Hybrid System: a Pilot Evaluation for a Therapeutic Proposal in Quadriplegia

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Abstract

This work presents the use of a hybrid system prototype towards the rehabilitation of quadriplegics. This device is composed of an upper-limb robotic orthosis that provides elbow movements with forearm support and a neuromuscular electrical stimulator for grasp generation. The pilot tests were performed with three quadriplegics (motor lesion levels C5 and C7) performing reach movements and grasp of a cylindrical object. The use of hybrid system increases the range of reach movement up to 17%; in addition, it enables patients to perform grasp and bringing an object close to the body. The patients experienced no discomfort during the use of such devices. These results show the feasibility of hybrid system for robot-assisted therapy, representing an alternative for therapy of spinal cord injured patients.

***Keywords**: Hybrid system, upper-limb orthosis, quadriplegia, neuromuscular electrical stimulation.*

Introduction

Quadriplegics present limitations in relation to reach and grasp movements due to upper limbs motor impairments following spinal cord injury (SCI). For most activities of daily living (ADLs), the hand must reach and grasp an object, and coordinate it until the activity is completed [1].

These impairments can be compensated through neuromuscular electrical stimulation (NMES) and hybrid systems (NMES combined with an orthosis) [2, 3]. Moreover, these techniques can be used for robot-assisted therapy [4].

Robot-assisted therapy has been used in neurorehabilitation for patients with upper limb motor impairments due to lesions of the central nervous system, e.g. SCI. The goal of this therapy is to induce neuroplasticity, resulting in motor function recovery. Besides, it stimulates learning new motion strategies [5, 6].

This work presents a pilot evaluation of quadriplegics assisted by a hybrid system performing reach and grasp movements. This evaluation aimed to show the feasibility of hybrid system for protocols of robot-assisted therapy.

Material and Methods

Participants

Three male individuals with quadriplegia were recruited from University Hospital to participate in this work (Table 1). Inclusion criteria were SCI of traumatic lesion, two years of SCI at least, motor lesion level between C5-C8, present shoulder movements preserved and age over 18 years. Exclusion criteria were based on the presence of cognitive impairments, upper limbs skin lesions, tendon transfer surgery involving the upper limbs, inability to remain seated freely in a wheelchair with back support, upper limbs musculoskeletal disorders and previous neurological impairments.

Table 1. Patients' characteristics

	Quadriplegic patients			Mean	SD
	A	B	C		
Age (year)	38	25	33	32.0	6.6
Body mass (kg)	64	80	78	74.0	8.7
Height (m)	1.72	1.83	1.72	1.76	0.06
Injury time (year)	8.8	3.6	13.5	8.5	5.0
ASIA[(a)] scale	C4A	C4A	C6A	-	-
Motor lesion level	C5	C5	C7	-	-
FIMm[(b)]	15	14	27	18.7	7.2
SCIM[(c)]	13	16	27	18.7	7.2
CUE[(d)]	46	66	118	76.7	37.2
DASH[(e)]	88.3	90	73.3	83.9	9.2

[(a)] American Spinal Injury Association [7]
[(b)] Functional Independent Measure - motor score [8]
[(c)] Spinal Cord Independence Measure III [9]
[(d)] Capabilities of Upper Extremity [10]
[(e)] Disabilities of the Arm, Shoulder and Hand [11]

This work was approved by the local ethics committee.

Hybrid System

The hybrid system is composed of an elbow robotic orthosis (ERO) that is coupled to the patient's right upper limb, and an 8 channel microcomputer controlled stimulator whose adhesive surface electrodes are placed on hand and forearm.

ERO presents one active degree of freedom (DOF) that provides elbow extension/flexion with forearm support, and four passive DOFs that improve the orthosis adaptability to the patient. It can be triggered by voice [12].

The 8 channel microcomputer controlled stimulator generates a monophasic square voltage output with maximum pulse width fixed at 300 µs and frequency at 25 Hz whereas the amplitude is adjusted to achieve the motor excitability threshold for each muscle [2].

Kinematic Procedures

For the kinematic analysis, two movement strategies were performed. These strategies were based on grasp and bringing an object close to the body and point-to-point movements; for both, the patients were seated in their own wheelchair in front of a task-table.

Patients A, B and C performed point-to-point movements with and without ERO. These movements started at the task-table center and extended in five directions spaced at 45°. The patients were instructed to reach with right hand the maximum distance in each direction (Fig. 1a).

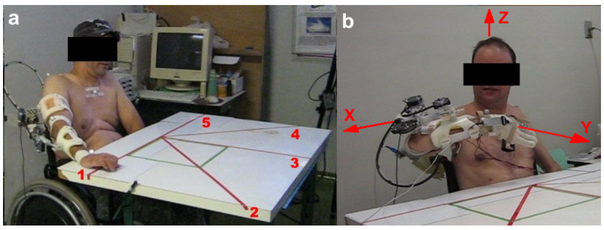

Fig. 1: Patient during kinematic procedures. a) Point-to-point movements; b) Grasp and bringing an object

Patients A and B were aided by hybrid system to perform palmar grasp, bring a cylindrical object close to the own mouth, return the object to the start position and release it (Fig. 1b).

For patient A, NMES was used to activate these muscles in sequence: Extensor Digitorum Comunis (2s); Lumbricalis, Interosseous, Flexor Digitorum Superficialis and Opponens Pollicis (15s); and Extensor Digitorum Communis (2s). Patient B received NMES in muscles: Extensor Digitorum Comunis (2s); Lumbricalis, Interosseous and Flexor Digitorum Superficialis (15s); and Extensor Digitorum Comunis (2s).

Kinematic data were recorded at 240Hz by three Motion Captures Units (Qualisys Medical AB, Gothemburg, Västra Götaland, Sweden) and analyzed using Matlab (Mathworks, Inc., Natick, MA, USA). For the point-to-point movements, five reflective markers were placed on shoulders, sternum, right elbow and right wrist; and one more marker was placed on object, for the grasp and bringing activity.

During point-to-point movements, wrist path and the distance between the wrist and the sternum were calculated to characterize the range of the reach movement. Length of the path travelled by the object, elbow angle and distance between the object and the sternum were computed in 3D space to verify the assistance provided by the hybrid system during object manipulation.

Results

One example of the wrist path during the point-to-point movements can be seen in Fig. 2a. The range of reach movement was characterized through the distance between the wrist (travelled on five directions) and the sternum (Fig. 2b). Comparing point-to-point movements with and without ERO, the orthosis improved the range of reach movement on directions 2(12.4%), 3(9.0%) and 4(3.4%), for patient A. For patient B, these improvements occurred on directions 2(8.2%), 3(17.3%), 4(6.7%) and 5(9.4%). Generally, the ERO limited the movements of patient C.

Table 2 shows the kinematic variables of the object during manipulation.

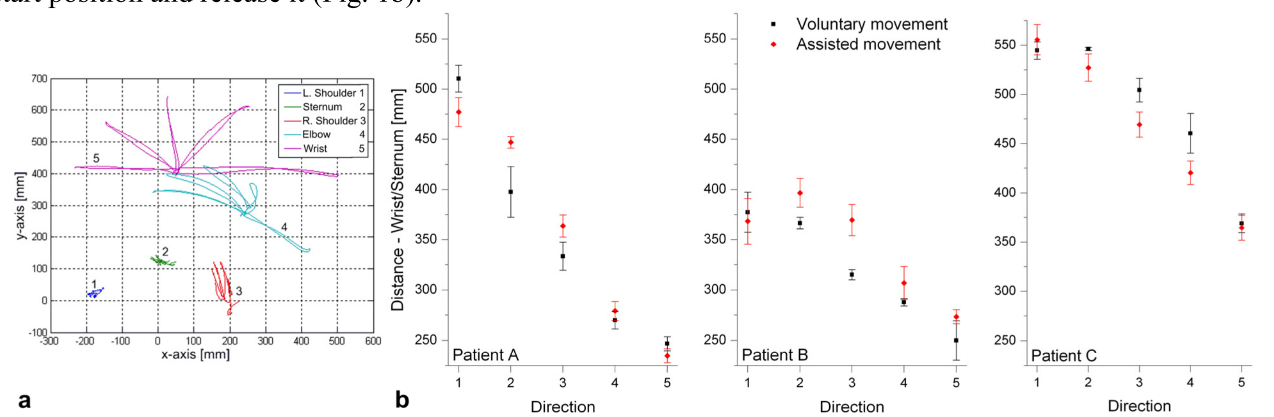

Fig. 2: Point-to-point movements. a) Markers path in the xy-plane; b) Distance between the wrist and the sternum for each direction (values in mean/SD of five movements in each direction)

Table 2. Kinematic variables of the object (values in mean(SD) of five object manipulations)

Patient	Distance - Object/Sternum [mm]				Length of the path - object [mm]
	Initial	Final	Minimum	Maximum	
A	401,2(5,3)	404,7(21,2)	83,0(19,3)	414,4(6,4)	1794,3(438,1)
B	346,2(24,4)	377,2(8,0)	65,8(24,4)	377,8(8,5)	1129,0(183,8)

Table 3. Angular variation of elbow joint (values in mean(SD) of five object manipulations)

Patient	Angle of the elbow joint [degree]			
	Initial	Final	Minimum	Maximum
A	5,5(5,8)	11,6(6,4)	4,3(5,8)	113,5(1,0)
B	14,8(16,5)	10,4(10,0)	6,9(11,4)	105,2(4,3)

Besides grasp, the elbow movements are needed to manipulate the object. The angular variation of elbow joint can be seen in Table 3.

Discussion

In relation to the range of reach movement, the results demonstrated that patients with higher lesion levels were benefited with the use of ERO. However, there were limitations on directions 1 and 5 due to the limit switches of ERO (safe range). In addition, patients presented some difficulty in associating shoulder movements and movements provided by orthosis. This difficulty can be minimized through a previous training.

Patients assisted by hybrid system were able to perform grasp and bringing an object close to the body without previous training, even presenting upper limb motor impairments. And they presented no discomfort after the use of such device.

These results show the feasibility of hybrid system for robot-assisted therapy. For C5 quadriplegics, the therapy can be based on training of reach and grasp movements aiming to improve motor coordination in activities that involve object manipulation (e.g. eating, drinking).

Conclusions

The hybrid system provides/aids upper-limb movements, and it can represent an alternative for robot-assisted therapy in quadriplegia.

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