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ARTICLE

Artificial gait in complete spinal cord injured subjects: how to assess clinical performance

Marcha artificial em indivíduos com lesão medular completa: como avaliar desempenho clínico

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ABSTRACT

Objective: Adapt the 6 minutes walking test (6MWT) to artificial gait in complete spinal cord injured (SCI) patients aided by neuromuscular electrical stimulation. **Method:** Nine male individuals with paraplegia (AIS A) participated in this study. Lesion levels varied between T4 and T12 and time post injured from 4 to 13 years. Patients performed 6MWT 1 and 6MWT 2. They used neuromuscular electrical stimulation, and were aided by a walker. The differences between two 6MWT were assessed by using a paired t test. Multiple r-squared was also calculated. **Results:** The 6MWT 1 and 6MWT 2 were not statistically different for heart rate, distance, mean speed and blood pressure. Multiple r-squared (r^2 = 0.96) explained 96% of the variation in the distance walked. **Conclusion:** The use of 6MWT in artificial gait towards assessing exercise walking capacity is reproducible and easy to apply. It can be used to assess SCI artificial gait clinical performance.

Keywords: spinal cord injury, walking, rehabilitation, paraplegia.

RESUMO

Objetivo: Adaptar o teste de caminhada dos 6 minutos (TC6) para marcha artificial de pacientes com lesão medular completa associado a eletroestimulação neuromuscular. **Método:** Nove participantes do sexo masculino com paraplegia (AIS A) participaram do estudo. O nível de lesão variou entre T4 e T12 , tempo de lesão variou entre 4 e 13 anos. Os pacientes realizaram dois TC6 (TC6-1 e TC6-2). Os participantes usaram eletroestimulação neuromuscular e foram auxiliados por andador. As diferenças entre os dois TC6 foram avaliadas pelo teste t pareado e calculado o r^2. **Resultados:** Não foi encontrada diferença estatística entre TC6-1 e TC6-2 para frequência cardíaca, distância, velocidade média e pressão arterial. O r^2 = 0,96 explica 96% da variação na distância caminhada. **Conclusão:** O uso do TC6 em marcha artificial para avaliação da capacidade de exercício de caminhada é reprodutível e fácil de aplicar. Esse teste pode ser utilizado para avaliar o desempenho clínico da marcha artificial de indivíduos com lesão medular.

Palavras-chave: lesão medular, marcha, reabilitação, paraplegia.

Assessing walking in patients with locomotion disorders is an important measure in rehabilitation. However, the walking ability of spinal cord injured (SCI) subjects ranges from total incapacity to near normal speed[1], due to the large variability of lesion.

Many methods were developed to allow gait of spinal cord injured subjects, including a variety of orthosis, neuromuscular electrical stimulation (NMES), hybrid orthosis[2] and exoskeleton[3]. Without walking aiding devices, complete SCI subjects are limited to the wheelchair, which is practical towards locomotion. One gait training option is the association with NMES, even quadriplegic patients are able to walk aided by body-weight support tool and NMES[4].

Since 1989, our laboratory has been developing technology to prepare subjects with spinal cord injury to walk again using NMES. Studies showed benefits of this gait training as increase in bone mass, the preservation of join integrity and cardiovascular improvement[4,5,6].

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As the artificial gait has demonstrated good results, clinical research is necessary to assess the evolution of such therapy. Some authors have developed ways to assess SCI walking. Walking index for spinal cord injury (WISCI) was validated[7] and revised later into the WISCI II[8]. Timed walking tests like the Time Up and Go (TUG) test, the 10-meter walk test, were developed and adapted to assess SCI patients[9]. The physiological cost index (PCI) is widely used[10], however heart rate steady state is necessary and it is not always obtained. The total heart beat index could also be an alternative method to represent energy expenditure[11].

The 6-minute walk test (6MWT) that measures the walked distance (in meters) during 6 minutes was first validated for SCI by Hedel et al.[9]. This test evaluates the system responses involved in exercise which include pulmonary and cardiovascular systems, neuromuscular units, muscle metabolism and assesses the submaximal level of functional capacity (relevant for daily activities)[12].

The 6MWT is used with success in pretreatment and post treatment comparisons, as functional status, and can predict morbidity and mortality[12]. Recently the 6MWT has been implemented to incomplete patients with SCI[9,13,14]. As 6MWT has been used to assess incomplete SCI subjects, the purpose of the current investigation was to adapt the 6MWT to assess complete SCI patients aided by NMES once the artificial gait was introduce recently as a therapy and now its importance increased not only of walking level, but also of walking performance.

The aim of the current investigation was to assess the artificial gait by 6 minute walking test (6MWT) adapted to complete spinal cord injured (SCI) patients aided by neuromuscular electrical stimulation.

METHOD

Subjects

Nine male individuals with paraplegia (AIS A) participated in this study. Lesion levels varied between T4 and T12 and time post injured from 4 to 13 years.

The mean age was 32.78 ± 11.58 years old, height 180 ± 0.05 cm, mass 74.33 ± 8.69 kg and 7.76 ± 3.18 years' post-injury.

At the time of the study, the subjects were all in a clinically stable state and none of them complained of respiratory symptoms or related history of cardiopulmonary disease.

Subjects were selected among patients who were admitted in the ambulatory clinic, *Hospital Universitário da Universidade Estadual de Campinas*. Important criteria for inclusion in the study were the walking ability using NMES and the use of ankle foot orthosis (AFO). All of them had sessions of gait training before tests.

State University of Campinas's Ethics Committee approval was obtained for this study protocol. Before tests, the procedures were described in detail and consent was obtained from all subjects.

Experimental protocol

Six-Minute walk test

The 6-min walk test was conducted according to the standardized protocol[12] and it was adapted to paraplegic patients. Subjects were instructed to walk in a hospital corridor and they were instructed to walk as fast as possible during 6 minutes. Physical therapists encouraged subjects with standardized statements[12], i.e., use an even tone of voice when using the standard phrases of encouragement. They were allowed to stop and rest any time they needed, but were instructed to return walking as soon as they felt able.

All of them had their quadriceps and fibular nerve stimulated with neuromuscular electrical stimulation (NMES): a 4-channel electrical stimulator delivered a signal of 25 Hz with monophasic rectangular pulses with 300 ms duration and a maximum intensity of 200 V (1 KΩ load).

The patients performed two tests (6MWT 1 and 6MWT 2) in the same period of day in two different days (interval of one week). They used an AFO and were aided by walker. Heart rate was collected beat-to-beat (S810, Polar®, Oulu, Finland); distance and test time were measured.

Before the artificial gait, the participants were involved in a protocol to avoid fatigue that was shared in phases: the first phase was quadriceps training with the participants seated in their chair and the second one was stand up and sitting training using NMES and following by keep standing.

Statistical analysis

Data is expressed as mean ± SD with level of significance set at $\alpha = 0.05$. The differences between 6MWT 1 and 6MWT 2 were assessed by using a paired t-test. Multiple r-squared was also calculated.

RESULTS

Table shows the results of heart rate, blood pressure, distance and speed of 6MWT 1 and 2. The variables were not statistically different. Could be observed that the heart rate range is 77 bpm, in 6MWT 1 and 78 bpm, in 6MWT 2. The intrarater reliability of 6-minute walk test was calculated $r^2 = 0.96$ and it explained 96% of the variation in the distance walked

DISCUSSION

This study demonstrates that 6MWT could be adapted to SCI patients aided by NMES. Furthermore, the test

Table. Results of 6MWT.

Variable	6MWT 1	6MWT 2
HR rest (bpm)	78.00 ± 8.75	79.00 ± 7.06
HR peak (bpm)	155.00 ± 15.06	157.00 ± 14.68
Distance (m)	21.13 ± 11.76	20.78 ± 11.84
Mean speed (m/s)	0.07 ± 0.24	0.07 ± 0.25
SBP in rest (mmHg)	115.56 ± 8.82	114.44 ± 5.27
DBP rest (mmHg)	76.67 ± 7.07	73.33 ± 7.07
SBP exercise (mmHg)	137.78 ± 24.38	138.33 ± 23.58
DBP exercise (mmHg)	75.56 ± 8.82	76.67 ± 8.29

*$p < 0.05$ to compare 6MWT 1 and 2; values were in mean ± SD. 6MWT: 6 minute walking test; HR: Heart rate; SBP: Systolic blood pressure; DBP: Diastolic blood pressure.

design can assess a large spectrum of complete SCI subjects.

The comparison of two 6MWT shows that it has good reproducibility and validity to assess SCI subject functional capacity, usually it is not necessary apply two tests to assess the SCI complete subject.

The 6MWT has been used as clinical exercise test to understand the impact of diseases on physical capacity, like obstructive lung disease, heart failure[12] and even in healthy adults to reference equations[15]. The choice of this test was done due its easily used in the clinical environment and the standard protocol developed[12] that make possible the test performance by different examinations. It has been used with success in order to evaluate the gait disorder in incomplete SCI subjects[9,13,14].

The distance walked varied between patients, it was always low. These results could be influenced by some factors. In the literature, when incomplete SCI subjects were assessed, the mean distances found were 524 m[13], 205 m[9], 170 m[14] and 120 m[16], in the present study only one patient was able to walk 45 m, the others participants walked less distance. All the subjects had complete SCI lesion and without the NMES they were not able to walk.

Other factor that influences the distance and speed walked is the kind of aid used. Melis et al.[17] showed differences in speed when SCI subjects walked aided by walker, crutches or canes. They showed that the gait with walker is the slowest. However, the best comparison to a patient is when the subject is compared with himself, because level of injury, time of rehabilitation and walking aid usually influence the performance.

Neuromuscular electrical stimulation has became a useful aid to locomotion, however it produces a high energy cost, which could be observed, in this study, by the large range found between rest and exercise heart rate and in the lower distance walked. Jacobs et al.[18] comparing the response of NMES walking in a 10-m test with incremental peak arm cranking exercise and found a similar peak exercise capacity measured by cardio-respiratory variables. It suggested that functional electrical stimulation walking could be also used to endurance conditioning[18].

Other benefit of artificial gait is the reduction of spasticity. A study developed in our laboratory demonstrated a reduction in spasticity after the artificial gait training with NMES[19]. Studies about the relationship of spasticity and walking in SCI subjects usually is focus on spasticity mechanisms of spasticity[20].

Scivoletto et al.[21], showed the negative effect of spasticity in walk performance of SCI subjects. They also included spasticity as an obstacle to get up, walk and sit down beyond causes an increase in effort and energy.

However, the principal limitation of NMES is the excessive neuromuscular fatigue[22,23]. The protocol routine involved a specific neuromuscular training before the gait, as was explained above, to avoid the fatigue and increase the participants performance. The fatigue and the high energy cost are the main causes of low performance developed by the SCI subject.

Many techniques have been developed to improve SCI patients quality of life. These patients have a large potential to increase the exercise capacity and consequently, to benefit the muscle skeletal and cardiorespiratory systems. Therefore, the development and standardize of exercise assessing are necessary.

The calculation of walking speed over 10 m, is commonly used in clinical gait assessment, however it may underestimate the SCI subject locomotion capacity. The 10 m test is very useful in the beginning of training, specially, due the fatigue caused by NMES and high energy cost. Following the training, the 6MWT showed capable of evaluating the physical and locomotion capacity more completely and in a very simple way.

In conclusion, the artificial gait has been improved and it has been introduced in ambulatory therapy with success. Consequently, to follow these patients progress tests need to be adapted. The use of 6MWT to assess the exercise walking capacity of complete spinal cord injury paraplegics is promising. The reproducibility of the test and its easy application are positive points.

The results suggest that 6MWT could be included in rehabilitation programmes as a clinical assessment tool for paraplegic patients and it yields many information about the therapy and its evolution.

New studies are necessary to observe others aspects of SCI artificial gait such as balance and the influence of stand up and sit down in the gait.

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