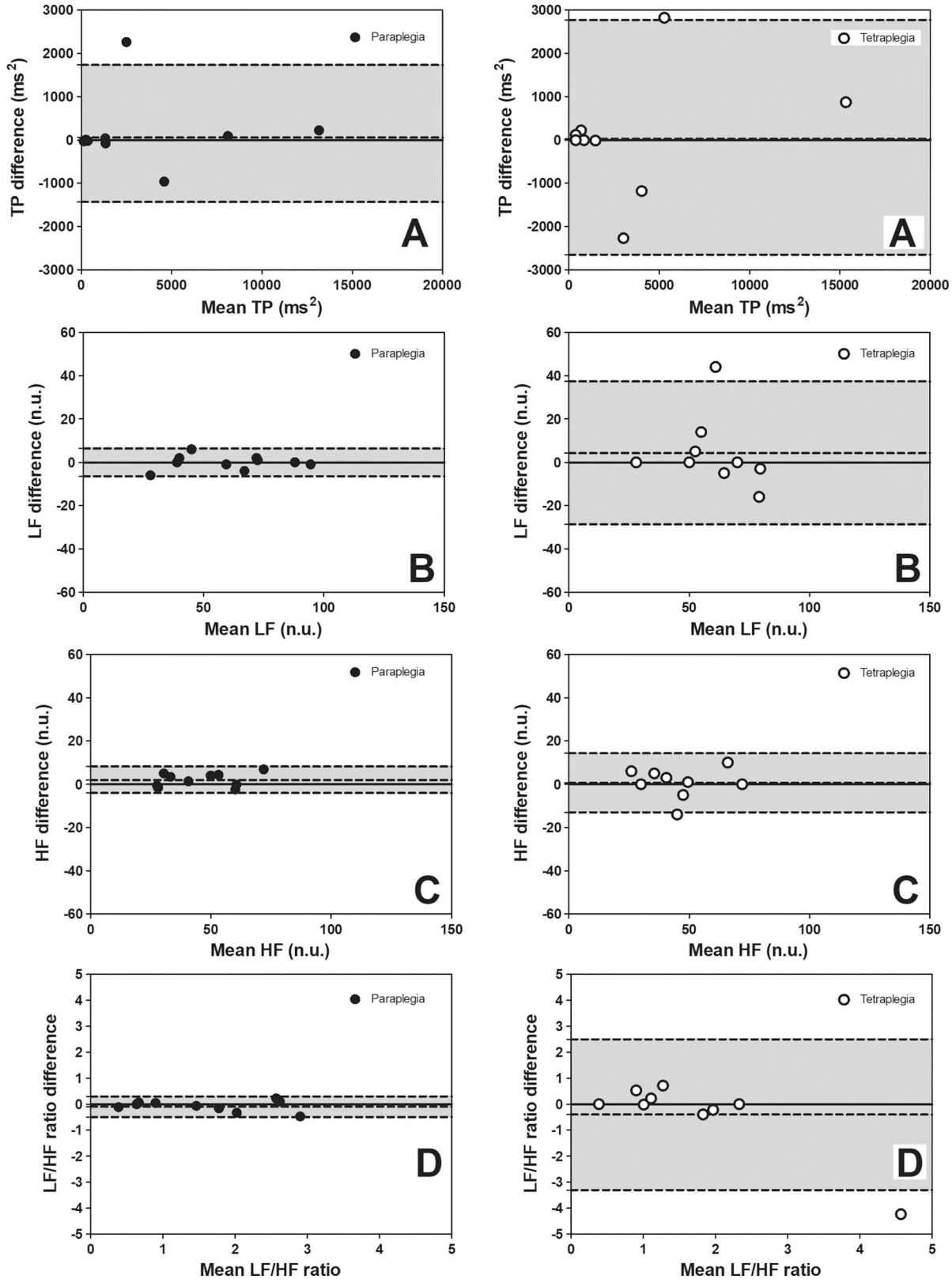

Figure 2 - Bland-Altman plot showing individual differences between HRV indices in frequency domain derived from ECG vs. Polar V800 in paraplegia (n = 10) and tetraplegia (n = 9) groups. The first and third horizontal dashed lines in each graph represent the 95% limits of agreement. S_d = standard deviation of the differences. (**A**) TP = total power; (**B**) LF = low frequency component; (**C**) HF = high frequency component; (**D**) LF:HF ratio = sympathovagal balance.

tor in 20 participants of both sexes. Similar results were also confirmed by Wallén et al. (2012)[23] in 314 participants of both sexes in terms of the SDNN (ICC = 0.840) and rMSSD (ICC = 0.930) recorded using a heart rate monitor (Polar RS800cx). In the frequency domain, Wallén et al. (2012)[23] obtained an ICC value of 0.926 in HF (ms^2) and 0.922 in LF (ms^2). Similar results were found by Giles et al. (2016)[24] who reported high reliability for all analyzed HRV indices. Both results agree with the findings observed in the present study with individuals with paraplegia and tetraplegia, except for the LF index in the tetraplegia group, which presented acceptable reliability (see Table 2). Both studies were performed with healthy adults of both sexes, with no changes in cardiac autonomic control, unlike the changes in the sympathetic nervous system found in individuals with high paraplegia and tetraplegia[23,24].

Lesser sympathetic influence and the greater parasympathetic influence on cardiac autonomic control are observed in individuals with SCI because the parasympathetic fibers originate in the vagus nerve, innervating the heart without passing through the spinal cord, whereas the sympathetic fibers originate in the spinal cord, between the first and fifth thoracic vertebrae[40,41]. According to a previous study, the damage of autonomic pathways related to SCI may not necessarily be associated with the level and the completeness of the injury. However, considering the origins of the sympathetic and parasympathetic fibers that innervate the heart, it could be supposed that the sympathetic control would have a greater loss the greater the level of the injury, while the parasympathetic control would remain unchanged[42]. It is noteworthy, however, that for both time- and frequency-domain HRV indices, excellent agreements were found in almost all indices in paraplegia and tetraplegia groups investigated in the present study; therefore, this evaluation method can be used regardless of the characteristics of the SCI.

From a practical perspective, changes in cardiac autonomic control resulting from SCI highlight the importance of having low-coast and accessible tools to investigate cardiac outcomes in the SCI population. Our results show that the Polar V800 heart rate monitor can be used by health professionals in clinical practice to assess and monitor HRV during the rest of people with SCI. As the heart rate monitor is a cheaper and easier tool to evaluate autonomic cardiac regulation at rest than the ECG, then a larger number of people with SCI could be assessed and monitored for health risks, mainly cardiovascular.

The present study has some limitations, such as (i) the small sample size in the tetraplegia group and (ii) the non-performance of a new test to evaluate the reproducibility (test-retest reliability) of the measurements. However, we emphasize that this is the first study addressing the validation of heart rate monitors in the population of individuals with SCI. As a strength, individuals with injuries at different levels, i.e., paraplegia and tetraplegia, were included, which increases the likelihood of the practical application of the findings. Therefore, additional studies should be conducted on this topic, but addressing situations during effort and in post-effort recovery. Understanding the HRV indices regarding exercise manipulation is essential, especially in individuals with SCI, as these indices are associated with lower cardiovascular risk and better health prognosis[43].

Conclusion

The Polar V800 heart rate monitor is a valid instrument for the evaluation of HRV in individuals with paraplegia or tetraplegia. The heart rate monitor can be used as an alternative instrument to the ECG for the assessment of cardiac autonomic control at rest in individuals with SCI. It has the advantages of lower cost, thus allowing the evaluation of more individuals and applicability in extra-laboratory environments.

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