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Response of the arterial blood pressure of quadriplegic patients to treadmill gait training

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Abstract

Blood pressure pattern was analyzed in 12 complete quadriplegics with chronic lesions after three months of treadmill gait training. Before training, blood pressure values were obtained at rest, during treadmill walking and during the recovery phase. Gait training was performed for 20 min twice a week for three months. Treadmill gait was achieved using neuromuscular electrical stimulation, assisted by partial body weight relief (30-50%). After training, blood pressure was evaluated at rest, during gait and during recovery phase. Before and after training, mean systolic blood pressures and heart rates increased significantly during gait compared to rest (94.16 ± 5.15 to 105 ± 5.22 mmHg and 74.27 ± 10.09 to 106.23 ± 17.31 bpm, respectively), and blood pressure decreased significantly in the recovery phase (86.66 ± 9.84 and 57.5 ± 8.66 mmHg, respectively). After three months of training, systolic blood pressure became higher at rest (94.16 ± 5.15 mmHg before training and 100 ± 8.52 mmHg after training; $P < 0.05$) and during gait exercise (105 ± 5.22 mmHg before and 110 ± 7.38 mmHg after training; $P < 0.05$) when compared to the initial values, with no changes in heart rate. No changes occurred in blood pressure during the recovery phase, with the lower values being maintained. A drop in systolic pressure from 105 ± 5.22 to 86.66 ± 9.84 mmHg before training and from 110 ± 7.38 to 90 ± 7.38 mmHg after training was noticed immediately after exercise, thus resulting in hypotensive symptoms when chronic quadriplegics reach the sitting position from the upright position.

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- Neuromuscular electrical stimulation
- Body weight support
- Blood pressure
- Orthostatic hypotension

Introduction

Cervical spinal cord injury which results in quadriplegia involves impairment of motor, sensory and sympathetic nervous system (SNS) functions. The extensive muscle paralysis associated with the absence or decrease of SNS interferes negatively with the cardiovascular responses during exercise, since these factors provide insufficient support for aerobic metabolism (1,2). Paraplegic subjects with injury level above the thoracic SNS outflow (T6 level) also have impaired SNS activity.

The lack of normal muscle activity damages the venous muscle pump, increases venous pooling in the lower extremities, and diminishes the venous return and cardiac output, reducing blood pressure in these subjects (3,4). The interruption of efferent SNS, damaging the normal baroreceptor reflex (5), and muscle paralysis are responsible for the orthostatic hypotension observed in quadriplegic individuals when moving from the supine or sitting position to upright posture (6-8). Hypotension is defined as systolic blood pressure lower than 90 mmHg for at least two consecutive measurements (9).

In an attempt to compensate for the decrease of blood pressure, tachycardia is observed due to the parasympathetic vagal withdrawal (10). However, this is not sufficient to compensate for the SNS impairment (6). Many studies have shown that head-up tilt causes a significant fall in blood pressure in quadriplegic persons (systolic and diastolic blood pressure) associated with an increase in heart rate (5,6,11).

Adaptations occur months or years after the lesion, allowing a change in body position without hypotension (12). The adaptation process probably involves the action of the renin-angiotensin system, antidiuretic hormone, aldosterone and arginine vasopressin, which are crucial in the regulation of blood pressure (13,14). Also, the development of spasticity may help decrease the hypotensive symptoms (11). Quadriplegic subjects with chronic injuries have blood pressure significantly lower than in normal individuals (6,15).

Neuromuscular electrical stimulation (NMES) permits the activation of paralyzed muscles through the electrical stimulation of intact peripheral motoneurons (16). NMES has been used to provide a functional gait (17) and to study the action of the spinal cord in the control of movement through basic motor patterns generated by sensory inputs, using the concept of task-oriented training (18,19). The functional muscle activity generated by NMES in the lower limbs improves venous return, increases cardiac preload, systolic volume and cardiac output, which in turn increase blood pressure during exercise (2,20). Studies have reported that exercise using NMES can be useful for improving physical capacity in spinal cord injured persons due to the improvement of the muscular system (21,22) and to the increase of cardiovascular stress, even at a moderate level (11,23,24).

Sampson et al. (11) observed that NMES applied over the quadriceps and pretibial muscles was efficient in the increase of blood pressure during stimulation in subjects with a spinal cord injury level above T6. The higher the intensity of the stimulation current, the higher the blood pressure, with saturation at 96 mA (at 160 mA no additional increase in blood pressure was observed). Thus, NMES is suggested to be a useful treatment for orthostatic hypotension in the early post-injury phase, accelerating the adaptation process.

Ashley et al. (25) observed a mean increase in systolic and diastolic blood pressure during NMES over the quadriceps in subjects in the sitting position (achieving 21 and 17 mmHg, respectively). Sampson et al. (11) observed that the blood pressure increased with NMES, although the increase of the tilting angle caused a decrease of blood pressure, even with NMES.

However, no studies have reported the blood pressure pattern during treadmill gait training when comparing rest, exercise and recovery phases. Changes in blood pressure during treadmill gait sessions are actually a warning of the risk of hypotension symptoms at the end of exercise in chronic quadriplegic subjects and are therefore shown here. In the present study, we compare blood pressure values obtained before and after 3-month treadmill gait training with 30-50% body weight relief provided by NMES.

Subjects and Methods

Twelve quadriplegic subjects (all males, mean age 33.83 ± 8.73 years) were recruited at the University Hospital to participate in the study. The lesion level varied between C4 and C7. All individuals had a complete lesion (ASIA Impairment Scale: A). Median time post-injury was 77.58 months (range 17-180 months). Mean body mass and height of subjects were 64.91 ± 12.68 kg and 178.0 ± 8.92 cm, respectively. The study was approved by the Hospital Ethics Committee and written informed consent was obtained from all participants. Inclusion criteria included intact lower motor neurons, which is a requirement for muscle contraction using surface electrical stimulation and towards developing walking capacity in the treadmill (Inbrasport, Classic CI, Porto Alegre, RS, Brazil) gait, with 30-50% body weight support (Biodex, Standard Unweighing System, Shirley, NY, USA) during 10 min consecutively. Another requirement was no history of cardiopulmonary disease. All subjects had their quadriceps and tibialis anterior muscles stimulated in the sitting position for at least 5 months in order to provide treadmill gait training (with 30-50% of weight relief) through knee extension provided by NMES. A 4-channel electrical stimulator delivered a signal of 25 Hz with monophasic rectangular pulses of 300-µs duration and a maximum intensity of 200 V (1 kΩ load).

Gait training consisted of 20-min sessions held twice a week for three months. Brachial blood pressure was measured with a sphygmomanometer. Blood pressure was measured before the treadmill walking session (rest phase, in the sitting position), after 10 min of gait training (in the upright position) and as soon as the patient returned to the sitting position (recovery phase). Two consecutive measurements were performed for each phase. Heart rate was determined by electrocardiography and was continuously monitored (SensorMedics Corp., Yorba Linda, CA, USA, Vmax 29c Cardiopulmonary Exercise Testing Instrument). Measurements were made before and after the training period. Gait was performed on a treadmill using a four-channel electrical stimulator over the quadriceps muscle group in order to provide for the stance gait phase and stimuli were applied to the common peroneal nerve to provide for the swing phase, through the withdrawal reflex. Manual assistance during treadmill walking was provided to all patients to avoid any harmful gait pattern. Treadmill speed started at 0.5 km/h and at the end of the study all subjects were capable of walking at 0.9 km/h.

Body weight support, between 30-50% of body weight, was used to facilitate and provide appropriate gait because it assists the stance cycle of gait, allows a weight relief that can be supported by the lower limbs of each patient and also assists trunk stabilization. Moreover, it is important to reduce the risk due to post-traumatic syringomyelia and fracture in osteoporotic bones (Figure 1) (16).

Data were analyzed statistically to determine the differences in blood pressure and heart rate during the rest, treadmill gait and recovery phases. Differences in systolic and diastolic blood pressures and heart rate after 3-month treadmill training were also investigated. Blood pressure data were compared

Figure 1. Treadmill gait training using neuromuscular electrical stimulation assisted by body weight support.

using *t*-tests. Data are reported as means ± SD. Differences were considered significant at $P < 0.05$.

Results

Before starting treadmill walking training, the 12 complete quadriplegic subjects presented mean systolic and diastolic blood pressures at rest of 94.16 ± 5.15 and 65.83 ± 5.15 mmHg, respectively. During treadmill gait, systolic blood pressure increased significantly to 105 ± 5.22 mmHg, but no significant changes were observed in diastolic blood pressure (70 ± 7.38 mmHg). When 20 min of gait training was achieved, electrical stimulation was turned off, and the patient returned to his wheelchair. Mean systolic and diastolic blood pressures were significantly lower in the recovery phase than during treadmill gait (86.66 ± 9.84 and 57.5 ± 8.66 mmHg, respectively).

After 3 months of gait training, subjects presented mean systolic and diastolic blood pressures at rest of 100 ± 8.52 and 65.83 ± 9.0 mmHg, respectively. During treadmill gait, systolic blood pressure significantly increased to 110 ± 7.38 mmHg, but no significant changes were observed in diastolic blood pressure (69.16 ± 7.92 mmHg). In the recovery phase, systolic and diastolic blood pressures significantly decreased to 90 ± 7.38 and 55.41 ± 7.82 mmHg, respectively.

After gait training, subjects presented a significant increase of systolic blood pressure at rest and during gait. No differences were observed in diastolic blood pressure at rest and during walking. In the recovery phase, no changes occurred in either systolic or diastolic blood pressure. A drop of mean systolic blood pressure from 105 ± 5.22 to 86.66 ± 9.84 mmHg before training and from 110 ± 7.38 to 90 ± 7.38 mmHg after training was observed (stimulation off). Table 1 presents the mean values obtained for systolic and diastolic blood pressures before and after training, during the rest, treadmill gait and recovery phases.

Before training, mean heart rate was 74.27 ± 10.09 bpm during rest, 106.23 ± 17.31 bpm during treadmill gait and 95.8 ± 17.42 bpm during recovery. After training, mean heart rate was 73.69 ± 8.51 bpm during rest, 109.23 ± 15.79 bpm during treadmill gait, and 94.2 ± 14.08 bpm during the recovery phase. Heart rate increased significantly from the rest to the gait phase, even before training. Moreover, values obtained during recovery were significantly higher than those obtained at rest before and after training. However, after training, no significant differences were observed in values obtained for any phase (rest, gait and recovery).

Table 1. Systolic (SBP) and diastolic (DBP) blood pressure during the rest, treadmill gait and recovery phases measured before and after walking training.

Phases	Blood pressure	Before training	After 3 months of training
Rest	SBP	94.16 ± 5.14	100 ± 8.52
	DBP	65.83 ± 5.14	65.83 ± 9.00
Treadmill gait	SBP	105 ± 5.22	110 ± 7.38
	DBP	70 ± 7.38	69.16 ± 7.92
Recovery	SBP	86.66 ± 9.84	90 ± 7.38
	DBP	57.5 ± 8.66	55.41 ± 7.82

Data are reported as mean ± SD in mmHg for 12 subjects.

Discussion

Many studies have shown that the use of NMES during exercise in quadriplegic subjects is capable of improving their physical capacity because of cardiovascular adaptations (23,26) through the increase of venous return, cardiac output and heart rate due to the parasympathetic vagal withdrawal and to the muscle contraction. Moreover, many studies have reported the effect of NMES in increasing the strength and endurance of paralyzed muscles (21,22,27, 28).

The present study has shown that, during treadmill gait, systolic blood pressure and heart rate increase significantly compared to rest values. The increase of heart rate during treadmill gait occurred probably due to parasympathetic vagal withdrawal and not because of sympathetic activity; maximal heart rate will therefore be within 100 and 125 bpm (29-32).

The increase of systolic blood pressure reflects the increase of cardiovascular activity (heart rate and cardiac output), and can be provided by NMES in the lower limbs (11,25,33,34). However, the increase was moderate because individuals with complete lesions present SNS impairment, which damages the cardiovascular responses during gait exercise in individuals with extensive muscle paralysis. No significant differences were observed in diastolic blood pressure from rest to gait. Exercise promotes the reduction of peripheral resistance due to the vasodilation of the activated muscle, with little interference in the diastolic blood pressure values (20). However, the mean increase of systolic and diastolic blood pressures observed was less than 21 and 17 mmHg, respectively, during NMES, as reported by Ashley et al. (25).

After 3-month training, a significant increase of systolic blood pressure at rest and during gait exercise was observed, with no differences in the diastolic blood pressure. Pollack et al. (35) did not observe any blood pressure differences after 12 weeks of NMES-induced leg cycle ergometer exercise in spinal cord-injured subjects. However, in that study they included in the same group paraplegic and quadriplegic subjects, who, of course, present different patterns of somatic and autonomic function. This may have contributed to the results obtained. However, Faghri et al. (23) also observed a significant increase of systolic blood pressure at rest after 36 sessions (12 weeks) of leg cycle ergometer exercise provided by NMES in individuals with chronic spinal cord injuries. They hypothesized that the increase of systolic blood pressure occurred due to adjustment of the renin-angiotensin system, which stimulates the arteriolar vasoconstriction, thus increasing blood volume.

Physical exercise in quadriplegic subjects seems to act on blood pressure control, which leads to increased rest values. This increase of systolic blood pressure is not a normal pattern associated with aerobic exercise in healthy individuals.

After the training period of 3 months, systolic blood pressure increased significantly during treadmill gait; however, no differences were observed in heart rate values, showing that the increase of systolic blood pressure occurred as the result of the increase of stroke volume (provided by NMES) with no influence of heart rate (36).

In the recovery phase, no differences were observed for systolic and diastolic pressure after the 3 months of training. Values remained significantly lower than the exercise phase ones (systolic blood pressure before training: from 105 ± 5.22 to 86.66 ± 9.84 mmHg; after training: from 110 ± 7.38 to 90 ± 7.38 mmHg).

Hypotension after exercise has already been extensively investigated in normal individuals, with a decrease of 10-12 mmHg for systolic blood pressure and a decrease of 5-7 mmHg for diastolic blood pressure after exercise compared to rest values (26). However, as quadriplegic subjects already present low blood pressure at rest, an additional decrease of blood pressure after exercise can produce symptoms of hypotension, even in chronic injuries (systolic blood pressure before training: at rest = 94.16 ± 5.14 mmHg and in the recovery phase = 86.66 ± 9.84 mmHg, and after training: at rest = 100 ± 8.52 mmHg and in the recovery phase = 90 ± 7.38 mmHg).

Therefore, despite the improvement in the cardiovascular responses provided by NMES in spinal cord-injured subjects, as reported in many studies (22,23,37,38), it is important to consider the reduction of blood pressure as soon as exercise ends. Two causes probably contribute to this significant decrease. First, the interruption of artificial stimulation of the paralyzed muscle impairs the leg muscle venous pump, which decreases the venous return, the stroke volume and, consequently, the systolic blood pressure. Second, the increase of muscle metabolism promotes the increase of local temperature, carbon dioxide concentration and hydrogen ions, which promote vasodilation in the activated muscle (26,39,40) and consequently decreases the diastolic blood pressure.

The present results show that treadmill gait provided by NMES can increase blood pressure values through the increase of heart rate and cardiac output. However, quadriplegics and high thoracic paraplegics can suffer some hypotension symptoms in the first minutes of the recovery phase due to the abrupt drop of venous return associated with vasodilation in the activated muscles (a systolic blood pressure drop of 17.46% before training and of 18.18% after training). Spinal cord rehabilitation centers should consider the risk of hypotension symptoms after the upright position, even when the patients are chronic ones.

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