ORIGINAL ARTICLE

Electrical stimulation and treadmill gait in tetraplegic patients: assessment of its effects on the knee with magnetic resonance imaging

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Study design: Evaluation of knees of tetraplegic patients who have been walking for several months with the aid of a system that involves neuromuscular stimulation, treadmill and a harness support device.

Objectives: To investigate if the training program could cause knee injury to tetraplegic patients.

Setting: Hospital das Clinicas – UNICAMP. Campinas-SP, Brazil.

Methods: Nine patients were evaluated. Clinical exam and magnetic resonance images (MRIs) were used for evaluation. MRIs were taken before and after the training program, in a 6-month interval for each patient. There were two sessions of training every week. Each session lasted 20 min.

Results: No severe clinical abnormality was observed in any patient. Mild knee injury was observed in four of nine patients studied.

Conclusions: Tetraplegic patients undergoing treadmill gait training deserve a close follow-up to prevent knee injury.

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Keywords: quadriplegia; treadmill gait; neuromuscular electrical stimulation; knee; magnetic resonance imaging

Introduction

It is estimated that the annual incidence of spinal cord injury (SCI), not including those who die at the scene of the accident, is approximately 40 cases per million population in the United States or approximately 11 000 new cases each year. The number of people in the United States, who are alive in June 2006 and have SCI, has been estimated to be approximately 253 000. The life expectancy for patients who survive the first year after injury is still below that of the general population, but has been increasing. Today, the subject who is injured at 20 years of age should live for 40 more years.

The classical rehabilitation protocol that is used below the level of lesion in tetraplegic patients underwent several changes during the last decades, because a 'cure' for SCI started to be possible in the foreseeable future^{1–6} owing to the increasing number of incomplete lesions, the rising life expectancy in SCI patients and the promising therapeutical modalities brought by the fast technological and medical

development.^{7–10} This change made necessary the development of therapeutical means to keep the neuromuscular system under conditioning below the level of lesion, keeping it able to respond properly to challenge brought by new interventions, such as locomotor training with harness support, treadmill apparatus and neuromuscular electrical stimulation (NMES).^{6,11–13}

Some concerns arise at the moment of the mobilization of such patients,⁴ making a careful orthopedic surveillance on these patients mandatory in order to promptly recognize signs of complications caused by the treatment. We face the presence of a number of potential risks of neuropathic arthropathy, such as microtraumata, articular instability and absence of nociception, proprioception and joint protecting reflexes.^{14,15}

This kind of training program lacks on studies that can measure its risks for the patients' joints, bones and muscles. Into the 21st century, it is expected that patients with incomplete or even complete spinal injuries might regain the capacity to walk. Therefore, it is necessary to investigate the dangers in innovative rehabilitation programs and try to protect the patients, keeping their joints intact until definitive therapies become available.

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Objectives

This paper intends to: (1) Survey the tetraplegic patients undergoing locomotor training to study the impact of the gait on the patients' knees; (2) Investigate complications inherent to the treatment such as neuropathic arthropathy^{14,16,17} and (3) Correlate clinical and radiological findings of these patients. It would be rather relevant to take a closer look on the knees of tetraplegic patients through magnetic resonance image (MRIs), in order to obtain a broader picture of their rehabilitation program, following previous studies showing the benefits obtained with treadmill gait and NMES.^{1,6,18}

Methods

The Biomechanics and Locomotor-System Rehabilitation Laboratory of the University Hospital of Unicamp (State University of Campinas) offers a gait-training program with neuromuscular stimulation. The primary goal is to prevent osteoporosis and neural bipedal gait facilitation. It consists of sessions in which the patients' trunk is stabilized by harness support,¹⁹ and then the steps are taken with the help of a device that alternately contracts both quadriceps muscle groups, followed by a withdraw reflex that is achieved through the stimulation of the fibular nerve.

Nine patients were investigated. All of them were searched for abnormal findings in the knee joint through clinical examination and MRI.

All subjects belonged to the Spinal Cord Injuries' Rehabilitation Ambulatory of the University Hospital. The study was approved by the local ethics committee. Inclusion criteria included intact lower motor neurons, which are required for muscle contraction using surface electrical stimulation, and no history of cardiopulmonary disease. Known knee injury before the study was an exclusion criteria. Body weight support (BWS) was provided by a harness suspended from an overhead support, and the support vest allowed for the free movement of the lower limbs. All subjects had their quadriceps and tibialis anterior muscles being stimulated for at least 5 months before the beginning of gait training, in order to allow for the treadmill walking, with 30–50% of BWS during 20 min consecutively, with quadriceps extension supported by NMES. A four-channel electrical stimulator delivered a signal of 25 Hz with monophasic rectangular pulses with 300 μ s duration and a maximum intensity of 200 V (1 k Ω load).

Individuals performed 6 months of treadmill walking training, twice a week, during 20 min each session. All individuals started the treadmill gait training at 0.5 km/h speed, which was increased according to the capacity of each subject. The highest achieved speed was 1.3 km/h. Electrical stimulation was used to provide the stance gait phase through quadriceps muscle activation and the swing phase triggered by the withdrawn reflex (stimuli to the common fibular nerve).

An MRI was taken before and 6 months after the beginning of the training. The same radiologist interpreted all exams.

We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

Results

Patient general information is summarized in Table 1. It includes age, time since lesion, lesion level, American Spinal Injury Association classification, height, weight and body mass index.

We have performed clinical exam on all patients participating in the study. The abnormalities were mild at most and are summarized in Table 2.

The MRI findings are summarized below.

Patient 1: No relevant lesion was detected in any exams.

Patient 2: This patient had suffered a complete lesion in the anterior cruciate ligament before the training program. In the first MRI, he presented a grade 1 lesion in the medial meniscus. The second MRI, which was carried out 6 months later, showed a grade 3 lesion. The abnormality is seen, as the increase in the amount of tissue appears white in the MRI (normal meniscus is black).

In the clinical exam, this patient had a mild valgus instability, which could only justify a lesion on the lateral meniscus (Figure 1).

Patient 3: In the second MRI, this patient showed an important contusion in the medial condyle, which does not appear in the first MRI, taken 6 months before. The contusion is the increased amount of bone that appears white in the medial condyle (normal bone should appear as a homogenous gray, as in the rest of the femur).

This patient had no abnormality in the radiograph. This patient had no clinical abnormality (Figure 2).

Patient 4: The second MRI showed a grade 2 lesion in the medial collateral ligament, which is the white image

Table 1 Patient general information

Number	Age	Time since lesion	Lesion level	ASIA	Height (m)	Weight (kg)	BMI
1	37	1 year 10 months	c5c6	A	1.81	67	20.45
2	36	3 years 2 months	c4	B	1.67	61	21.87
3	28	2 years 2 months	c5	A	1.80	65	20.06
4	25	2 years 7 months	c7	B	1.78	53	16.73
5	32	8 years	c6	A	1.75	55	17.96
6	46	6 years 8 months	c5c6	A	1.75	47	15.35
7	30	3 years 8 months	c4	D	1.86	77	22.26
8	35	2 years 1 month	c5	A	1.80	73	22.53
9	30	10 years 1 month	c5c6	A	1.81	80	24.42

Abbreviations: ASIA, American Spinal Injury Association; BMI, body mass index.

Table 2 Clinical exam

Patient	Axis	Swelling	Lachman	Jerk-test	Valgus instability	Varus instability	Ant. drawer	Post. drawer
1	nl	nl	nl	nl	60° R & L	30° R & L	1+/4	neg
2	nl	nl	nl	nl	30° R	nl	nl	neg
3	nl	nl	nl	nl	nl	nl	nl	neg
4	nl	nl	nl	nl	nl	nl	nl	neg
5	nl	nl	nl	nl	nl	30° R	nl	neg
6	nl	nl	nl	nl	nl	60° R	1+/4	neg
7	nl	nl	nl	nl	nl	30° R & L	nl	neg
8	nl	nl	nl	nl	nl	30° R & L	nl	neg
9	nl	nl	nl	nl	nl	nl	nl	neg

Abbreviations: ant., anterior; neg, negative; nl, normal; post., posterior.

Figure 1 Patient 2 – MRI. **Figure 2** Patient 3 – MRI.

that appears inside the ligament. The first MRI showed no lesion in this structure. No clinical abnormality (Figure 3).

Patient 5: No relevant lesion was detected in any exams.

Patient 6: The second MRI showed a grade 3 lesion in the medial meniscus, seen as the decreased thickness in the

inner portion of it. Such lesion was not present in the first MRI. This patient had some varus instability, which could have predisposed to the injury (Figure 4).

Patient 7: No relevant lesion was detected in any exams.

Patient 8: No relevant lesion was detected in any exams.

Patient 9: No relevant lesion was detected in any exams.

Figure 3 Patient 4 – MRI.

Figure 4 Patient 6 – MRI.

Discussion and conclusions

This study may bring doubt about the safety of the harness support/treadmill gait training for tetraplegics. Before the study began, it was believed that no severe lesion could be caused by walking for only short periods on the treadmill.

However, the abnormalities that appeared in some patients in this study could be caused by direct force on the joint. On the other hand, it could be just a normal reaction of the organism to the additional stress generated by gait, having no clinical relevance. Furthermore, little is known about the normal process of atrophy that occurs in the joints of tetraplegic individuals. Therefore, we presently cannot tell the difference between the inevitable atrophy-related lesions from the treadmill-related ones.

The significance of MRI findings is extremely controversial. While the sensitivity of this exam is high, the specificity can be low for some abnormalities.

The capacity of radiologists to interpret MRIs has evolved greatly, since the method was first used to study the knee. Several types of pathology have been related to specific changes in the MRI pattern.²⁰ However, it is now known that the interpretation of the MRI is not always simple. There are some pitfalls in its analysis, and therefore great care should be taken when it is to decide the therapeutic approach on the basis of the MRI alone.

Recent literature says that there is little knowledge on the prognostic value of the MRI appearance of cruciate ligament rupture on functional outcome scores and complaints. Furthermore, no conclusions can be drawn about the natural course of meniscal or collateral ligament injury seen at MRI, because study results on this subject are sparse.²¹ This study concluded that anterior cruciate ligament and posterior cruciate ligament lesions can heal spontaneously after a MRI diagnosis. According to it, the decision to operate should not be based on the image only, but mostly on the clinical

relevance of the disability caused by the lesion and its impact on the functional status of the patient. In this research, we are obviously dealing with patients with no complaints of knee pain owing to the lack of sensitivity. On that basis, we should not precipitate the decision of interrupting the treadmill training of our patients without consistent data to justify it.

There are studies showing opposite views on the value of the MRI in diagnosing cartilage lesions: one says that MRIs are quite accurate at detecting severe cartilage lesions and to determine the most adequate therapeutic approach.²² Four years later, another independent study concluded that MRI is only reliable at excluding such lesions, but that the arthroscopy is still the preferable method for a secure diagnosis.²³

According to all data that were collected, it seems reasonable to admit that we have, at present, not enough information to determine in what cases the MRI abnormality actually reveals a pathology that is enough to justify the interruption of the treadmill training or even justify specific treatment (surgical or not). After all, it has already been proven that the training program can bring positive results for the cardio-respiratory system.¹ It seems that the most adequate option is to wait for more consistent signs of knee injury in such patients. Meanwhile, it is prudent and ethical to maintain a close follow-up and observe if any new signs of injury appear.

We believe that similar risks might exist during the rehabilitation of paraplegics. Although our study focused only on tetraplegics, we believe every center that deals with spinal cord injured individuals should watch patients for the possibility of knee injury during training.

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