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JSM Physical Medicine and Rehabilitation

Research Article

Effect of Handcycling on Cardiopulmonary System of Tetraplegics as A Result of Spinal Cord Injury

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Submitted: 17 August 2020
Accepted: 01 September 2020
Published: 03 September 2020
ISSN: 2578-3572

Keywords
- Spinal cord; Tetraplegia; Sports for persons with disabilities; Autonomic nervous system; Function respiratory test

Abstract

Design of the study: Pre-post, uncontrolled, longitudinal study of exercise training in persons with tetraplegia

Objective: To evaluate the effects of handcycling training on heart rate variability, pulmonary function, and respiratory muscle strength in tetraplegic people, as a result of spinal cord injury.

Location: Rehabilitation center, Faculty of Health Sciences, UNIVAP, São José dos Campos, SP, Brazil

Methods: Seven tetraplegics (with C6 to C7 injury, men, age 28.00 ± 6.97 years, and body mass index of 22.13 ± 5.18 kg/m²) underwent handcycling training for three months. Heart rate variability, spirometry, and manometer were assessed before and after the training period.

Results: For the heart rate variability, only low frequency/high frequency (Wavelet) post-training decreased, going from 5.17 ± 0.75 to 3.29 ± 0.70 (p = 0:02). There were no significant differences for the spirometric parameters evaluated. The maximum inspiratory pressure increased from 74.28 ± 14.84 to 101.42 ± 21.35 cmH2O (p = 0.01), and the maximal expiratory pressure increased from 72.85 ± 84.28 ± 21.38 to 17.18 cmH2O (p = 0.04).

Conclusion: Handcycling practice promoted positive effects on the cardiopulmonary system of tetraplegic patients with decreased low frequency/high frequency and improved their respiratory muscle strength.

INTRODUCTION

In addition to sensory-motor impairment, spinal cord injury (SCI), according to the level, affects cardiovascular and bronchopulmonary autonomic control. Studies have shown that tetraplegic people present lower heart rate (HRV) and blood pressure variability, and minor component of very low frequency (VLF) [1], as well as less increased heart rate (HR) in response to exercise and delayed HR recovery after exercise [2].

SCI can also result in weakness or paralysis of the respiratory muscles, leading to decreased lung volume and capacity, limiting the effectiveness of coughing; as a consequence, people with tetraplegia are prone to the retention of secretions, atelectasis and pulmonary infections [3]. In combination, tetraplegic patients experience stiffness of the rib cage, decreased lung compliance, increased abdominal compliance with paradoxical breathing movements, and subsequent increased work to breathe. The loss of sympathetic innervation and vagal predominance results in hypersensitivity and airway diameter reduction [3]. These complications compromise the physical performance of these people, including their activities of daily living.

Physical inactivity increases the tendency for cardiac diseases under normal conditions [4]. This becomes even more disturbing in people with SCI, as this is their main cause of morbidity and mortality [5]. Therefore, it is recommended that tetraplegics acquire an active lifestyle as soon as possible [1,6].

An adapted sport becomes an alternative for physical, psychological and social rehabilitation of people with some disabilities and makes a positive contribution to their quality of life and functional independence [7]. Handcycling, practiced using a handbike is among the sports adapted for people with SCI [6]. This sport promotes increased functional activity of the upper limbs, which favors the improvement of cardiorespiratory fitness [8]. Claydon et al. [9], demonstrated that physical exercise for people with SCI is safe, even in the presence of autonomic dysfunction.

Training studies on the effects of hand cycling in people with SCI are very scarce. Silva et al. [10], showed that after arm cranking aerobic training (30 min/session, three times/week, 6 weeks), paraplegics significantly increased the FVC and the ventilatory muscle endurance (VME), so that sustained maximum ventilation for 70% of MVV (MVV-70%) post-training were not different from the initial values of the control group. The study by Mukherjee [11] showed that the arm-propelled three-wheeled chair (APTWC) training (15 minutes, twice daily, for 12 weeks) is efficient and improves fitness status in patients with paraplegia. Valent et al. [12], found in a observational study on the influence of hand cycling during and 1 year after rehabilitation clinically relevant improvements in physical capacity in patients with paraplegia.

None of these studies showed the effects of training with hand cycling on the autonomic modulation in people with SCI. Therefore, the physiological effects in lung function parameters, and cardiovascular autonomic control caused by hand cycling practice in tetraplegic people need to be elucidated. The aim of this study was to evaluate the HRV, pulmonary function and respiratory muscle strength in tetraplegic people as a result of SCI, before and after a training program using the handbike.

It is believed that sports activities can improve lung function and cardiovascular autonomic control of people with SCI, which will contribute to an increased tolerance to physical activity and improved quality of life.

METHODS

This pre-post, uncontrolled longitudinal study was approved by the Human Research Ethics Committees of Universidade do Vale do Paraíba (UNIVAP), number 18353613.0.0000.5503, and registered in the Clinical Trials, protocol number NCT02177929. The participants read and signed the informed consent form before participating in the study. The study is part of a doctoral thesis and was carried at UNIVAP in 2016.

PARTICIPANTS

Twelve people with SCI were selected from a list of interested in practicing in adapted sport at the UNIVAP Health Center. Five of them were excluded (one for tendinitis of the upper limbs, one for severe urinary infection, one due to severe pressure ulcers, one for lack of transportation, and one for not having completed the training protocol). The study sample, characterized in Table 1, consisted of seven male, sedentary tetraplegics. All participants had a sedentary lifestyle, and only three of them were doing conventional physiotherapy.

Inclusion criteria included: age between 18 and 48 years, complete or incomplete cervical SCI, more than eight months after injury, spasticity of the lower limbs less than or equal to 2 (modified Ashworth scale), clinical stability, and medical authorization for physical activity. They could not have an orthopedic dysfunction of their upper limb, severe deformities, associated respiratory diseases, cardiovascular abnormalities, or risk factors such as hypertension, diabetes or obesity; use cardiac depressant or stimulatory medications.

Exclusion criteria were major neuropathic pain, severe urinary infection, and less than an 80% attendance at trainings.

EVALUATION AND DATA ACQUISITION

Participants were evaluated before and after the training period, considering the HRV, respiratory tests of pulmonary function, and respiratory muscle strength. All data collections were performed in the morning of the days when participants did not perform training.

Heart rate variability (HRV)

The intervals between R waves of the electrocardiogram were obtained by a Polar® RS800 heart rate monitor. Data collection was performed for 7 min, and preceded by at least 2 min of rest. The monitor belt was positioned below the chest muscles of participants, who remained seated in their wheelchairs throughout data collection.

The acquired data were transferred to a microcomputer equipped with Polar® *ProTrainer software*. The signal was manually filtered, to remove artifacts, and exported to *Matlab 6.1*. Data processing was performed in *analisevfc software*, developed by Nascimento [13] for the temporal analysis of the following variables: HR, intervals between R waves (RR), standard deviation of all NN Intervals (SDNN), square root of the mean square differences of sucessive NN intervals (rMSSD), and number of pairs of adjacent NN intervals differing by more than 50 ms (pNN50). Continuous Wavelet Transform (CWT) and Fast Fourier transform (FFT) were used to obtain, through the spectral analysis, the Low Frequency (LF, 0.04 to 0.15 Hz), High Frequency (HF, 0.15 to 0.4 Hz), and LF/HF variables. The signals obtained in the first and last minute of data collection were excluded.

Table 1: Clinical and anthropometric characteristics of the sample.

Patient	Age (years)	Weight (kg)	Height (cm)	Time of injury (months)	Degree of injury	AIS	Etiology
1	37	83	170	22	C6	A	Diving
2	26	72	180	33	C6	C	Car accident
3	23	49	169	19	C6	A	Gunshot
4	25	56	173	48	C7	C	Diving
5	31	73	168	132	C6	A	Car accident
6	36	87	180	180	C6	B	Diving
7	18	50	180	22	C6	A	Fall
Mean ± SD	28.00 ± 6.97	67.14 ± 15.55	174.28 ± 5.5	65.14 ± 64.34	-	-	-

SD: standard deviation; AIS: American Spinal Injury Association Impairment Scale

Respiratory tests

First, the participants were informed about the procedures to be administered. The data collections were conducted with participants seated in their wheelchairs. To prevent air leakage, a nose clip was attached, and then participants were asked to perform at maximum effort for the time required for each maneuver.

Spirometry

To perform spirometry, a computerized spirometer, with turbine flow sensor (Microquark, the Cosmed brand, equipped with the PFT software suite, version 9.1b) was used, which was attached to a hard plastic mouthpiece (6.5 cm long and 2.5 cm diameter).

The following procedures were tested: slow vital capacity, forced vital capacity (FVC), and maximum voluntary ventilation (MVV), according to the criteria of the Brazilian Consensus on Spirometry [14]. The parameters assessed were: FVC, peak expiratory flow (PEF), forced expiratory volume in one second (FEV1), Tiffeneau index (FEV1/FVC%), mean forced expiratory flow at 25-75% of FVC ($FEF_{25-75\%}$), and MVV. Each maneuver was repeated three times [14], and the highest value was selected for analysis.

Manometry

The maximal respiratory pressures were measured using a Ger-Ar analog manometer®, scaled from -300 to +300 cmH2O, attached to the trachea (13.5 cm long and 2.5 cm in diameter) and a rigid plastic mouthpiece (6 cm in length, 2 cm proximal and 2 cm diameter of distal diameter), containing a millimeter leak orifice on its distal end [15].

The maximum inspiratory pressure (MIP) was obtained by a maximal inspiration performed from the residual volume (RV). The maximal expiratory pressure (MEP) was obtained by a maximum expiration preceded by a maximal inspiration, at the level of total lung capacity (TLC) [15], with the cheeks pressed to prevent air retention in the space between the teeth and cheeks.

Each maneuver was performed at least three times, with a 1-2 minute interval of rest between them [16]. The pressures sustained for at least 2 seconds were recorded. The highest value found, with variation less than 10% between the maneuvers, was selected for analysis [17].

Training protocol

Before and after workouts, vital signs and the general health of participants were evaluated. In addition, participants were instructed about the use of sunscreen, hydration, and proper nutrition.

The patients participated in 20 to 30 minutes of handcycling training, with three to five intervals of about 2 min, composing sets of 2 to 8 min of continuous cycling, according to the subjective perception of individual effort evaluated using the Borg 10-point scale which ranged from 4 to 7[6]. The training time was distributed into approximately 20 min of forward pedaling, and 10 min distributed between backward pedaling and slalom (with cones). The frequency of training was twice a week, with an intensity level ranging from 65 to 85% of HR reserve; these HR reserve values were similar to those found by Valent et al.[6]. The distance ranged from 250 to 3,000 m, and was added on average 900 m was added in each month of training. The time, intensity, and distance were gradually increased over the training period.

The trainings were performed outdoors in the morning, for a period of three months. One handbike (handvikn brand) was used, with 90º angle between the backrest and the seat, and 19º between the seat and the floor; two elastic bands (120 cm long and 90 cm wide) (Figure 1) were used to secure the hands of patients to the handlebars, when necessary. All patients used a helmet, as well as knee and elbow pads during the training.

DATA ANALYSIS

The Lilliefors testing and the extreme values were used to verify the normality of the data. The data showed normal distribution, with no extreme values. The Student t-test was used for comparisons between the means of the parameters assessed pre and post-training ($p < 0.05$). Statistical analysis was performed using the *Bioestat* 5.0 software.

RESULTS

The HRV analysis showed that only LF/HF (Wavelet) increased post-training ($p = 0.02$). The other parameters assessed showed no significant differences (Table 2).

No participant experienced signs and symptoms of autonomic dysreflexia during any procedure.

There were no significant differences before and after training for any of the evaluated parameters, as demonstrated by spirometric analysis (Table 3).

The analysis of maximal respiratory pressures showed a significant increase in MIP and MEP post training. The MIP moved from -74.28 ± 14.84 to -101.42 ± 21.35 cmH_2O ($p = 0.01$), and the MEP changed from 72.85 ± 21.38 to 84.28 ± 17.18 cmH_2O ($p = 0.04$) (Figure 2).

DISCUSSION

Several studies have used the HRV to estimate the effect of physical activity on cardiac autonomic control in people without SCI [18,19], but such effect in people with SCI remains uncertain.

Figure 1 Participant sitting in the hand bike ready to train.

Table 2: Values in mean and standard error of heart rate variability analyzed in time and frequency domains (Fourier and Wavelet), and the p value.

		Before	After	p
Time domain	HR (bpm)	85.37 ± 5.63	84.11 ± 5.31	0.73
	RR (ms)	720.11 ± 52.55	728.57 ± 48.82	0.80
	SDNN (ms)	41.22 ± 3.52	41.79 ± 8.05	0.94
	rMSSD (ms)	16.81 ± 3.76	22.42 ± 5.84	0.21
	pNN50 (%)	1.34 ± 0.74	4.43 ± 2.44	0.19
Frequency domain (Wavelet)	LF (ms^2)	205.25 ± 47.08	316.87 ± 116.49	0.42
	HF (ms^2)	55.56 ± 19.66	155.88 ± 57.16	0.08
	LF/HF	5.17 ± 0.75	3.29 ± 0.70	0.02*
Frequency domain (Fourier)	LF(ms^2)	225.92 ± 38.59	298.22 ± 110.73	0.60
	HF(ms^2)	94.61 ± 39.08	144.97 ± 53.02	0.51
	LF/HF	4.58 ± 1.01	3.35 ± 0.69	0.36

* Significant value.

Table 3: Spirometric values of mean, standard deviation, and p value.

	Before	After	p
FVC (L)	3.36 ± 0.98	3.26 ± 0.86	0.33
FVC (% exp)	63.84 ± 19.99	62.40 ± 17.12	0.44
FEV_1 (L)	2.82 ± 0.83	2.89 ± 0.70	0.51
FEV_1 (% exp)	53.47 ± 15.46	50.97 ± 19.12	0.54
PEF (L/s)	6.41 ± 1.89	6.18 ± 1.98	0.42
PEF (% exp)	66.15 ± 18.67	65.94 ± 17.25	0.88
FEV_1/FVC (%)	87.44 ± 7.78	88.56 ± 6.31	0.63
FEV_1/FVC (% exp)	103.52 ± 8.28	104.51 ± 7.51	0.74
FEF_{25-75} (L/s)	3.39 ± 1.06	3.52 ± 1.26	0.73
FEF_{25-75} (%exp)	64.60 ± 19.32	70.48 ± 27.48	0.45
MVV (%)	97.30 ± 29.37	104.81 ± 33.45	0.09
MVV (%exp)	67.30 ± 21.46	73.12 ± 24.76	0.07

FVC: forced vital capacity; FEV_1: forced expiratory volume in one second; FEF 25-75%: mean forced expiratory flow between 25-75% of FVC curve; MVV: maximum voluntary ventilation; % exp.: expected percentage

For Claydom and Krassioukov[1], the abnormal cardiovascular regulation post-SCI is related to the level of the injury and severity of the autonomic pathways. According to Jan et al. [20], in cervical or high-thoracic (above T6) SCI, the cardiovascular system loses sympathetic innervation, but the parasympathetic remains intact, via the vagus nerve, which may result in bradycardia, hypotension, autonomic dysreflexia, and abnormal cardiovascular responses to certain stimuli, such as physical exercise [7].

This study observed that, despite the lack of sympathetic activity stated on injuries above T6, the LF component did not disappear in the studied tetraplegic patients, even in complete injuries, which for Malliani [21] is related only to cardiovascular sympathetic modulation. These findings corroborate those from Claydom and Krassioukov[1], who highlighted some hypotheses: 1) the sympathetic oscillations can occur even in the absence of downward sympathetic control from spinal sympathetic neurons; 2) the destruction of sympathetic descending pathways may have been incomplete; and 3) the LF component may be mediated by parasympathetic mechanisms.

According to Melo et al. [23], Jan et al. [20], and Parati et al. [22], the LF component is modulated by both the sympathetic and parasympathetic systems. These authors believe that SCI causes autonomic impairment and damage to the baroreflex activity. Therefore, the use of LF to evaluate the sympathovagal activity in people with SCI requires careful interpretation. According to Jan et al. [20], the LF component may reflect the baroreflex instead of sympathetic and vagal activity.

Some authors [23] believe that the SDNN parameter reflects sympathetic activity. For others [20], this parameter reflects the sympathetic and parasympathetic influence. It is believed that the rMSSD and pNN50 parameters are related only to the parasympathetic influence [20,23]. Our study observed an increase of rMSSD and PNN50 post training, although not significant one. Considering this information, the significant reduction in LF/HF ratio may be related to increased post training cardiovascular parasympathetic activity. This hypothesis is in accordance with the affirmation of Melo et al. [23], Hautala et al. [24], and Carter et al. [25], that regular physical activity in healthy people, especially aerobic, increases cardiac vagal activity.

Likewise, Sloan et al. [26], demonstrated that aerobic training (12 weeks) promoted increased parasympathetic activity in healthy men; however, this was not observed for strength training. The benefits were lost in four weeks, showing that

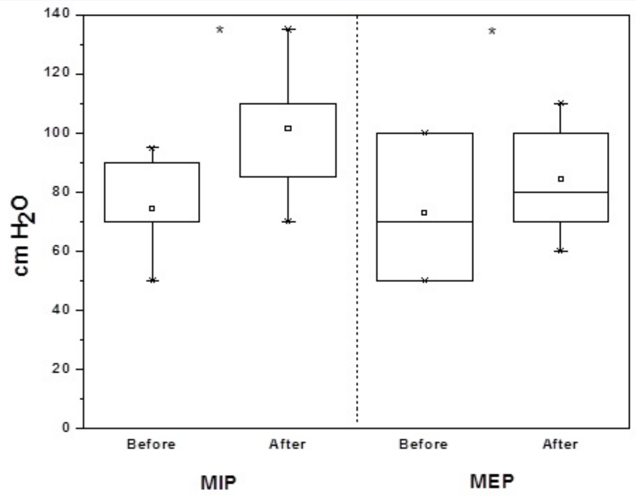

Figure 2 Boxplots for the Maximum Inspiratory Pressure (MIP) and Maximal Expiratory Pressure (MEP) in mean and standard deviation. * Significant difference.

physical exercise should be regular. A study conducted by Panda and Krishna [4] found that three months of aerobic training was not sufficient to promote an effect on cardiac autonomic activity in healthy people.

Four studies indicated below evaluated the beneficial effects of long term aerobic training on people with SCI [6,27-29]; however, different assessment measures were used.

Milia et al. [27], studied the cardiovascular effects of exercise training (3 hours/week arm cycling for one year) in paraplegic patients (level T4-L1). The authors concluded that the training promoted an improvement in myocardial performance, increased pre- and post-load, attributed to the improvement in vasomotor tone, and consequent increases of the venous return, which could compensate the sympathetic downward loss. These findings, although derived from paraplegics, could not explain the bradycardia of tetraplegic patients in this study, even with the increased parasympathetic activity induced by training. This demonstrates the importance of peripheral adaptations to exercise on cardiovascular control.

Tawashy et al. [28], reported more endurance, increased VO_2, and greater orthostatic tolerance in tetraplegic patients (3 months after injury) after aerobic circuit training (stationary arm bike, boxing, sliding motion, and wheeling, 3 times a week for 8 weeks). Valent et al. [6], found increased peak power and VO_2 peak with hand cycling training (3 times/week for 19 weeks) in tetraplegic patients. McLean and Skinner [29] demonstrated increased peak power and VO_2 peak, as well as improved endurance and reduced skinfold in post training tetraplegic patients with stationary arm bike (3 times / week for 10 weeks).

The spectral analysis by wavelet transform was more sensitive in identifying the decrease in LF/HF ratio compared to post training Fourier transform. This fact probably occurred because the signal time-frequency representation provided by the wavelet transform is the most suitable for non-stationary signals such as the HRV signal [2], because it is adaptable to changes in signal characteristic [30]. Thus, it shows advantages over the Fourier transform [31], which analyzes the signal as it was standing in small segments, using a time window of fixed length, providing good results for stationary signals [30].

The spirometric data showed no significant alteration in post training pulmonary function. Similar results were found in studies conducted by Valent et al. [6].

All participants had spirometric results with restrictive characteristics ranging from mild to very severe. Schilero et al. [3], attributed this to respiratory neuromuscular weakness.

The MVV mean value before training, as expected, was below normal levels. For the age of the sample, the normal values for MVV are between 166.9 ± 20.2 and 170.2 ± 29.7 [17]. As MVV decreases, the ventilation required for a particular exercise intensity increases, which reduces the efficiency and, consequently, the ventilatory exercise tolerance. Thus, the gain in MVV represents an increase in exercise tolerance. Although not statistically significant, there was an improvement of 7.7% in MVV after training.

According Paleville et al. [15], tetraplegic patients have stiffness of the rib cage, which can be attributed to ankylosis of the involved joints, due to chronic inability to deepen inspiration and the spasticity of the intercostal muscles. Furthermore, due to abdominal distension resulting from weakness or paralysis of the abdominal muscles, the fibers of the diaphragm muscle work with a poorer excursion, leading to a negative length-tension curve. These mechanical changes may have contributed to the insignificant spirometric values.

The pre-training MIP mean value (-74.28 ± 14.84 cmH_2O) was similar to that found in previous studies with tetraplegic patients (-71.7 ± 28.9 [32] and -72.5 ± 18.6 cmH_2O [33]). However, the pre-training MEP mean value (72.85 ± 21.38 cmH_2O) was higher than that found in previous studies with tetraplegic patients (20.7 ± 5.5 [34] and 40.9 ± 16.1 cmH_2O [33]). This difference may be due to the possible influence of the pressures generated by the muscles of the mouth and oropharynx. Further more, the elastic recoil pressure of the respiratory system [35] may have influenced the results, especially for MEP. The values found of MIP and MEP are below the normal values (-124 ± 44 and 233 ± 84) [36] for the age of the studied sample, demonstrating muscle weakness.

This study demonstrated that handcycling promoted improvement in respiratory muscle strength in tetraplegic patients, which was higher for the inspiratory muscles. This can be explained by the fact that the function of the expiratory muscles of tetraplegics can be more affected than the inspiratory muscles [3].

Considering that the majority of participants presented SCI C6 with American Spinal Injury Association Impairment Scale (AIS) A or B, the increase in respiratory pressure can be attributed to an increased performance of the preserved accessory muscles. Tetraplegic patients with paralysis or weakness of the respiratory muscles begin to use the accessory muscles and upper trapezius (cranial nerve XI), scalenes (C2-7 roots), sternocleidomastoid (cranial nerve XI), pectoralis major (C5-7 roots), platysma (facial nerve) and milohioideo (trigeminal nerve) [3,15]. This musculature may have been required during the hand cycling training, both during the pedaling motion and for the higher ventilatory requirements necessary to maintain the exercise.

Postma et al. [37], observed that people with SCI show a decline in pulmonary function throughout five years, higher than expected for people of the same age without SCI. The authors believe that factors such as increased body mass index, lower respiratory muscle strength, and decreased physical fitness are related to this decline. Therefore, handcycling practice can be used as a way to prevent this decline in pulmonary function.

CONCLUSIONS

Satisfactory results were observed regarding the autonomic control and respiratory muscle strength. Considering the sensory motor impairment of these people, these findings are relevant because the benefits promoted in the cardiopulmonary system are directly related to improved functionality and quality of life. For this reason, it is suggested to measure quality of life in a future study. In the clinical setting, these findings demonstrate the importance of performing a sport as a form of rehabilitation. For people affected by SCI, handcycling can be adopted as a continuing sports and recreational activity.

Some parameters assessed did not achieve significant results. It is believed that future studies with a larger sample and an increase in the training period may help enhance the effects of the proposed program.

ACKNOWLEDGEMENTS

Abreu EMC and Alves RS thank CAPES/PROSUP (Ministry of Education, Brazil) for the doctorial fellowship.

CONFLICT OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Cite this article

de Carvalho Abreu EM, Silva Lima FP, de Paula Júnior AR, Lima MO (2020) Effect of Handcycling on Cardiopulmonary System of Tetraplegics as A Result of Spinal Cord Injury. JSM Physical Med Rehabil 4(1): 1013.