UPPER LIMB MOVEMENT STRATEGIES IN THE REHABILITATION OF QUADRIPEGICS

1Renato Varoto, 2Fernando Tadeu Bueno Martin, 2Roberta de Oliveira, 2Enio Walker Azevedo Cacho, 1,2Alberto Cliquet Junior

1Department of Electrical Engineering, University of São Paulo (USP at São Carlos); 2Department of Orthopedics and Traumatology, Faculty of Medical Sciences, University of Campinas (UNICAMP), São Paulo, Brazil

Keywords
Quadriplegics, motor control, dynamic orthosis, neuromuscular electrical stimulation.

Abstract
The aim of this paper was the proposition for a joint use of neuromuscular electrical stimulation and elbow dynamic orthosis (EDO) in order to generate upper limb quadriplegic movements based upon movement assessment strategies. Six quadriplegics were recruited from the University's Hospital Ambulatory. Eight healthy subjects were also selected to obtain reference parameters. The ASIA criteria were used to evaluate the neurological and motor level. Upper limb kinematics data was captured through the use of an image system (Qualisys System™), the EDO workspace being also assessed through instrumentation. Quadriplegics (no stimulation / no orthosis) presented a decrease in the reaching tangential velocity and end up spending more time during the performance of this task when compared to healthy subjects. Moreover, the limited elbow and shoulder ranges of motion (sagittal and horizontal planes) lead to a reduction in the workspace, restricting some activities of daily living. The application of both NMES and the EDO can allow for an efficient treatment focused on upper limb and trunk motor strategies for quadriplegics.

1 Introduction
Patients with cervical spinal cord injury present loss of sensory and motor function, which change depending on the level of injury. In high cervical lesions (C4, C5) some patients become totally dependent for carrying out activities of daily living (ADL's). Thus, the lower level of injury (C6, C7, C8) predicts a better ability in performing the ADL's. Functional improvement could be observed in these patients, independent of the neurological level due the new motor strategies acquired and learned during the rehabilitation process [1]. Elbow extension through external rotation and shoulder abduction, as well as the tenodesis, are the most common compensatory strategies described in clinical evaluations of quadriplegic upper limbs. However, these strategies can not support the complete loss in the workspace produced by the injury, being therefore necessary to better comprehend and analyze these strategies.

The kinematic studies of reach-to-grasp in quadriplegic subjects may help to identify the motor control deficit, serving as a basis for the rehabilitation process [2]. Two approaches have been developed with the aim to assist motor and functional recovery: a dynamic orthosis and Neuromuscular Electrical Stimulation (NMES).

The dynamic orthoses generate a mobilizing or supportive force on a targeted tissue resulting in passive gains or passive-assisted range of motion. They can also be used as an active-resistive exercise modality [3].

Still in this area, robotic exoskeletons have emerged as orthoses, to provide motor assistance and functional compensation for disabled people [4].

For spinal cord spinal injured individuals, a technique that has contributed for rehabilitation is Neuromuscular Electrical Stimulation (NMES). NMES is a methodology that uses bursts of short electrical pulses to generate muscle contraction. NMES has been used in upper limb rehabilitation towards restoring motor hand function; a multichannel microcomputer controlled stimulator with monophasic square voltage output can be used and muscle activation sequences are defined to perform palmar and lateral prehension and power grip. The sequences used did allow subjects to demonstrate their ability to hold and release objects that are used in daily living, permitting activities such as drinking, eating, writing and typing [5].

This work proposes the use of an elbow dynamic orthosis (EDO) and NMES as strategies towards generation of upper limb movements in quadriplegics. This proposal is based on patients' kinematic assessment in relation to strategies for upper limb movements.

2 Methods

2.1 Evaluation

Six quadriplegic patients enrolled at the University Hospital's Ambulatory were recruited (Table 1) and all of them signed informed consent forms; the work has been approved by the Local Research Ethical Committee (#595/2005). Eight healthy subjects (HS) were also selected (29.2y ± 8.01).

Neurological and motor level assessment relied on the ASIA criteria [6]. The kinematics data acquisition and the EDO were used to evaluate changes in the quadriplegics’ workspaces.
Table 1: Characteristics of quadriplegic patients.

<table>
<thead>
<tr>
<th>Patients</th>
<th>LI (ASIA)</th>
<th>MI</th>
<th>Age (year)</th>
<th>PI (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>C4B</td>
<td>C5</td>
<td>6</td>
<td>39</td>
</tr>
<tr>
<td>P2</td>
<td>C4A</td>
<td>C5</td>
<td>7</td>
<td>42</td>
</tr>
<tr>
<td>P3</td>
<td>C6A</td>
<td>C6</td>
<td>10</td>
<td>33</td>
</tr>
<tr>
<td>P4</td>
<td>C6B</td>
<td>C6</td>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td>P5</td>
<td>C8B</td>
<td>C8</td>
<td>18</td>
<td>40</td>
</tr>
</tbody>
</table>

Mean/SD 36.6/4.54 11.3/4.03

(a) Kinematic assessment through infrared cameras;
(b) EDO assessment; LI, Level of lesion and impairment scale ASIA; MI, Motor level; Mi, Motor index; PI, time post injury.

For the kinematic assessment data were recorded by four infrared cameras for motion analysis (Qualisys System™) and five reflexive markers (Fig.1). During the capture process, the subjects stayed unrestrained in their own wheelchair, with feet and upper limbs supported and with the trunk and hip aligned at the backboard. Subjects were invited to reach a target placed within arm’s length, measured from medial border of axilla to the distal wrist crease, using their right arm (Fig.1a). The initial arm posture was with hand and wrist in neutral position, relaxed fingers, shoulder at 0° and elbow at 90°.

The trunk and shoulder anterior displacement were evaluated in the sagittal plan by the midsternum and right acromion markers (Fig.1b).

The temporal variable (maximum tangential velocity and movement time), shoulder and elbow angles were calculated in accordance with Michaelsen et al [7].

2.2 Therapeutic approach

The EDO presents one degree of freedom, and being coupled to the subject’s arm and forearm provides elbow flexion/extension with forearm support. The mechanical structure and electrical circuit of the EDO are detailed in [8]. The control module of the EDO is responsible for voice pattern recognition of the user, whereby a function can be called using a keyword, and for emitting an electric tension signal to the switching and/or the speed selection modules. Thus, the subject has voluntary control of the elbow’s movements by voice.

The dynamic orthosis has another important electrical circuit called range limit. The operation of this circuit is based on reed switches that limit the range of elbow extension/flexion movements. The direction inversion of the movement occurs when the reed switch is activated (Fig. 5).

In clinical tests, five quadriplegic subjects used the orthosis in repetitive movements of elbow flexion/extension. To perform these cycles, the range limit circuit was used.

Thus, the EDO provided/aided elbow extension and flexion movements with angular variation about 100°, for the forearm in relation to the arm, and the average angular speed was around 12°/s (Fig. 6 and Fig. 7). For these measurements, the Fiber Optics S700 Joint Angle Shape Sensor ® (Measurand Inc., Canada) (sample rate of 120 Hz) was used.

![Fig. 5: Subject with the EDO.](image)

![Fig. 6: Angular variation of the forearm in relation to the arm of each quadriplegic (A-P2, B-P3, C-P4, D-P5, E-P6).](image)

![Fig. 7: Average angular speed of the forearm in relation to the arm of each quadriplegic (A-P2, B-P3, C-P4, D-P5, E-P6).](image)
NMES is applied in order to restore the quadriplegic reach-to-grasp movements. A system for outpatient use, including a stimulator with eight channels controlled by a computer and programmed in accordance with the desire task, was developed. The stimulation is achieved through surface self-adhesive electrodes placed in selected muscles. The stimulation program begins with the strengthening of all muscle groups that are part of the reach-to-grasp control synergies. The sequence of stimulation aims at the restoration of the palmar and lateral prehensions, recovery of reaching movements and postural stability. The palmar reaching and grasping was divided into four phases: (1) hand opening and reaching (m. common finger extensor, m. thumb abductor and m. triceps), (2) positioning of the object in the hand (m. radial carpal extensor, m. thumb abductor, m. lumbricalis and m. triceps), (3) prehension of the object (m. superficial finger flexor, m. thumb opponent), and (4) release (m. common finger extensor and m. thumb abductor). For phase two, the lateral reaching and grasping uses the m. superficial finger flexor instead of the m. lumbricalis. The postural stability is produced by the lumbar erector spinae stimulation during the all four phases.

3 Results

On the kinematic tests, no patient (n=3) reached the central target proposed (Table 1).

The quadriplegics showed a trunk and shoulder anterior displacement similar of those produced by healthy subjects during reaching movement tasks. The movement was slower for the quadriplegics in relation to the HS (Table 2).

<table>
<thead>
<tr>
<th>Angle (º)</th>
<th>Shoulder</th>
<th>Trunk</th>
<th>MT (s)</th>
<th>MV (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.096/0.012</td>
<td>1.69</td>
<td>0.527</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>0.074/0.022</td>
<td>1.64</td>
<td>0.537</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>0.093/0.024</td>
<td>1.27</td>
<td>0.311</td>
<td></td>
</tr>
<tr>
<td>Patients</td>
<td>0.089/0.011</td>
<td>1.54/0.22</td>
<td>0.458/0.12</td>
<td></td>
</tr>
<tr>
<td>HS</td>
<td>0.097/0.032</td>
<td>0.92/0.12</td>
<td>0.992/0.12</td>
<td></td>
</tr>
</tbody>
</table>

In relation to the range of motion, the quadriplegics presented shorter shoulder and elbow ranges in both planes when compared with the HS (Tables 3).

<table>
<thead>
<tr>
<th>Angle (º)</th>
<th>Horizontal</th>
<th>Sagittal</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>53.3</td>
<td>34.4</td>
</tr>
</tbody>
</table>

4 Discussion

The reach-to-grasp movements need a large variety of anticipatory motor strategies and stability for the postural control maintainer. Some factors such as reaching velocity, movement direction and body inertia have a direct influence on postural control. The paralyses of the trunk and shoulder girdle muscles are prejudicial for the quadriplegic reaching movements. In the present study, no substantial difference was shown for the trunk anterior displacement, between normal and disabled groups. This could be due to the fact that the target was placed within the arm length and trunk use was not needed to perform the required task.

Shoulder protraction is a component of the synergy of reaching movements, giving the appropriate support to the anterior displacement. Quadriplegics exhibited a shoulder protraction similar to that of the healthy subjects. However, the paralyzed muscles of the trunk could influence the shoulder girdle movements. Thus, it is rather important to observe the necessity of the dynamic stabilization of the trunk that could be implemented by the NMES of the lumbar trunk extensor in the sitting position [9].

For individuals with higher cervical injuries (C4 and C5), the movement into the workspace may be impossible without the aid of therapeutic means, since the triceps is a key muscle for the arm positioning in space. In quadriplegics, the strategies for compensation of the insufficient elbow extension involve shoulder and scapular movements, in order to reach for an object next to the body. And these strategies are particular to each individual. Therefore, in this study (Tables 2 and 3) results have shown the difficulty of the quadriplegics in reaching the target due to lack of activation of the triceps muscle. The absence of triceps muscle can also lead to plastic changes in biceps muscle, which without an opponent, may suffer a process of muscle shortening. These results clearly show the need for alternative methods to be added to the conventional rehabilitation process, towards improving the workspace of these individuals. Some NMES protocols of reaching movements are proposed to promote an elbow extension through the biceps braquialis stimulation. It was demonstrated an improvement in the workspace in which the subjects could grasp and release objects besides an increase in the movement velocity [10]. A higher velocity is necessary because, generally, quadriplegic movements are slower than for the healthy subjects.
An important aspect is the fact that the cervical lesions may impair the segments responsible for the triceps inervation, leading to an inability or weakness of the stimulation response. Thus, the utilization of the EDO associated with NMES during the reaching movements can be aid in the maintenance of the range of motion and in the motor learning process.

About the elbow joint, the EDO aids the patients in providing wider range of motion (about 100°).

The EDO can help cervical lesion individuals (with impairments in movements of elbow flexion/extension) in activities that involve the action of reaching an object (e.g. a glass) close to the body. And, in relation to other systems, the EDO is simple and can be used in a day to day basis and not only as clinical therapy. However, voluntary movements of shoulder and scapula are a requirement.

The trunk and triceps muscle stimulation in addiction with the EDO are therapeutic choices that could complement the palmar and lateral prehension protocols. In this way, the training session becomes more functional besides facilitating the motor learning process. A NMES protocol that produces a lateral and palmar prehension allowing a quadriplegic subject to pick up, transport and release objects of daily living was developed [5].

Based on patients' evaluation in relation to upper limb movements, the voluntary movements of shoulder and scapular performed by the patient combined with the flexion/extension movements provided by the orthosis and NMES represent an important strategy towards the rehabilitation of quadriplegics. Thus, reach and grasp movements become feasible.

Besides the movement restoration, another aspect is that dynamic orthoses can be used as a therapy. This therapy is based on training sessions where the patient performs repetitive oriented tasks aided by robot, and it is used in neurorehabilitation for patients with paralysed extremities due to lesions of the central or peripheral nervous system, like spinal cord injuries. The objective of the therapy is to recover motor function, improve movement coordination, and learn new motion strategies [11]. The repetitive movements provided by this therapy combined with somatosensory stimulation may induce cortical neuroplasticity.

In this way, the EDO can be used on the therapy aided by robot to provide repetitive elbow extension and flexion movements, and NMES would be used for somatosensory and peripheral nerves stimulations. This training can induce functional gain on this task. Finally, dynamic orthoses and NMES used for therapy represent another strategy towards upper limb movement restoration.

5 Conclusions

Quadruplegics present a workspace reduction that affect the execution of some functional activities of daily living. NMES associated with the EDO yields upper limb motor rehabilitation strategies.

Acknowledgements

São Paulo State Research Foundation-FAPESP.

References


Prof. A. Cliquet Jr. cliquet@fcm.unicamp.br cliquet@sel.eesc.usp.br