CARDIORESPIRATORY RESPONSES OF PATIENTS WITH SPINAL CORD INJURIES

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SUMMARY

The objective of this study was to investigate cardiorespiratory responses (Heart Rate, Blood Pressure, VO2, VCO2 and Ve) to Neuromuscular Electrical Stimulation (NMES) of the quadriceps in patients with spinal cord injury. Ten patients (five paraplegics and five tetraplegics) participated in this study. The protocol of the test consisted of ten minutes of rest, twenty minutes of NMES of the quadriceps and ten minutes of recovery. The findings in this study indicated that, during NMES, the patients demonstrated low levels of VO2 and VCO2 and slow gas kinetics for tetraplegic individuals, and a fast gas kinetics for paraplegic individuals. Moreover, there were increases in blood pressure and heart rate. Cardiorespiratory responses increased with descending spinal cord injury level, meaning that the more severe the lesion, the lower the values. Therefore, most of the patients presented some limitations in cardiorespiratory responses, indicating the performance of exhaustive exercise, but the use of NMES can elicit improvements in exercise tolerance due to its benefits.

Keywords: Disabled Individuals; Rehabilitation; Medical Technology, Exercise.

INTRODUCTION

In addition to physical and sensorial malfunction, there are many sequels resulting from spinal cord injuries, for example, the musculoskeletal system atrophy, spasticity, autonomic malfunction, metabolic, hormonal and neuromuscular changes, reduction of breath capacity, blood stream and of heart structures dimensions, which, together with a sedentary status, may lead to cardiovascular and respiratory diseases. Those changes restrain physiological responses to motion activities, and may trigger a fast establishment of fatigue(1,2).

Spinal cord injury is widely investigated, whether through stem cells transplant, through drugs and electric fields administration, as well through the execution of synchronic and repetitive movements, such as gait training using the Body Support System and the rehabilitation of upper and lower limbs through Neuromuscular Electric Stimulation. Those techniques may result in spinal cord function recovery(3,4,5).

The Neuromuscular Electric Stimulation is an alternative technique for restoring and/ or recovering lost sensorial-motor functions through the artificial activation of skeletal muscles(6,7). Artificially induced exercises on quadriceps of individuals presenting spinal cord injuries are performed at the initial phase of the Gait Rehabilitation Program through NMES, because the quadriceps is the mostly active muscle during upright stance and gait. Thus, this study aimed to examine the cardiorespiratory variants – Blood Pressure (BP), Heart Rate (HR), Oxygen Consumption (VO2), Carbon Dioxide Production (VCO2), Minute Ventilation (Ve), Oxygen Partial Pressure (Po2), Carbon Dioxide Partial Pressure (Pco2) – during quadriceps NMES in paraplegic and tetraplegic patients.

METHODOLOGY

This research was approved by Ethics Committee of the State University of Campinas (UNICAMP). After consent, 10 male patients with spinal cord injuries (5 paraplegic and 5 tetraplegic) participating on the NMES Program were enrolled in this study.

The number of 10 patients is significant for conducting this study, because there are just a few groups with this approach, for example, in USA, Canada, Scotland, Japan, and this one in Brazil. Patients enrolled on the Neuromuscular Electric Stimulation program are approximately 20% tetraplegic, 5% hemiplegic, and 75% paraplegic. Those factors limit samples, in addition to the strict exclusion criteria due to those patients' complex clinical picture.

Rehabilitation system of individuals with spinal cord injuries through Neuromuscular Electric Stimulation consists on the placement of self-sticking electrodes over skin surface, over the motor points of the muscles and/or directly on peripheral nerves, according to desired movements. The Program is divided into three steps: (1) the conditioning phase is performed with individuals seated in their own wheelchairs, with 20 minutes of quadriceps muscle stimulation, alternately producing right and left knee extension, followed by 15 minutes of fibular nerve stimulation, evoking, by reflex, the alternate dorsiflexion of right and left foot; for tetraplegic patients, 20 minutes of upper limbs Stimulation are added; (2) when knee extension maintenance is seen, biped support training is initiated with the aid of a walker and concurrent stimulation of the right and left quadriceps muscles; (3) then, gait training is initiated with the aid of a walker and quadriceps and fibular nerves stimulation.

During the conditioning phase, biped support and gait training were performed in a once-a-week basis and the time of sessions varied according to each individual's performance, for approximately 45 minutes.

The ASIA Protocol (deficiency scale by the American Spinal Injury Association) was used, according to Barros Filho and cols., for classification as complete injury (A) or incomplete injury (B, C or D) and the FIM Protocol (Functional Independence Measure)(8). Those patients' profiles are shown on Table 1.

Values for average and standard deviation achieved for height (cm) and body mass (kg) of paraplegic patients are, respectively: 177 ± 7.8 and 84.6 ± 14.1. For tetraplegic patients, values achieved

Study conducted by the Department of Electric Engineering and Bioengineering, University of São Paulo (USP), São Carlos, Brazil.

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are, respectively: 177.2 ± 6.94 and 62.4 ± 5.02.

Cardiorespiratory evaluations (BP, HR, VO2, VCO2, Ve, Po2 and Pco2) were made during daytime and patients were asked to comply with the following recommendations[9,10]:

• No strong physical activity must be done on the 3 days prior to tests.

• 24 hours prior to test, the ingestion of caffeine, alcoholic beverages and nicotine is not allowed.

• Drugs must be withdrawn 24 hours prior to the tests.

• Intestine évidement shall be made in the previous night or by morning, and the bladder évidement, immediately before test or through the use of a catheter, in order to avoid autonomic dysreflexia.

• A controlled diet must be followed (30 minutes prior to the test), for example, allowing 50g of bread, 10g of cheese, 10g of ham, and 200 ml of orange juice or a fruit, in order to avoid hypoglycemia during exercises.

Patients	Age (years)	Level of Injury	ASIA	FIM*	Injury Cause	Injury Time (years)	Date of NMES onset	Current Training Phase on NMES Program
1	33	T9-T10	A	116	Gun shot	4	Aug/2002	Gait
2	28	T9	A	116	Gun shot	4	Jan/2002	Gait
3	36	T6-T7	B	116	Car accident	4	Feb/2000	Gait
4	40	T6	A	114	Gun shot	9	Feb/2000	Gait
5	31	T5	B	113	Car accident	16	Sep/1999	Gait
6	35	C7	A	71	Gun shot	8	Jun/2002	Conditioning
7	31	C6-C7	B	88	Car accident	12	Mar/1999	Conditioning
8	25	C5-C6	A	65	Diving	10	Feb/2003	Conditioning
9	26	C5	A	74	Diving	2	Feb/2001	Conditioning
10	28	C4-C5	A	55	Diving	14	Mar/1999	Conditioning

Table 1: Profile of patients with spinal cord trauma.

The Test Protocol consisted of 10 minutes of rest, 20 minutes of NMES on right/ left quadriceps (concentric isotonic contraction) and 10 minutes of recovery at rest (Figure 1).

The used stimulation parameters were: kind of bipolar single-phase wave, duty cycle 4/12, 25 Hz frequency, pulse duration of 300 ms and 0 – 150 V amplitude, adjustable according to each patient in order to maintain maximum extension of the knee during quadriceps stimulation.

The BP was measured by sphygmomanometer method during the 5th, 25th, and 35th minute of test execution. The HR was monitored by Electrocardiogram (ECG), recording data from rate-to-rate (the ECG was the method selected for measuring HR, because, in the pilot study, we used the Polar S810 and noise was captured during NMES in some cases). For VO2, VCO2, Ve, Po2 and Pco2 evaluation, the gas analyzer Sensormedics Vmax 29C was used, recording data from breath-to-breath. The acquisition of cardiorespiratory parameters was achieved by using the Vmax Software.

Figure 1 - Experimental procedure

Visual inspection of charts was performed, and then, based on achieved results, two groups could be formed (paraplegic and tetraplegic). From data regarding test transition phases (rest, NMES, and recovery) the average and standard deviation of the cardiorespiratory variants values were achieved for the patients in each group.

RESULTS

According to the results showed on Tables 2 and 3, tetraplegic patients presented lower values for the cardiorespiratory variants during rest and NMES when compared to the paraplegic group.

Regarding hemodynamic parameters, during rest, the occurrence of bradycardia and hypotension was seen only in the tetraplegic group. During NMES, there was an increase of HR and Systolic BP in the majority of paraplegic and tetraplegic patients, while Diastolic BP did not present changes. However, in some patients, there was bradycardia or unchanged HR at the beginning of the NMES, but with a late linear increase, and, in other cases, an initial increase, followed by a drop and a new increase was also noticed.

Paraplegic patients reached permanent regimen at the beginning of the stimulation, presenting a fast gases kinetics (Figure 2-a) compared to tetraplegic patients, who reached the permanent regimen at the end of the NMES, presenting a slow gases kinetics (Figure 2-b). Furthermore, high Po2 levels and low Pco2 levels were seen in most of the patients (Figure 3).

During recovery, patients presented a linear decrease in gases kinetics, reaching rest values, but the HR was still high (Figure 4).

DISCUSSION

During rest and NMES, low values for VO2, VCO2 and Ve were seen in patients. Also, those values were inversely proportional to the injury level, meaning that, in tetraplegic patients, values were lower than those achieved in paraplegic patients. These results may be related to weakness or some degree of palsy of respiratory muscles, in addition to a reduced lung and thoracic grid distensibility(11), because motor root for diaphragm occurs between C3-C5, for abdominal muscles between T7-T12 and for thoracic and intercostal muscles, between T8-T12. Also, oxygen demand on a paralyzed muscle can be reduced and hypokinetic stream may lead to a reduction on O2 and CO2 transport due to the lack of musculoskeletal pump and vasomotor control at rest[9].

Also, patients with spinal cord injuries, particularly those with injuries above T6 may show a loss of sympathetic control of the heart, adrenal cord and vasomotor response, as well as a loss of thermoregulatory response[9,12,13], which can be related to the low cardiorespiratory levels, to the slow gases kinetics and resultant changes on Po2 and Pco2 levels during NMES.

Cardiorespiratory variables	Rest	NMES	Recovery
Vo_2 (l/min)	0.22 ± 0.02	0.48 ± 0. 01	0.25 ± 0.02
Vco_2 (l/min)	0.15 ± 0.01	0.40 ± 0.08	0.19 ± 0.02
Ve (l/min) BTPS	10.01 ± 1.41	18.2 ± 3.64	11.98 ± 2.23
pO_2 (mmHg) STPD	93.48 ± 2.73	100.63 ± 3.37	105.61 ± 2.24
pCO_2 (mmHg) STPD	37.99 ± 1.77	35.43 ± 1.12	32.33 ± 1.51
FC (bpm)	85.4 ± 8.01	99.25 ± 9.57	93.99 ± 7.65
Systolic BP (mmHg)	116 ± 5.4	144 ± 5.4	121 ± 8.94
Diastolic BP (mmHg)	76 ± 5.4	74 ± 8.94	74 ± 8.94

Table 2: Cardiorespiratory parameters of paraplegic patients.

Paraplegic patients reached permanent regimen at the beginning of the NMES, which shows a good conditioning, because the fast VO2 kinetics at the beginning of the exercise demonstrates that there is enough O2 for the muscle exercised to generate ATP, with prevalence of aerobic route. In comparison, the tetraplegic presented a slow gases kinetics, which reflects the prevalence of lactic anaerobic route, because the slow VO2 kinetics at the beginning of the exercise indicates insufficient O2 levels for the muscle exercised to generate ATP, so ATP production results from anaerobic glycolisis[14].

Cardiorespiratory variables	Rest	NMES	Recovery
Vo_2 (l/min)	0.15 ± 0.01	0.29 ± 0.02	0.16 ± 0.01
Vco_2 (l/min)	0.10 ± 0.01	0.23 ± 0.02	0.12 ± 0.01
Ve (l/min) BTPS	9.38 ± 1.18	14.48 ± 3.71	9.6 ± 0.96
pO_2 (mmHg) STPD	98.73 ± 2.34	104.39 ± 3.79	106.70 ± 2.89
pCO_2 (mmHg) STPD	35.08 ± 2.36	32.62 ± 2.42	30.55 ± 1.53
FC (bpm)	67.39 ± 5.65	89.64 ± 8.22	83.84 ± 6.28
Systolic BP (mmHg)	104 ± 4.41	128 ± 5.03	112 ± 4.47
Diastolic BP (mmHg)	68 ± 3.36	70 ± 6.36	70 ± 5.67

Table 3: Cardiorespiratory parameters of tetraplegic patients.

Changed Po2 and Pco2 values indicate exhaustive exercises performance, because ventilation increases more than the VO2 resulting in a higher Po2. High Po2 values reduces oxygen fixation on hemoglobin, the Bohr effect, which reduces blood ability to transport oxygen to muscles activated during exercises, and thus, reduces performance levels. In an exhaustive exercise, for the same reasons pointed out for oxygen, the steady or reduced Pco2 demonstrates that there is no excessive accumulation of H ions as a result of CO2 excess. As for the Pco2 increase, it results in an increase of the ventilation in order to eliminate the excess of CO2[15].

Bradycardia and hypotension seen in tetraplegic patients during rest may be related to neural regulation of cardiovascular function, due to a sympathetic dysfunction for the heart and for the blood vessels below injury level, which, together with the musculoskeletal pump loss, lead to a reduction of the venous feedback and of the cardiac effectiveness[16,17].

During the NMES, an increase of the HR and of the systolic BP were noticed in patients, although the ones having spinal cord injuries may present a loss of the vasoconstrictor response below injury level (lower limbs, splenic and abdominal areas), which may result in blood concentration on lower limbs and hypotension during exercise with upper limbs or orthostatism (passively seated or upright stance). So, these results are related to the hemodynamic benefits provided by NMES, such as activation of the musculoskeletal pump, which increases venous feedback, the ventricular filling, myocardial fibers distensibility, contraction strength, systolic volume, the HR, the cardiac output and the BP, according to Frank Starling's Law[9].

Also, musculoskeletal pump activation and the venous feedback increase, provided by the NMES in lower limbs, enable humoral factors action, that is, the transport of metabolic substrates of the artificially activated muscle (for example, the lactic acid and the high body temperature), which may help patients to respond to physical exercise stress, resulting in an increase of the HR and Ve. Humoral feedback may be related to an elevated HR on recovery period. In the study by Kjaer et al.[18], a HR increase was seen in paraplegic and tetraplegic patients during the act of pedaling induced by NMES and those values remained high at the recovery period, due to the action of the humoral feedback, because when the same procedure was performed with vascular occlusion on lower limbs, the HR response to exercise was lower reflecting the reduced venous feedback limiting the transportation of metabolites substrates of the artificially activated muscle[18].

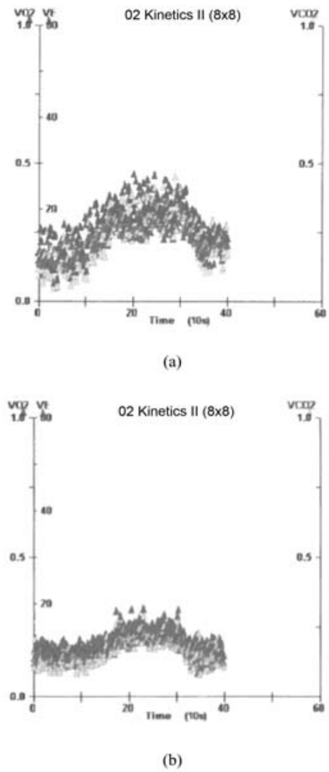

Figure 2: Fast gases kinetics in paraplegia (a) and slow gases kinetics in tetraplegia (b).

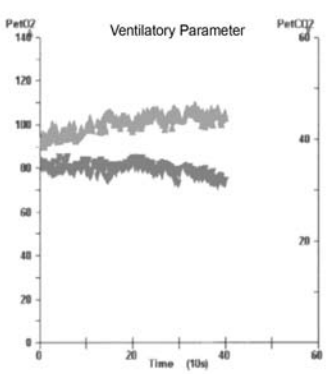

Figure 3: Increase of Po2 and reduction of Pco2.

Regarding the HR increase at the beginning of the NMES, this can be related to vagal tonus output. Meanwhile, the unchanged HR at the beginning of the NMES can be related to vagal parasympathetic tonus control for the S-A nodule and the humoral factors can explain the late increase on HR. Also, the HR increase seen in some patients during NMES can be related to some degree of preserved sympathetic control for adrenal cord (presenting innervation between T3-L3 with a higher portion between T6-T10) and for the heart (in patients with spinal cord injury level above T6), because the loss of sympathetic control for the heart may not result in cardiac acceleration during exercise and the loss of sympathetic control for adrenal cord may result in abnormal release of catecholamines, that is, adrenaline and noradrenaline[10,13].

The bradycardia at the beginning of NMES, concurrently to the BP increase, probably has not been associated to autonomic dysreflexia, because systolic BP increase did not occur above 40 mmHg from baseline value[16]. Sweat was also not seen above injury level, as well as piloerection and malaise. So, the dissociation between HR and BP may be related to the increase of venous feedback, resulting in a Starling's effect, with increase on blood pressure and activation of the barorreceptor reflex, with resultant bradycardia. This result is similar to those found in individuals with spinal cord injuries that returned to supine position, after the orthostatic stress with NMES in lower limbs(19).

These data on HR responses in individuals with spinal cord injuries above T6 are also important for patients submitted to heart transplantation, and thus present a denervated heart.

However, care must be taken in the interpretation of HR data, because their fluctuations may also be related with a distorption of the ECG signal, because some patients have metal shafts, pins and even gun bullets lodged in the body. Also, Morh et al. verified the stimulation pattern reflected on signals achieved by Electrocardiogram, changing HR results in patients with spinal cord injuries[20]. Therefore, upon facing these problems, Jacobs and Mahoney (2002) selected the palpation method during evaluations(21), but this is not a scientific method and the HR measurement constitutes a methodological problem during NMES.

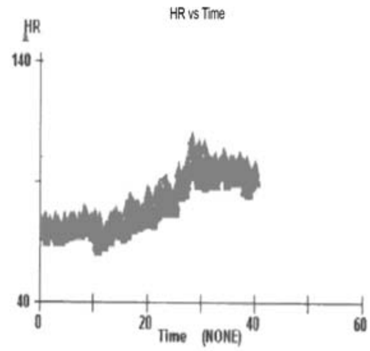

Figure 4: HR response.

CONCLUSION

In the patients evaluated during this study, it was seen that the kind of injury (complete or incomplete) did not interfere on cardiorespiratory parameters during rest and NMES. But responses were different from each other according to the injury, physical activity and functional independence measures, meaning that paraplegic patients perform gait training and also present a higher Functional Independence measure (FIM) compared to tetraplegic patients, who are still in conditioning phase for gait and present a lower Functional Independence Measure (Table 1).

Although cardiorespiratory responses present some limitations, the patients demonstrated ability to perform an artificially induced exercise, which suggests potential compensatory mechanisms and the use of the lactic acid as a power source for muscular function[21]. These factors constitute exercise paradigms in patients with spinal cord injuries.

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