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# Autonomic cardiovascular control recovery in quadriplegics after handcycle training

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**Abstract.** [Purpose] The aim of this study was to investigate the cardiovascular autonomic acute response, during recovery after handcycle training, in quadriplegics with spinal cord injury (SCI). [Subjects and Methods] Seven quadriplegics (SCIG −level C6–C7, male, age 28.00 ± 6.97 years) and eight healthy subjects (CG −male, age 25.00 ± 7.38 years) were studied. Their heart rate variability (HRV) was assessed before and after one handcycle training. [Results] After the training, the SCIG showed significantly reduced: intervals between R waves of the electrocardiogram (RR), standard deviation of the NN intervals (SDNN), square root of the mean squares differences of sucessive NN intervals (rMSSD), low frequency power (LF), high frequency power (HF), and Poincaré plot (standard deviation of short-term HRV −SD1 and standard deviation of long-term HRV −SD2). The SDNN, LF, and SD2 remained decreased during the recovery time. The CG showed significantly reduced: RR, rMSSD, number of pairs of adjacent NN intervals differing by more than 50 ms (pNN50), LF, HF, SD1, and sample entropy (SampEn). Among these parameters, only RR remained decreased during recovery time. Comparisons of the means of HRV parameters evaluated between the CG and SCIG showed that the SCIG had significantly lower pNN50, LF, HF, and SampEn before training, while immediately after training, the SCIG had significantly lower SDNN, LF, HF, and SD2. The rMSSD30s of the SCIG significantly reduced in the windows 180 and 330 seconds and between the windows 300 seconds in the CG. [Conclusion] There was a reduction of sympathetic and parasympathetic activity in the recovery period after the training in both groups; however, the CG showed a higher HRV. The parasympathetic activity also gradually increased after training, and in the SCIG, this activity remained reduced even at three minutes after the end of training, which suggests a deficiency in parasympathetic reactivation in quadriplegics after SCI.

**Key words:** Spinal cord injury, Heart rate variability, Exercise training response

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## INTRODUCTION

Cardiovascular sympathetic control is impaired or even absent in people who have suffered a spinal cord injury (SCI) above the T6 spinal segment[1–3)]. Myers et al.[4)] reported the importance of measuring the degree of autonomic dysfunction, which is related to physical function and general health, in subjects with SCI sequelae.

The cardiovascular changes resulting from SCI are associated with autonomic dysfunction, and they may manifest as lower heart rate variability (HRV)[5)], lower acceleration of heart rate (HR) during exercise, and slower deceleration of HR

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after exercise[6, 7]. HRV is considered a tool with great potential for quantifing the residual cardiovascular sympathovagal regulation after SCI[1] at rest or while performing exercise[8, 9], as well as in the recovery phase of healthy people[10–14] or subjects with SCI[15].

Physical inactivity is very common among people with SCI and is related to cardiovascular deconditioning, which predisposes to cardiovascular disease[2, 5, 9, 16]. Aerobic exercise can prevent heart disease by increasing vagal modulation and decreasing sympathetic activity[17]. However, sympathetic hyperactivity or reduced cardiac vagal parasympathetic tone after exercise is associated with an increased risk of cardiovascular disease[11–13, 17].

Among the aerobic sports that can be practiced by people with SCI, hand cycling stands out, whether as a form of recreation or rehabilitation. However, little is known about the effects of exercise in general on the cardiovascular autonomic modulation in people with SCI, which justifies this study.

The aim of this study was to investigate the cardiovascular autonomic acute response, during recovery after handcycle training, in quadriplegics with spinal cord injury (SCI).

## SUBJECTS AND METHODS

This clinical trial was a controlled cross-sectional study that was approved by the Human Research Ethics Committee of the Universidade do Vale do Paraíba (UNIVAP), number 18353613.0.0000.5503, and registered in the Clinical Trials, protocol number NCT02177929. The subjects read and signed the informed consent.

This study recruited 15 subjects, who were divided into two groups: a control group (CG, n=8), consisting of people without neurological diseases; and a spinal cord injury Group (SCIG, n=7), made up of participants with traumatic SCI. To determine the level of spinal cord injury, SCIG participants underwent a physical examination for the evaluation of dermatomes and myotomes following the guidelines established by the American Spinal Injury Association.

Inclusion criteria were: age between 18 and 40, no cardiovascular abnormalities, or risk factors, such as hypertension, diabetes, or obesity, or use of cardiac depressant or stimulatory medications. The subjects with SCI had complete or incomplete thoracic or cervical SCI, clinical stability, and were more than eight months after injury.

Exclusion criteria were athletes and pregnant women. Subjects were excluded from SCIG if they had urine infection or severe pressure ulcers.

Subjects were classified as sedentary if they performed physical activity for two hours or less per week and active if they performed physical activity for three or more hours per week[18].

The study sample was composed only of males, to exclude the interference of hormonal changes during the menstrual cycle on cardiovascular autonomic control. According to Yildirir et al.[19] and Sato et al.[20], the LF power and LF/HF ratio is higher in the luteal phase, which indicates increased sympathetic activity at this stage of the menstrual cycle; while in the follicular phase, the HF power is greater, which indicates increased parasympathetic activity at this stage.

The study sample is characterized in Table 1.

The HRV of all subjects was evaluted. For this, the intervals between R waves of the electrocardiogram (RR or RRi), the so-called normal-to-normal (NN) intervals, were obtained using a Polar® RS800CX at a sampling rate of 1,000 Hz before and after handcycle training.

During each collection period, the participant sat on a handbike. Data collection was conducted for the seven minutes before and seven minutes immediately after the complete on of training. Before starting the data collection, participants remained at rest for at least two minutes in the seated position. The heart monitor strap was positioned just below the chest muscle. The subjects were instructed to breathe spontaneously throughout the procedure. Data collection was conducted in the morning, outdoors.

Before and after the training, the vital signs and general health conditions of participants were evaluated.

Participants performed one-handcycle training. The CG performed training for 20 minutes, without rest intervals. The SCIG performed training for 20 minutes, with three rest intervals of approximately two minutes, with blocks of five minutes of continuous cycling. The subjective perceived exertion was assessed using the 10-point Borg scale, and ranged from 4–7 in both groups. The training period consisted of about 15 minutes of forward cycling and five minutes distributed between reverse and slalom (with cones) cycling. The intensity level of training for the CG ranged from 65 to 90% of the reserve HR, and that of the SCIG ranged from 50 to 80% of the reserve HR. The training differences between groups were necessary to prevent arm muscle fatigue, and inability to keep training at the proposed time in the SCIG.

The training was held in the morning, outdoors. The handbike (Handvikn brand) used had a 90° angle between the backrest and seat, and a 19° angle between the seat and floor. When necessary, two elastic bands, 120 cm long and 90 cm wide, were used to fix the hands of the quadriplegics to the handlebars. All subjects used a helmet, kneepads, and elbowpads during the training.

The acquired data were transferred to a microcomputer equipped with Polar ProTrainer software. The time series was manually inspected for artifact and ectopic beats. Subsequently, the signals were analyzed by linear (time domain and frequency) and nonlinear (Poincaré plot, and sample entropy) methods, using Kubios HRV Analysis® software.

For temporal analysis, the following variables were obtained: RR, standard deviation of the NN intervals (SDNN), square root of the mean squared differences of successive NN intervals (rMSSD), and number of pairs of adjacent NN intervals

**Table 1.** Characteristics of participants in the control (CG) and spinal cord injury (SCIG) groups

| | SCIG | CG |
|---|---|---|
| N | 7 | 8 |
| Age (years) | 28.0 ± 7.0 | 25.0 ± 7.4 |
| Weight (kg) | 67.1 ± 15.6 | 74.8 ± 12.4 |
| Height (cm) | 174 ± 5.5 | 177 ± 4.9 |
| BMI (kg/m$^2$) | 22.1 ± 5.2 | 23.7 ± 2.9 |
| Complete SCI (AIS A) | 71.4% | - |
| Injury time (months) | 65.1 ± 64.3 | - |
| Sedentary | 57.1% | 50% |

BMI: body mass index; AIS: American Spinal Injury Association Impairment Scale

differing by more than 50 ms (pNN50). The latter two indices are related to parasympathetic modulation[21)].

For spectral analysis, the Fast Fourier Transform (FFT) was used to obtain: low frequency (LF −0.04 to 0.15 Hz) power, which for some authors is related only to sympathetic modulation[22)], and for others is both sympathetic and parasympathetic activity[23)]; high frequency (HF −0.15 to 0.4 Hz) power, representing the parasympathetic activity; and the LF/HF ratio, which is related to the sympathovagal balance. The LF and HF power were expressed in both absolute (ms$^2$) and normalized units (n.u.). Normalized units were obtained by dividing the power of a given component (LF or HF) by the total power minus the very low frequency (VLF) power.

A Poincaré plot was used to obtain the standard deviation of the instantaneous beat-to-beat variability (SD1), which is correlated with short-term variability in HR and is influenced mainly by parasympathetic modulation, and the standard deviation of the long term continuous RR intervals (SD2), which is a measure of long-term variability and reflects sympathetic activation[20)]. Furthermore, a Poincaré map allows visual analysis that summarizes the short and long-term levels of the series of RR intervals in a figure. This map consists of plotting each RR interval in relation to the next interval to produce a set of coordinate points (RRi, RRi + 1)[24)].

Sample entropy (SampEn) indicates the complexity and irregularity of the RRi time series. The length (m) of the subseries and the tolerance (r) were fixed at m =2 and r=0.2[25)]. The complexity of HR, given by the entropy calculation, may represent a sympathovagal general marker with values ranging from zero to two. High values (close to 2) indicate better autonomic balance. On the other hand, a low complexity of the HR is related to aging and cardiovascular diseases[9, 25)].

For analysis of the basal signal (before training), the first two minutes were excluded from the time series. Recovery after training was first analyzed using data covering all of the 7-min recovery period (After training$_{total}$), and then the recovery period was divided into two windows, with durations of a little more than three minutes each (After training$_1$ and After training$_2$), for the analysis of the initial and end recovery stages. The rMSSD was calculated in 14 consecutive windows of 30 seconds (rMSSD30s) each during the seven-minute recovery period after training. This index is related to the parasympathetic reactivation after exercise[13, 14, 26)]. No part of the recovery signal was excluded, so that there was no data loss in the first few seconds.

Statistical analysis was performed using BioStat 5.0 and Excel2010 software. Data normality was verified using two tests: Lilliefors and extreme values. To compare the averages of the parameters evaluated before and after training, Student's t-test or the Mann-Whitney test was used. To compare the average of the parameters between Before training and, After training$_1$ and After training$_2$ during recovery after training, and also to compare between the averages of rMSSD30s, ANOVA followed by the post hoc Tukey test or the Kruskal-Wallis followed by the Student-Newman-Keuls test was used. To compare the averages of rMSSD30s between the CG and SCIG, ANOVA followed by the Bonferroni test was used. To compare the averages of the parameters between the CG and SCIG, ANOVA or the Kruskal-Wallis test was used. Statistical significance was accepted for values of $p<0.05$.

## RESULTS

There were no statistically significant differences between groups in the evaluated physical characteristics (age, weight, height, and BMI).

The SCIG showed significantly reduced RR, SDNN, rMSSD, LF, HF, SD1, and SD2 after training. The SDNN, LF, and SD2 remained decreased throughout the recovery period (Table 2).

The CG showed significantly reduced RR, rMSSD, pNN50, LF, HF, SD1, and SampEn after training. Only RR remained decreased throughout the recovery period (Table 3).

Comparisons of the means of HRV parameters between the CG and SCIG showed that the SCIG had significantly lower pNN50, LF, HF, and SampEn before training, while immediately after training, the SCIG had significantly lower SDNN, LF, HF, and SD2.

**Table 2.** Means and standard errors of the HRV parameters of the spinal cord injury group (SCIG) which were analyzed in the time domain, frequency domain, and using nonlinear methods

| | | Before training | After training$_{total}$ | After training$_1$ | After training$_2$ |
|---|---|---|---|---|---|
| Time domain | RR (ms) | 797 ± 72.5 | 695 ± 68.7† | 690 ± 68.9 | 700 ± 69.0 |
| | SDNN (ms) | 59.6 ± 12.4 | 33.5 ± 4.7† | 33.8 ± 5.0 | 28.4 ± 3.4‡ |
| | rMSSD (ms) | 25.6 ± 8.0 | 14.2 ± 3.2† | 14.4 ± 3.3 | 13.7 ± 3.4 |
| | pNN50 (%) | 6.7 ± 3.0 | 1.4 ± 0.6 | 1.4 ± 1.0 | 1.3 ± 0.5 |
| Frequency domain | LF (ms$^2$) | 879 ± 284 | 260 ± 82.1† | 311 ± 91.8 | 231 ± 71.9‡ |
| | LF (n.u.) | 79.2 ± 4.6 | 80.8 ± 2.4 | 81.2 ± 3.7 | 77.8 ± 2.3 |
| | HF (ms$^2$) | 95.3 ± 31.1 | 61.2 ± 25.3† | 51.0 ± 16.7 | 64.1 ± 29.1 |
| | HF (n.u.) | 20.8 ± 4.6 | 19.1 ± 2.4 | 18.8 ± 3.7 | 22.1 ± 2.3 |
| | LF/HF | 5.4 ± 1.2 | 4.7 ± 0.6 | 5.6 ± 1.3 | 3.8 ± 0.4 |
| Nonlinear methods | SD1 (ms) | 18.1 ± 5.6 | 10.1 ± 2.3† | 10.2 ± 2.3 | 9.7 ± 2.4 |
| | SD2 (ms) | 82.1 ± 16.8 | 46.1 ± 6.4† | 46.6 ± 6.7 | 38.7 ± 4.6‡ |
| | SampEn | 1.0 ± 0.2 | 1.0 ± 0.2 | 1.0 ± 0.1 | 1.1 ± 0.2 |

†p≤0.05; ‡vs. Before training p<0.05

**Table 3.** Means and standard errors of the HRV parameters of the control group (CG) which were analyzed in the time domain, frequency domain, and using nonlinear methods

| | | Before training | After training$_{total}$ | After training$_1$ | After training$_2$ |
|---|---|---|---|---|---|
| Time domain | RR (ms) | 793 ± 35.0 | 618 ± 20.8† | 600 ± 22.3§ | 637 ± 20.5§ |
| | SDNN (ms) | 65.9 ± 5.8 | 55.4 ± 8.4 | 49.9 ± 10.1 | 50.1 ± 7.9 |
| | rMSSD (ms) | 44.0 ± 6.5 | 23.6 ± 5.4† | 22.1 ± 5.7 | 24.8 ± 5.4 |
| | pNN50 (%) | 23.2 ± 6.3 | 7.3 ± 3.3† | 6.5 ± 3.2‡ | 8.3 ± 3.5 |
| Frequency domain | LF (ms$^2$) | 1726 ± 175 | 773 ± 300† | 455 ± 146‡ | 1350 ± 471 |
| | LF (n.u.) | 73.6 ± 5.2 | 80.6 ± 2.0 | 77.0 ± 4.5 | 84.2 ± 2.2 |
| | HF (ms$^2$) | 753 ± 196 | 285 ± 103† | 315 ± 127 | 305 ± 96.5 |
| | HF (n.u.) | 26.4 ± 5.2 | 19.4 ± 2.0 | 22.8 ± 4.5 | 15.8 ± 2.2 |
| | LF/HF | 4.8 ± 1.7 | 4.5 ± 0.5 | 4.6 ± 1.0 | 6.3 ± 1.0 |
| Nonlinear methods | SD1 (ms) | 31.2 ± 4.6 | 16.7 ± 3.9† | 15.7 ± 4.0 | 17.6 ± 3.8 |
| | SD2 (ms) | 87.7 ± 7.2 | 76.2 ± 11.3 | 68.4 ± 13.6 | 68.5 ± 10.6 |
| | SampEn | 1.4 ± 0.1 | 0.9 ± 0.1† | 1.0 ± 0.1§ | 1.0 ± 0.1 |

†p≤0.05; ‡vs. Before training p<0.05; §vs. Before training p<0.01

The rMSSD30s of the SCIG significantly reduced in the windows 180 and 330 seconds, and between the windows 300 seconds in the CG (Fig. 1).

## DISCUSSION

The SCIG showed decreased sympathetic (LF, SD2) and parasympathetic activity (rMSSD, HF, SD1) in the recovery period after training. Their decreased SDNN reflects a reduction in sympathetic and parasympathetic activity[3, 18]. The decreased RR reflects sympathetic predominance.

Similarly, the CG showed decrease in sympathetic (LF) and parasympathetic activity (rMSSD, pNN50, HF, SD1) in the recovery period after training. In addition, their RR decreased. There was also decreased SampEn, which represents sympathovagal balance. During the exercise there was a decrease in parasympathetic activity and an increase in sympathetic activity, while after exercise the opposite was observed[11, 13]. In the CG, the parameters returned to basal values, except RR, probably because the recovery time was short.

Comparison of the two groups' data revealed that the SCIG had a lower HRV relative to the CG. The training and recovery behavior was also differentiated, because only the RR remained decreased in the recovery period in the CG. On the other hand, in the SCIG, the SDNN, LF, and SD2 remained diminished, which indicates that the CG had a greater ability to adapt than the SCIG.

It is known that the ability to vary the heart rate to external stimuli is an important physiological role in the homeostasis

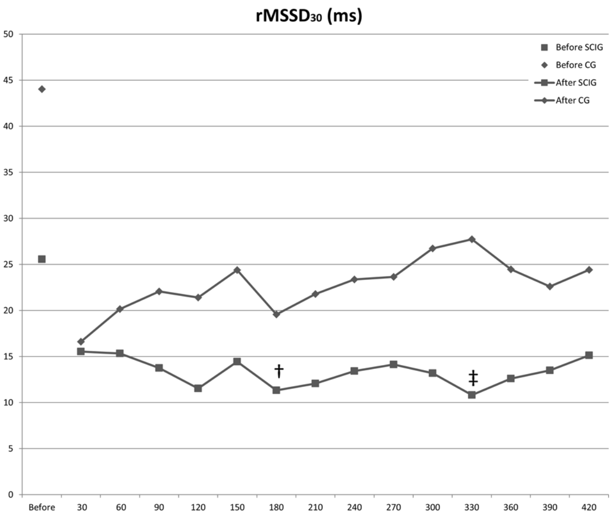


**Fig. 1.** $rMSSD_{30s}$ behavior in the control (CG) and spinal cord injury (SCIG) groups before training and on the recovery period after training.
†SCIG 180 vs. CG 300 $p<0.05$; ‡SCIG 330 vs. CG 300 $p<0.05$

of an organism, even in simple situations such as postural change[3)] and especially during physical exertion[11)]. High HRV is a sign of good adaptability, which implies a healthy individual with well-functioning autonomic control mechanisms, and it also reflects increased parasympathetic modulation and decreased sympathetic modulation. Conversely, lower variability is often an indicator of abnormal and insufficient adaptability of the autonomic nervous system, implying the presence of a physiological malfunction, and it also reflects increased sympathetic modulation[21, 27)].

Probably the association between the marked reduction in sympathetic activity (because the sympathetic nerve roots below the T6 spinal segment)[1–3)] and reduction in parasympathetic activity (physical deconditioning)[4)] promoted the reduction of HRV in the SCIG before or after training.

The $rMSSD_{30s}$ showed contrasting behaviors between the two groups. The $rMSSD_{30s}$ of the CG increased gradually, in agreement with previous studies[12, 14, 26)]. In the SCIG, this index showed a tendency to remain lowered until the final minutes of the recovery period after training, reflecting impaired parasympathetic reactivation, which is consistent with the observations of Myers et al[4)].

A reduced HRV may reflect an intrinsic deficiency in vagal reactivation, an impairment in barorreceptor sensitivity, deconditioning associated with high-level SCI, some combination of these factors[4)], and this issue needs further investigation and clarification.

It is important to consider that besides autonomic activity, other factors contribute to recovery after exercise. These include the interruption of stimulation by exercise from the central command of the cerebral motor cortex, and the reduction of stimuli from metaboreceptors, baroreceptors, and thermoreceptors, as well as hormonal factors such as norepinephrine, epinephrine, angiotensin, endothelin, and vasopressin[4, 26)].

It is noteworthy that there is no guidance in the literature on exercise prescription for most disabilities including SCI. The exercise prescription for healthy people may not necessarily be transferred to people with SCI. The absence of prescription guidelines for physical exercises hinders the development and implementation of physical activity programs for this population. Therefore, studies of physical activity should be given priority in future research[16, 28–30)].

Further studies are needed to determine the time required for recovery from exercise by people with SCI. Moreover, it is necessary to identify more precisely the physiological mechanisms involved in the autonomic control after SCI, at rest, during, and after exercise. The resolution of these issues is important for the establishment of guidelines for exercise prescription for this population, who need the benefits of physical activity.

In conclusion, there was a reduction of sympathetic and parasympathetic activity in the recovery period after the training in both groups. However, the CG showed a higher HRV, and their parasympathetic activity gradually increased after training. In the SCIG, this activity remained reduced even at three minutes after the training had ended, which suggests a deficiency in parasympathetic reactivation in quadriplegics with SCI.

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