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Wrist Rehabilitation Following Stroke: Initial Clinical Results

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Abstract—**In 1991, a novel robot named MIT-MANUS was introduced as a test bed to study the potential of using robots to assist in and quantify the neuro-rehabilitation of motor function. It introduced a new brand of therapy, offering a highly backdrivable mechanism with a soft and stable feel for the user. MIT-MANUS proved an excellent fit for shoulder and elbow rehabilitation in stroke patients, showing in clinical trials a reduction of impairment in these joints. The greater reduction in impairment was observed in the group of muscles exercised. This suggests a need for additional robots to rehabilitate other target areas of the body. The focus here is a robot for wrist rehabilitation designed to provide three rotational degrees of freedom. A previous paper at ICORR2003 and its companion book described the basic system design and characterization [1]. In this paper we present clinical results from five (5) stroke patients. A comprehensive review of the wrist robot design, characterization, and initial clinical results are being submitted elsewhere (IEEE Transactions on Neural Systems and Rehabilitation Engineering).**

I. INTRODUCTION

EACH year, about 700,000 Americans become victims of stroke [2], making it the third most frequest cause of death and the leading cause of disability in the country. The damage to the neurons and pathways in the central nervous system caused by stroke can cause two types of impaired motor control to appear immediately, namely a loss of volitional movement on the affected side (hemi-paresis) and inappropriately timed or graded muscle activations. With time, other impairments will appear including hyperactive stretch reflexes, increased resistance to passive movement due to changes in the passive mechanical properties of muscle (spasticity), and hypo-extensibility of the muscle-tendon contracture [3].

Stroke rehabilitation is a restorative process that seeks to hasten and manage recovery by treating the disability [4], largely through physical therapy. The main goal of physical rehabilitation is to maximize motor performance and minimize functional deficits however limited by the neurological deficit [5]. The human brain is capable of self-reorganization, or plasticity, so that learning and remembering permits the possibility for motor recovery [1]. Afferent and efferent limb stimulation can lead to the re-establishment of the neural pathways that control volitional movement, so that neurological rehabilitation can be derived from therapy.

This therapy generally involves one-on-one interaction with a therapist who assists and encourages the patient through a number of repetitive exercises. The repetitive nature of therapy makes it amenable to administration by properly designed robots. A robotic therapist can eliminate unnecessary exertion by the therapist, deliver highly reproducible motor learning experience, quantitatively monitor and adapt to patient progress, and ensure consistency in planning a therapy program. MIT-MANUS, developed at the Newman Laboratory for Biomechanics and Human Rehabilitation at MIT, provides a platform for the study of human motor control and recovery as well as a tool for the administration of physical therapy. It is a planar, two-degree-of-freedom robot providing exercise for the upper extremity as the patient completes a series of “video games” that involve positioning the robot end effector. The design of this robot, completed in 1991, is based on a five-bar, parallel drive Selective Compliance Assembly Robot Arm (SCARA). By minimizing the endpoint impedance of the robot, the feel of the robot can be modulated through control, allowing safe patient interaction without excessively interfering with the patient's natural arm dynamics. The controller sets up a virtual spring and damper between the task-defined, time-dependent equilibrium point and the position of the end effector [6].

Clinical trials involving MIT-MANUS and its clones [7] have shown that robot-aided neuro-rehabilitation has a positive impact, reducing impairment in both inpatients and outpatients [2], [8]-[15]. The results of these studies, as measured by standard clinical instruments, showed statistically significant improvement in motion control at the shoulder and elbow (the focus of the exercise routines), but no change at the wrist and fingers (which were not exercised). This result suggests a local effect with limited generalization of the benefits to the unexercised limb or muscle groups. According to the notion of task specificity, improvements due to physical rehabilitation are focused on a

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targeted area, so that in order for a patient to relearn a given task, each required limb segment for that task must be rehabilitated. If this is true, then the appropriate experiment requires that our shoulder-and-elbow robot-aids should be expanded to exercise different groups of muscles and limb segments. This, along with the success of MIT-MANUS, has motivated the development of new modules designed specifically for rehabilitation of the wrist, fingers, ankle and legs. This paper focuses on the initial clinical results of a robot for wrist rehabilitation. Wrist and forearm articulation play an important role in enhancing the usefulness of the hand by allowing it to take a variety of orientations with respect to the elbow.

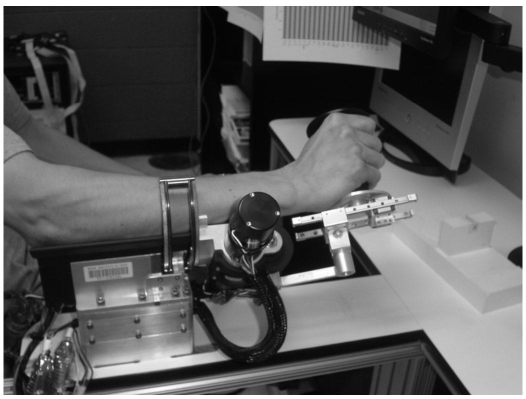
Fig. 1. Photograph of the novel 3-DOF Wrist Robot.


Fig. 2. On-going Wrist Training (White Plains, NY).


Fig. 3. Robot with 5 active and 2 passive dof.

II. Description of the Wrist Robot

We have recently introduced to the clinic a novel wrist robot designed with three degrees of freedom (dof): abduction-adduction (ab-ad), flexion-extension (flex-ext), pronation-supination (pro-sup). This robot, shown in Figure 1, has ranges of motion of 115º in flex-ext, 80º in ab-ad, and 150º in pro-sup. This low-impedance robot can be operated stand-alone or mounted at the tip of our companion planar robot, MIT-MANUS, allowing 5 active dof (plus 2 passive dof) at the shoulder, elbow and wrist (see Figures 2 and 3). This combination of devices allows us the unique opportunity to test whether functional training is essential or if specificity of training to a particular limb segment can achieve similar outcomes [S. Fasoli et al., submitted to ICORR 2005]. The two robots will also allow us to verify whether the training sequence to different limb segments affects outcomes, in particular, proximal versus distal training.

A previous paper at ICORR2003 and its companion book described the basic system design and characterization of the wrist robot [1]. A comprehensive review of the wrist robot design, characterization, and initial clinical results are being submitted elsewhere (IEEE Transactions on Neural Systems and Rehabilitation Engineering).

A suite of interactive video games has been developed to administer robotic wrist therapy, much like the games used with MIT-MANUS. Video games for the wrist may require motion in one, two, or all three degrees of freedom sensed and actuated by the robot.

III. Ongoing Trial – Proximal Versus Distal Training

To compare the effects of specifically training proximal versus distal limb segments, we have recently begun a study in which we recruit naive persons with chronic impairments after stroke. Outpatients are included in the study if they meet the following criteria: the subject a) has a first single focal unilateral lesion with diagnosis verified by brain imaging (MRI or CT scans) that occurred at least 6 months prior; b) has cognitive function sufficient to understand the experiments and follow instructions (Mini-Mental Status Score of 22 or higher or interview for aphasic subjects); c) has a Motor Power score ≥1/5 and <4/5 (neither hemiplegic nor fully recovered motor function in the muscles of the shoulder and elbow and wrist); d) is naive in that he/she has never experienced robot-assisted therapy; e) has given informed written consent to participate in the study. Patients are excluded from the study if they have a fixed contraction deformity in the affected limb. Trials commence only after baseline assessment across three consecutive evaluations, 2 weeks apart, shows a stable condition in motor impairment scales (Fugl-Meyer F-M and Motor Power MP). Patients qualified for robot therapy are randomly assigned to one of four groups:

a) 06 weeks of robot-delivered wrist therapy followed by 06 weeks of shoulder-and-elbow training using the planar robot (03 times per week: 36 sessions).

b) 06 weeks of shoulder-and-elbow training followed by 06 weeks of wrist robot training (03 times per week: 36 sessions)

c) 12 weeks of alternating shoulder-and-elbow and wrist training (with at least 24 hours between alternations) using the planar and wrist robots in standalone mode (03 times per week: 36 sessions).

d) 12 weeks of training with half of the session focusing on shoulder-and-elbow training and half of the session focusing on the wrist training (03 times per week: 36 sessions) using the planar and wrist robots in standalone mode.

In this paper we report preliminary results of this study at the completion of stage a). Five (5) naive stroke outpatients with no previous exposure to robot therapy have received 6 weeks of training on the wrist robot (3 sessions/week) followed by 6 weeks of training on the planar robot (3 sessions/week) at the Burke Rehabilitation Hospital. Admission Fugl-Meyer (max /66) for these 5 patients was 33±14.7 with a range in the three pre-treatment evaluations of 19.5 to 42.3. Table 1 shows the results for the shoulder-and-elbow and wrist-and-fingers subcomponents of the UE Fugl-Meyer and Motor Power scale expanded to incorporate wrist muscle groups (max /90). Although our small sample of five subjects prohibits us from running any meaningful statistics, it appears that larger gains in clinical scores were specific to motions exercised during the particular 6-week period and not to the un-exercised limb segment. In fact, these distal gains far exceed our expectations.

TABLE I
CLINICAL SCORES OF THE WRIST MODULE PILOT STUDY

Timeline: 6 wks wrist 6wks planar N=5	Change Admission to Discharge of Wrist Training (mean±sem)	Change Admission to Discharge of Planar Training (mean±sem)	Total Change (mean±sem)
F-M s/e (/42)	1.8 ± 0.8	2.2 ± 1.0	4.0 ± 1.8
MP (/90)	0.9 ± 1.3	2.4 ± 1.1	3.3 ± 1.5
F-Mw/h (/24)	5.8 ± 2.6	0.8 ± 0.4	6.6 ± 2.9

Clinical scores of the wrist module pilot study with five (5) naive outpatients. The total Fugl-Meyer change in 12 weeks for these 5 patients was 10.6 ± 4.7.

Figure 4 shows a sample run of a video game performed by a pilot patient while rotating the wrist in flex-ext and ab-ad toward targets on a screen. Shown are plots of flex-ext vs. ab-ad at admission (top) and discharge (bottom) [16]. The time history of position, (derived) velocity, and applied torques are also available.

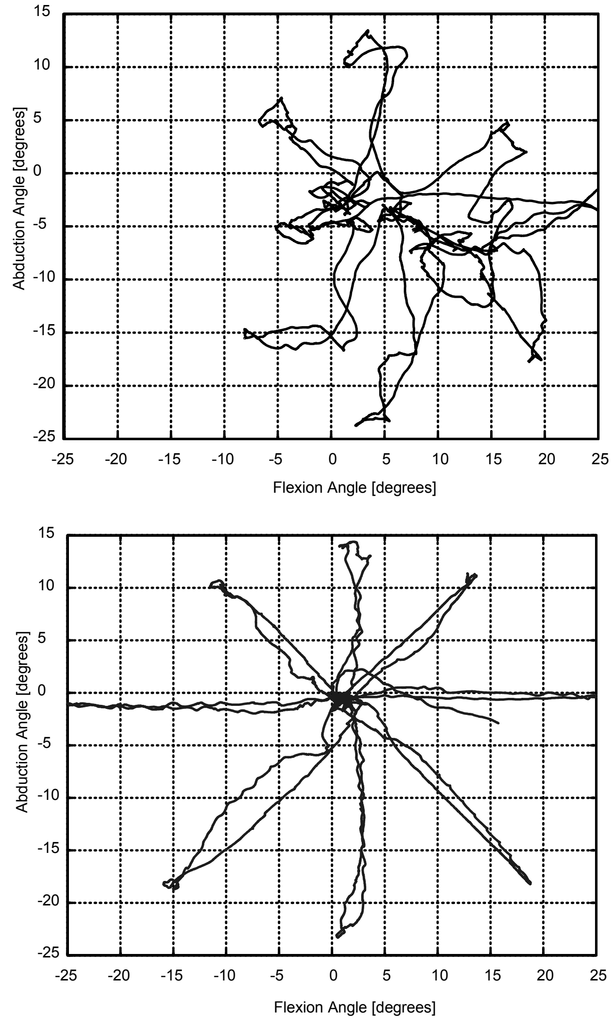

Fig. 4. Impact of wrist training. Graphs show changes in wrist movement while moving unconstrained towards targets at admission (top) and discharge (bottom) for one pilot patient

Considering that improvements of this magnitude in persons with severe or mild chronic impairment due to stroke are remarkable (15% of the absolute 66-point Fugl-Meyer scale), these clinical results are promising. These clinical changes are readily observable in the kinematic and kinetic information collected by the robot (see for example Figure 4). Of complementary interest, while we [17] and others have shown that normal reaching movements may be accurately described as “optimally smooth” in the sense of minimizing mean-squared jerk, very little is known of equivalent wrist movements [18]-[23]. Would an equivalent optimally smooth criterion emerge? Even in the presence of rotations? To address this question, we are currently investigating what constitutes normal unconstrained movement of the wrist [24]. This investigation will provide a basis of understanding of healthy wrist motion behavior necessary to evaluate impairment and measure rehabilitation progress. Figure 5 shows a sample run of a video game performed by a young unimpaired subject.

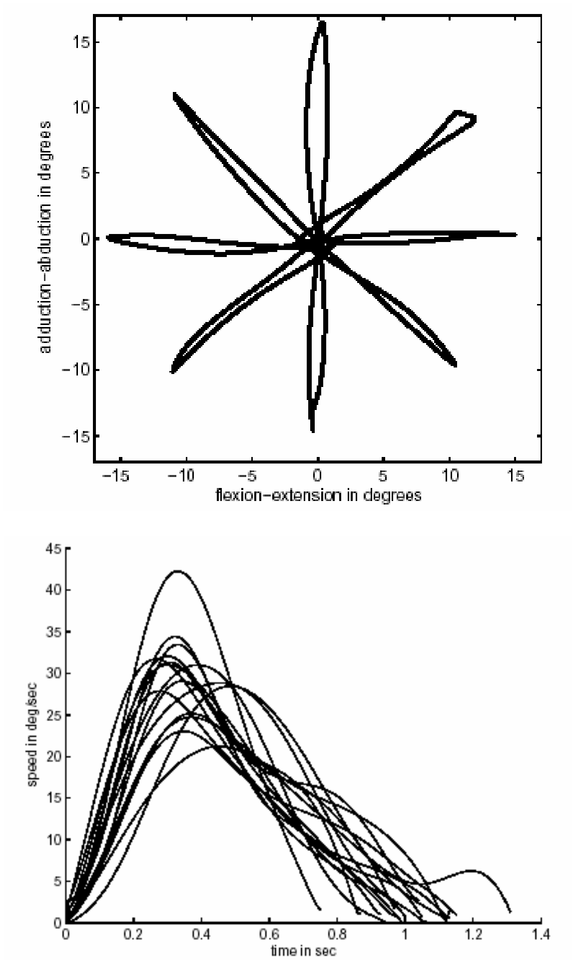

Fig. 5. A sample of unimpaired point-to-point wrist movements (top) with respective speed profiles (bottom). Data was collected using Flock of Birds (Ascension Technology) for comparison with data from the wrist robot.

IV. CONCLUSIONS

The development and success of MIT-MANUS as a robotic aid for neuro-rehabilitation has prompted the development of new devices targeting motions often affected by stroke. This paper provides an overview of the transition of the wrist robot from its design to its implementation as a clinical device. The wrist robot is capable of providing continuous passive motion, strength, sensory, and sensorimotor training for the wrist. In its final form, this device will offer insights into human motor control and human learning, as well as the potential for customizable, adaptive, and rigorously quantified therapy in solo operation or mounted at the tip of the planar MIT-Manus.

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