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# *Robotic training and clinical assessment of forearm and wrist movements after incomplete spinal cord injury: a case study*

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*Abstract*— **The effectiveness of a robotic training device was evaluated in a 24-year-old male, cervical level four, ASIA Impairment Scale D injury. Robotic training of both upper extremities was provided for three hr/day for ten consecutive sessions using the RiceWrist, an electrically-actuated forearm and wrist haptic exoskeleton device that has been designed for rehabilitation applications. Training involved wrist flexion/extension, radial/ulnar deviation and forearm supination/pronation. Therapy sessions were tailored, based on the patient's movement capabilities for the wrist and forearm, progressed gradually by increasing number of repetitions and resistance. Outcome measures included the ASIA upper-extremity motor score, grip and pinch strength, the Jebsen-Taylor Hand Function test and the Functional Independence Measure. After the training, improvements were observed in pinch strength, and functional tasks. The data from one subject provides valuable information on the feasibility and effectiveness of robotic-assisted training of forearm and hand functions after incomplete spinal cord injury.**

***Keywords: Spinal cord injury, robotic training, arm motor function recovery***

## I. INTRODUCTION

Neurologically induced weakness of the upper limbs is the rule following tetraplegia and results from partial or complete paralysis of muscles below the level of the injury. The residual strength of partially paralyzed muscles is an important determinant of independence and function in people with tetraplegia. For example, strength of the wrist extensor muscles has a significant impact on hand function in people with C5-C6 injuries [1]. Therefore, small improvements in upper-extremity strength in persons with tetraplegia can make a clinically significant difference in feeding, bathing, and other functional activities [2,3]. Indeed nearly 50% of the tetraplegics indicates that regaining arm and hand function would most improve their quality of life than any other lost function [4].

Because treatment intensity has a profound effect on motor recovery, the use of robotics has potential to automate labor-intensive therapy procedures and to improve the cost-effectiveness of SCI rehabilitation. To date, several studies have found that robotic-assisted stroke rehabilitation therapy in addition to traditional physical and/or occupational therapy, can improve motor recovery after stroke [5] and that robotic devices are safe and feasible in rehabilitation. Robots hold promise for enhancing traditional post-injury therapy over extended time periods, in a consistent and precise manner, without fatigue; can be automated for many tasks; and demonstrates an advantage over traditional therapy by recording real time performance of subjects during training sessions [6]. Despite this evidence, there is relatively much greater technology development and research focused on improving leg strength and gait after SCI, and relatively less emphasis on upper extremity strength and function. Although there has been considerable interest in robotic gait training after SCI [7,8,9], to our knowledge no study on robotic rehabilitation of arm and hand function in SCI has been published. Therefore, the proposed study will be a novel first attempt to use robotic upper-extremity training in this population.

The objective of this study was to demonstrate the feasibility and effectiveness of robotic training of forearm and wrist movement in persons with incomplete tetraplegia.

## II. METHODS

### *A. SUBJECT*

A 24 year old male with incomplete SCI at the C4 level (American Spinal Injury Association (ASIA) D according to

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American Spinal Injury Association Impairment Scale) 6.5 month post injury was enrolled in this study. Entry criteria were 1) diagnosis of a complete or incomplete cervical lesion at least 6 month prior to the study; 2) upper-extremity weakness associated with tetraplegia; 3) a minimum age of 18 years; 4) no joint contracture, recent trauma to forearm and hand or severe spasticity as measured by a Modified Ashworth Scale greater than 3 out of 4; 5) no planned alteration in upper-extremity therapy or medication for muscle tone during the course of the study; 6) no other neurological disease or condition (e.g., severe arthritis, extreme shoulder pain) that would interfere with valid administration of the measures or with interpreting motor testing; 7) English-language comprehension sufficient to give informed consent and cooperate with the intervention..

The subject gave his written informed consent after having received verbal and written information. The study was approved by University of Texas Health Science Center at Houston Institutional Review Board for Human Subject Research.

The subject was recruited from the outpatient clinic of TIRR Memorial Hermann. On initial medical exam subject presented minimum voluntary movements on right upper extremity whereas moderate to normal voluntary movements were preserved on the left side. After enrollment subject participated in 10 sessions of robotic therapy over 2 weeks.

### B. *ROBOTIC REHABILITATION DEVICE*

The RiceWrist is an electrically actuated upper-extremity and wrist haptic (force feedback) exoskeleton device that has been designed for rehabilitation applications. The kinematic design of the RiceWrist allows for reproduction of most of the natural human wrist and forearm workspace. The device features force isotropy, and high torque output levels such as would be required during robot-aided training and/or rehabilitation. Another important feature of the design is the alignment of the axe of rotation of human joints with the controlled degrees of freedom of the exoskeleton. The problem of measurement of arm position is thus reduced to the solution of the exoskeleton kinematics, with no further transformations required. This makes it possible to actuate the robot to control feedback to a specific human joint, for example to constrain the forearm rotation during wrist rehabilitation, without affecting other joints (Figure 1). The device design extends from prior work by Dr. O'Malley. A thorough discussion of specific design considerations for the original robotic exoskeleton and how each was addressed can be found in Gupta and O'Malley [10]. The RiceWrist has three therapeutic modes, which enable treatment to be tailored to persons' abilities: passive, triggered, and active-constrained, modes. In the passive mode, the subject is passive and the robot carries the movement. In the triggered mode the subject overcomes a threshold before the robot takes over the movement. In the active-constraint mode, resistance is given to the subject.

### C. *ROBOTIC TRAINING PROTOCOL*

Robotic training was provided with the RiceWrist for three hours per day on ten consecutive weekdays. The RiceWrist is an electrically actuated forearm and wrist haptic exoskeleton device that has been designed for rehabilitation applications. Therapy sessions were tailored individually for each joint's movement capability. The purpose of the single-joint exercises was to improve strength and active ROM of each joint. All three therapeutic modes: passive, triggered, and active-constrained mode were incorporated into the training protocol. The treatment was progressed gradually, by increasing number of repetitions and amount of resistance applied. No other therapeutic intervention for upper extremity training was provided during the study period.

### D. *TASK DESCRIPTION*

The patient was seated comfortably in an upright position with the knees flexed at about 90°, trunk maintained against the back of the chair, shoulder slightly abducted and elbow slightly flexed. The subject faced the computer monitor. The forearm was secured inside of a splint that was mounted to inferior part of the forearm ring. The hand was grasping a handle. The right hand was wrapped with an elastic bandage to secure the contact between palm and handle. The center of wrist joint was aligned with the robot's wrist joint axes.

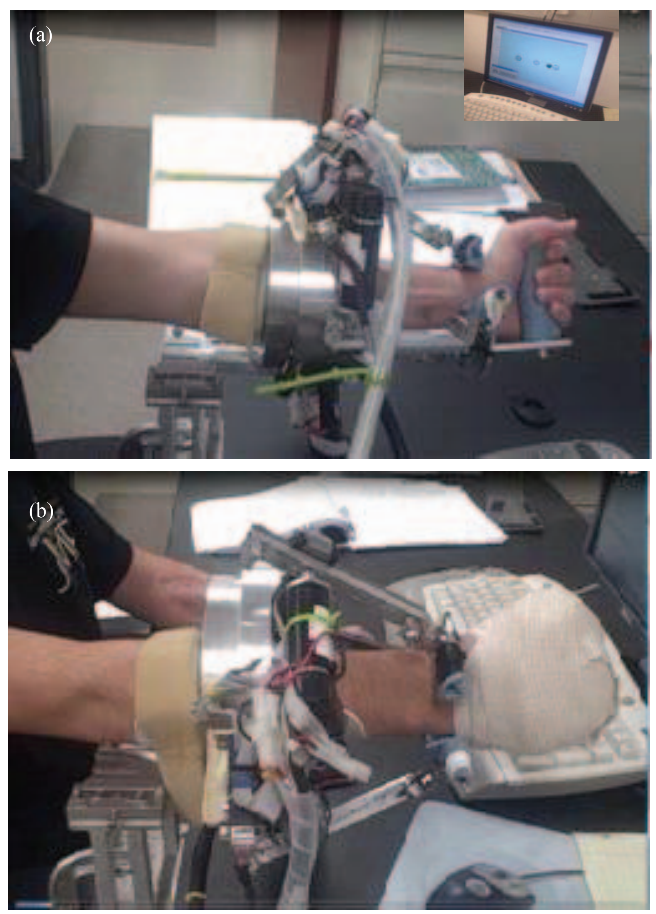


Figure1. Training with RiceWrist (a) forearm pronation/supination, (b) wrist ulnar/radial deviation

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The subject performed single-joint exercises in one of the three control modes. If the subject was able to perform voluntary movement , then a target hitting task was displayed on the monitor and subject was asked to move the pointer to hit the active target (Fig 1a). The task difficulty was increased by adding number of repetitions and amount of resistance applied in related control modes.

### *E. CLINICAL MEASURES*

The subject was right-hand dominant (pre injury), and required supervision only to moderate assistance in most activities of living, such as eating, bathing, dressing upper and lower body, bladder and bowel management transfer to tub or shower and climbing up and down the stairs as measured by Functional Independence Measure (FIM). He had Ashworth Score of 1 in supinator muscle group on left side and 1 in flexor muscle group of right wrist, the other muscle groups of forearm and wrist had no increase in tonus.

The upper extremity motor portion of the American Spinal Injury Association (ASIA) was used to describe motor impairment of his arm The baseline ASIA score was total 8 and 23 for right and left side respectively (maximum score = 25 indicating no impairment).

The pre-and post treatment clinical outcome measures included (ASIA) upper-extremity motor scale, grip strength, pinch strength, Jebsen Taylor Hand Function test (JTHFT) and FIM. Strength of selected muscles (biceps, triceps,wrist extensor, finger flexor, finger abductor) in both upper extremity are scored using the Medical Research Council grade (0 = no contraction; 5= normal power). The total score indicates residual muscle function (range 0-50 for both upper extremity motor score). A hand held dynamometer was used to record the grip strength. The maximum score of three attempts was recorded in lbs. A pinch gauge was used to measure the pinch force. The maximum score of three attempts was recorded in lbs. Finally JTHFT was applied to measure the time needed to perform 6 everyday activities (e.g, flipping cards, feeding) using both upper extremities. Although the original test did not include a time limit, administration of subtests discontinued after 180 sec if the subject was not able to complete the task by that time. Total score was the sum of task completion times, with lower times representing better performance. Pain and fatigue after each training session was recorded by asking the subject to rate his pain, discomfort and fatigue on a 4-point scale ranging from (0 =strongly disagree, 4 =strongly agree).

## III. RESULTS

ASIA- Upper extremity motor score: for upper extremity manual muscle strength increase at T1 level was observed on right side only. Subject was able to move the little finger abductor muscles in a full range in gravity eliminated position. Muscle strength of left extremity did remain same.

Grip Strength: Changes in grip strength were observed on the left side.

Pinch strength: Changes in pinch strength on both sides showed an increase after the treatment.

TABLE I.
Functional scores before and after robotic-assisted training

| **Task** | | **Pre-treatment** | **Post-treatment** |
|---|---|---|---|
| ASIA –upper extremity motor score | Right | 8 | 9 |
| | Left | 23 | 23 |
| Grip Strength | Right | 0 | 0 |
| | Left | 28.5 | 26.5 |
| Pinch strength | Right | 0 | 2 |
| | Left | 6.5 | 10 |
| FIM | | 58 | 61 |

ASIA: American Spinal Injury Association, FIM: Functional Independence Measure

FIM score: Independence in daily activities was observed in following subtests such as grooming, dressing lower body and going up and down the stairs. Functional scores before and after training are shown in Table 1.

Hand functions such as manipulating and moving small objects, grasping, lifting also showed improvements. Comparing to baseline performance, the subject was able to initiate some of the subtests after robotic training (Table 2).

TABLE II
Jebsen Taylor Hand Function Test before and after robotic training

| **Subtest** | **Pre-treatment (sec)** | | **Post-treatment (sec)** | |
|---|---|---|---|---|
| | Right | Left | Right | Left |
| Simulated Page Turning (5 cards) | n/a | 11.82 | 150(5) | 7.09 |
| Lifting Small. Common Objects (2paper clips, bottle cap, pennies, cup) | n/a | 20.88 | 180 (2) | 20.44 |
| Simulated Feeding (5 kidney beans) | n/a | 17.53 | n/a | 15.25 |
| Stacking checkers (4 checkers) | n/a | 44.13 | 180(2) | 20.03 |
| Lifting Large, Light Objects (5 cans) | n/a | 6.87 | n/a | 5.87 |
| Lifting Large, Heavy Objects (5 cans) | 180 (2) | 6.85 | 180(4) | 6.28 |

Test was ended at180 sec. nr in () represents completed items, n/a=subject could not perform the task.

The subject's self report on pain and discomfort level did not show any significant increase during therapy sessions (Figure 2). Level of fatigue showed slight increases after each session but no therapy session was missed or had to be rescheduled because of the above-mentioned symptoms.


Figure2. Fatigue, discomfort and pain ratings after each session over the training period

## IV. DISCUSSION

This single case study demonstrates the preliminary results of a robotic training protocol for training of forearm and wrist movements after SCI. The results suggest that the current robot-based therapy produced positive gains in a subject with incomplete SCI. The specific factors that contributed most to the measured gains remain unclear, but the results of this feasibility study are promising. The current intervention used highly repeatable single joint movements, focusing on forearm and wrist. It is obvious that the gain from the repetitive training could be extended in overall arm function as it is demonstrated with an improvement in hand functions as measured with the JTHFT. Generalization has been demonstrated in similar studies with stroke patients using robotic assisted training as intervention [6]. The findings from these studies have shown that patients undergoing repetitive hand flexion/extension movement training showed improvements not only in the trained distal part of the extremity (i.e, hand movements) but overall in the arm functions. Limitation of this study was the lack of measuring muscle strength of trained muscles groups separate, especially the wrist extensors. It would also be important to measure the range of wrist extension during any pinch grip testing. It is well know that wrist extension may cause a tenodesis effect, which is one of the main therapeutic aims in restoring hand functions in tetraplegics. A tenodesis referes to opposition of the thumb and index finger with either active or passive wrist extension. Achieving a functional tenodesis grasp enables participation in activities of daily living. In the current report, subject demonstrated an improvement in finger functions, such as grasping, lifting and manipulation of small objects. He also required less assistance in accomplishing activities such as lower body dressing. We speculate that the improvement may be associated with wrist extensor muscle strength. Another key factor to consider in the current study was the safety of robotic training in subjects with SCI. Based on the findings of this pilot study, no adverse events were observed. The use of repetitive robotic exercises did not result in significant fatigue or discomfort as reported by the subject.

## V. CONCLUSION

In conclusion, the data from one subject provides valuable information on feasibility and clinical effectiveness of the RiceWrist in robotic training of forearm and wrist movements after spinal cord injury. Given the preliminary evidence of the effectiveness of robotic training in a single case, further research is warranted to explore the effectiveness in a controlled clinical trial with a larger sample size.


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