Assessment of paraplegic gait: angles, flexion/extension ratio, peak moment and six-minute walking test.

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Abstract

The aim of this study was to evaluate kinematics characteristics, the flexion/extension ratio of the hip and knee joints, peak moment and the cardiovascular effort during neuromuscular electrical stimulation (NMES) stimulated gait of paraplegic patients. Eleven healthy control subjects (CG) and 10 paraplegic subjects (PG) with lesion levels between T4 and T10 were assessed. The kinematic and kinetic data were collected by a six-camera system ProReflex (Qualisys) and a force plate - AMTI. The PG walked aided by a walker, an ankle foot orthosis and a four channel NMES system, that stimulated the quadriceps muscular group and the fibular nerve. The six min walking test (6MWT) was done and heart rate, blood pressure and distance were measured. The kinetic results showed that in PG the hip and knee moment peaks were lower than in CG, the hip flexion/extension ratio of PG was lower than that of CG and this ratio was higher for the knee. The 6MWT demonstrated the high energy cost of PG during gait. Results suggest that NMES gait training for paraplegic individuals is of low risk towards causing lower limb joint lesions and this type of walking also requires a high amount of energy and can be used to improve cardio respiratory conditioning to these patients.

1 Introduction

Neuromuscular electrical stimulation (NMES) is used with spinal cord injured (SCI) subjects (1) to restore movement, prevent physical complications arising from the lesion (3), promote standing and walking (2) and yielding pattern generators for locomotion (4). During NMES gait training; a concern is the risk for osteoarticular and muscular lesions (5) due to factors such as deficits in proprioception, sensitivity, joint stability and osteoporosis. Another important factor set to be taken into consideration is cardiovascular alterations that can affect gait capacity (6). Evaluation of the ability to walk in persons with SCI is an important measurement for rehabilitation evaluation (6). Considering these factors, gait analysis and exercise capacity of paraplegic patients are important instruments to evaluate changes caused by SCI. The aim of this study was to evaluate kinematic characteristics, the flexion/extension ratio of the hip and knee joints, peak moment and the cardiovascular effort during NMES stimulated gait of paraplegic patients.

2 Methods

The Control Group (CG) was comprised of 11 healthy volunteers (five female and six male) with a mean ±SD age of 28.10 ± 4.41 years, body mass of 66.45 ± 13.19kg, height of 1.67 ± 0.09m. The Paraplegic Group (PG) who had been paraplegic (T4 to T10) for more than 18 months (two female and eight male subjects) with age of 36.70±15.48 years, mass of 70.50±8.81kg and height of 1.74±0.09m was comprised of 10 volunteers. One volunteer was classified as ASIA-C and nine as ASIA-A and all had been in NMES- assisted gait training for at least six months. The Local Research Ethics Committee approved the protocol and the volunteers signed an informed consent form. The kinematics and kinetics data were collected by a six-camera system ProReflex (Qualisys), a force plate (AMTI, Newton, MA, USA), Q Trac Version 2.5 software (240 Hz sampling rate) and analyzed using Q Gait 2.0 software (Qualisys motion capture systems).
Volunteers were instructed to walk at a comfortable speed. The passive reflective markers were placed bilaterally on the lower limbs. Paraplegics used a walker, a rigid ankle foot orthosis, and a four channel NMES System (25 Hz signal with monophasic retangular pulses of 300µs duration and a maximum intensity of 200V - 1kΩ load) stimulating the quadriceps muscular group and the fibular nerve. Four tests for each volunteer and a descriptive analysis of the data were done.

3 Results

Figure 1 presents typical gait positions for the hip, knee and ankle joints for both groups. Figure 2 presents the peak extension and flexion of the hip, knee, and ankle for each paraplegic and the mean for the CG. Figure 3 shows the mean angles for hip, knee and ankle for CG and PG, during the gait cycle. The hip flexion/extension was 1.86 ± 0.40 and 0.76 ± 0.40, the knee was 0.54 ± 0.20 and 1.56 ± 1.78 for CG and PG, respectively.

To evaluate cardiovascular effort during gait training, the Six Minute Walk Test following a standard protocol (7) adapted for paraplegics was administered on separate days from those for kinematics and kinetics. Heart Rate was collected beat-to-beat (S810, Polar®, Oulu, Finland), and blood pressure, distance and time were measured. Only seven male paraplegic volunteers performed this test.

The Six Minute Walk Test results for PG showed a heart rate of 76.00± 7.90 bpm at rest and 152.71 ± 15.56 bpm during exercise, systolic blood pressure of 115.71 ± 9.76 mmHg at rest, 141.43 ±
22.68 mmHg during walking test, diastolic blood pressure of 75.71 ± 7.87 mmHg at rest, 77.14 ±
and 9.71 mmHg during exercise. The distance walked was 23.66± 12.28m and the mean speed was
0.08 ± 0.03 m/s.

4 Discussion and Conclusions
This study has shown that the peak for hip and knee joints were lower for most of the PG when
compared to the CG. Aside from this, the relation of flexion/extension presented lower values in
80% of the PG for hip joint and higher values in 60% for the knee joint when compared to CG.
Flexion/extension values suggest a probable decrease in flexion of the hip during NMES gait in
relation to extension and an increase in flexion of the knee in relation to knee extension, as can be
observed in Figure 3. There is low risk for lesions in these joints during NMES gait training. A
study by Ferro et al 2007 (5) did not show significant lesions in the knee joint of tetraplegic patients
who had gone through NMES gait training with partial weight support. This is probably also the
case for the paraplegic volunteers in this study, based on the values of the data for moment and
angle. There is a shoulder overuse in paraplegic and tetraplegic patients in daily activities (8), and
the gait with a walker transfers part of the body weight from the lower limb to the upper limb,
which may influence the diminishing of values for moments. This type of walking also uses a high
amount of energy that can be observed in the variation found between cardio respiratory variables at
rest and exercise during the walking test. The degree of lesion did not influence the distance
traveled during the test and the distance walked varied among patients, but it was always short.
Aside from this, NMES gait training can be used to improve cardio respiratory conditioning in
patients (9). Some of the differences found in the gait of paraplegic individuals as compared to
normal individuals may be reduced if an integrated sensory-motor system were utilized to make gait
training more efficient (10). Gait analysis helps not only to develop new equipment, but also to
direct and improve training by verifying the level of risk to the patients. The results suggest that
NMES gait training for paraplegic individuals is low risk towards causing joint lesions. Also, the
flexion/extension relation for peak is rather important because it does not depend on methods used
to normalize the data; and therefore values from all research centers can be compared.

References
neuromuscular electrical stimulation controlled by an artificial neural network. *Int J Artif
patients assessment of its effects on the knee with magnetic resonance imaging. *Spinal Cord*, may 8, 2007;
[Epub ahead of print].
of patients with spinal cord injuries submitted to rehabilitation program: a clinical and ultrasound based

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