Fine Finger Motor Skill Training with Exoskeleton Robotic Hand in Chronic Stroke

Stroke rehabilitation

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Abstract— **Background and Purpose. Stroke survivors often show a limited recovery in the hand function to perform delicate motions, such as full hand grasping, finger pinching and individual finger movement. The purpose of this study is to describe the implementation of an exoskeleton robotic hand together with fine finger motor skill training on 2 chronic stroke patients.**

Case Descriptions. Two post-stroke patients participated in a 20-session training program by integrating 10 minutes physical therapy, 20 minutes robotic hand training and 15 minutes functional training tasks with delicate objects(card, pen and coin). These two patients (A and B) had cerebrovascular accident at 6 months and 11 months respectively when enrolled in this study.

Outcomes. The results showed that both patients had improvements in Fugl-Meyer assessment (FM), Action Research Arm Test (ARAT). Patients had better isolation of the individual finger flexion and extension based on the reduced muscle co-contraction from the electromyographic(EMG) signals and finger extension force after 20 sessions of training.

Discussion. This preliminary study showed that by focusing on the fine finger motor skills together with the exoskeleton robotic hand, it could improve the motor recovery of the upper extremity in the fingers and hand function, which were showed in the ARAT. Future randomized controlled trials are needed to evaluate the clinical effectiveness.

Keywords— stroke rehabilitation, exoskeleton, therapeutic robotics, EMG

I. INTRODUCTION

Stroke survivors often show significant disability of the hand to perform delicate motions, such as full hand grasping, finger pinching, individual finger movement and thumb adduction and abduction. Thus, a specific hand exercise is an important part of the rehabilitation in order to accomplish daily tasks. Besides conventional physiotherapy, it has been shown that robot assisted training is an important factor to improve the recovery of the arm functions [1,2]. A variety of rehabilitation devices have been developed, from uni-manual, single joint, bimanual devices with multiple degrees of freedom, and virtual reality systems to EMG-triggered devices [3]. They all provide repetitive and precise movements for the recovery on the upper extremity (UE) and focus mainly on the wrist, elbow and shoulder; such as Bi-Manu-Track [4], MIT-Manus [5], Reha Digit [6], Hand and Wrist Assisting Robotic Device (HWARD) [7], Hand Motion Assist Robot [8] and the Exoskeleton Robotic Hand [9]. However, there are a limited number of devices, which are able to train each finger individually or restore the lateral grasp to perform the opposition of the thumb to the palm such as HandCARE [10], Amadeo from Tyromotion [11] and Rutgers Hand Master I/II [12]. Therefore, an exoskeleton robotic hand was developed to train the fine finger motor-skills, with the ability of hand grasping, three-point-grip and pincer-grip to enable delicate grasping functions and multiple training possibilities. This is the first pilot study to examine the therapeutic effect on figures by using an exoskeleton robotic hand on patients after stroke. The purpose of this study is to describe and discuss the effects of robotic training and the performance details of two patients who underwent 20 sessions of intervention and targeting on fine finger motor skills.

II. METHODS

The initial exoskeleton robot was developed by Tong, K.Y. et al. [9, 13, 14] and controlled by EMG signals to the affected limb and enabled assistive hand grasping/opening for patients after stroke. It consists of an actuator platform, linear actuators, and five-finger assemblies. Each finger assembly is actuated by one linear actuator to generate the finger flexion/extension. The actuator moves the proximal interphalangeal (PIP) and metacarpophalangeal (MCP) joints at the same time. . The range of motion (ROM) achieved 55°of the MCP and 65° of the PIP joints for flexion from full extension (i.e. 0° flexion). The robotic hand was adjustable for different finger length and provides comfortable interaction between the hand and the robotic system.

Based on this robotic hand development platform, a new control algorithm was developed for fine finger motor functions, which included the three-point-grip and pincer-grip. The robotic hand has installed strain gauges (Figure 1) to measure the flexion/extension force of each MCP and PIP joint moment individually. The control algorithm directly used the finger force to trigger the robotic hand movement. The maximum flexion/extension force was measured by maximum voluntary contraction during hand grasping/opening before each training session. Each MVC was maintained for 5 seconds, and 2 minutes rest was allowed between two consecutive contractions to avoid fatigue. The robot started the hand movement when it detected that the measured flexion/extension force was larger than the threshold (20% of

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the maximum force). The fingers and hand were placed in the exoskeleton robotic hand by Velcro straps. The open design allowed the patient to pick up and interact objects during training and the weight of the robot is 600grams (Figures 1 and 2).

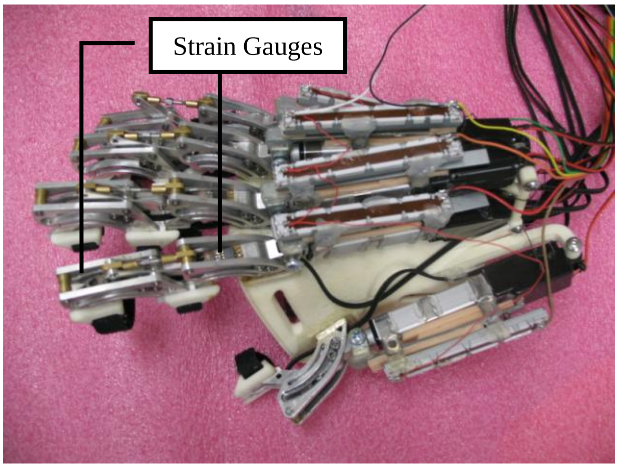

Figure 1 The robotic hand system with strain gauges

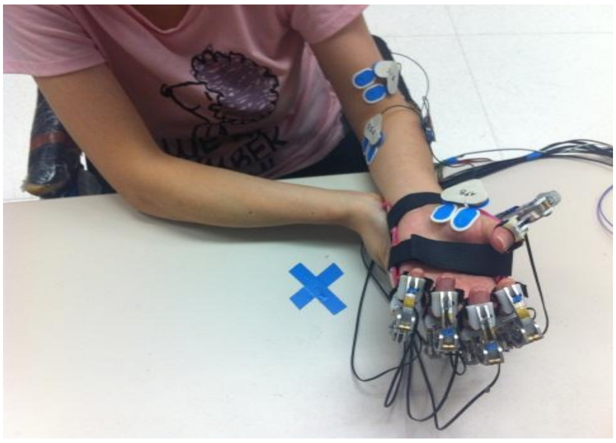

Figure 2 Participant wearing the exoskeleton robotic hand with EMG electrodes.

Each patient received 20 sessions of exoskeleton robotic hand training four to five times per week. Each session included 10 minutes of physical therapy, 20 minutes of robotic hand training and 15 minutes of functional training task without the robotic hand for fine motor skills on delicate objects (card, pen, coin).

The EMG electrodes were attached on the first dorsal interosseous muscle (FDI), abductor pollicis brevis (APB), extensor digitorum (ED), flexor digitorum superficialis (FDS), biceps brachii (BIC), and triceps brachii (lateral head; TRI). The co-contraction index (CI) was used to compare the co-activation among different muscle pairs to evaluate the muscle coordination pattern [15]. The CI of the agonist-antagonist muscle pairs (FDI-ED, ED-FD and BIC-TRI) during the fine motor function training without robotic hand were evaluated.

The 20 minutes of robotic hand training includes 3 hand function tasks (Figure 3-5). The patients were seated in an upright position with 0° shoulder flexion, 90° elbow flexion and 0° wrist flexion. The hand was placed in the middle of the table:

Task1 (Full-hand-grasping): These movements were designed to train the hand opening and grasp. The training includes 1 minute of full-hand-grasping/opening without any objects, then 3 minutes of functional hand grasping/opening by moving an object on a table (sponge: 14x8.5x3 cm and 10g) 50 cm to the left and right and 30cm forwards and backwards. The movements also train the abduction, flexion, adduction and extension of the shoulder as well the flexion and extension of the elbow.

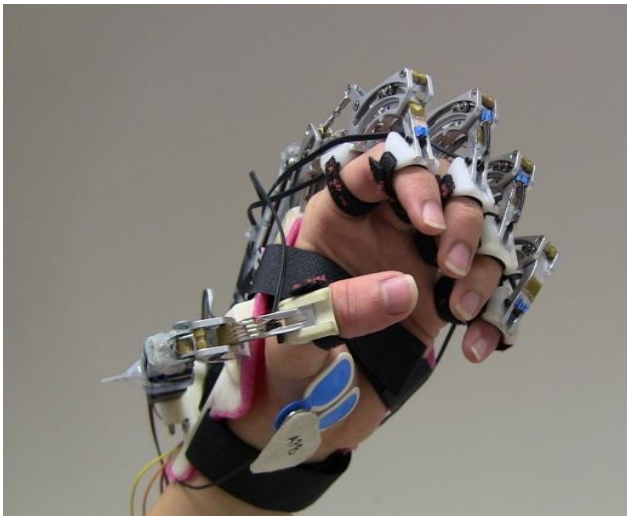

Figure 3 Full-hand-grasping

Task2 (Three-point-grip): The ring and little finger are held in a mid-range position of the robotic hand at 27.5° of MCP flexion and 32.5 of PIP flexion. The training includes 2 minutes of three-point-grip training (thumb/index/middle finger), without an object followed by 6 minutes of object transport (described as task 1).

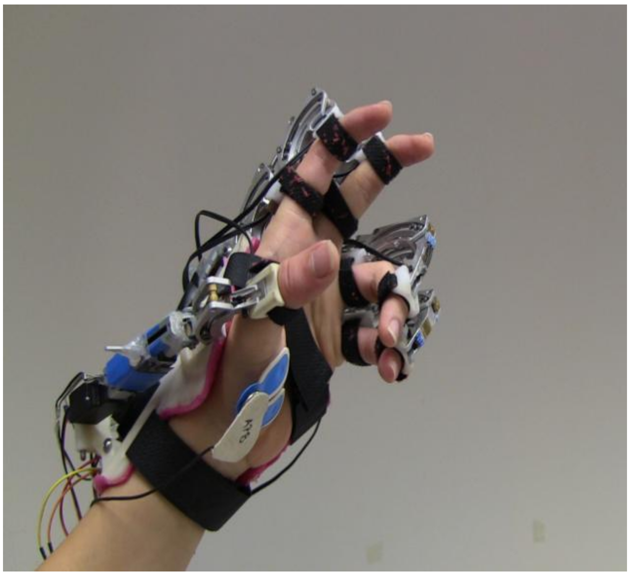

Figure 4 Three-point-grip

Task3 (Pincer grip): The middle, ring and little finger were held in the mid-range position as described above. The training includes 2 minutes of pincer-grip (thumb/index finger) without an object followed by 6 minutes of object transport (described as task 1).

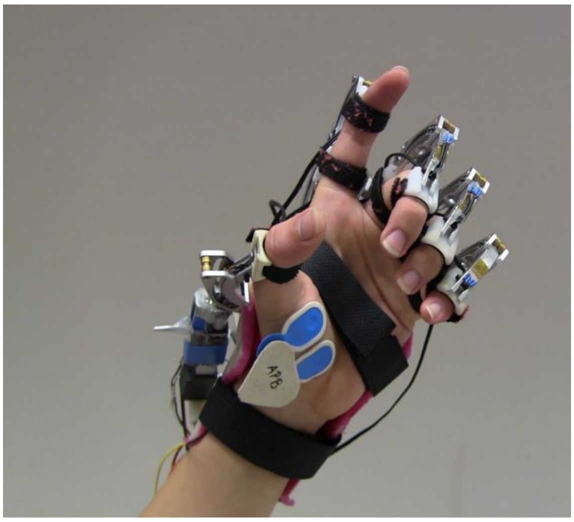

Figure 5 Pincer grip

The 15 minutes of fine motor functional tasks without the robotic hand included: holding a pen, grasping a card and picking up a one dollar Hong Kong coin (comparable to 25 US cent, 5.6g and 0.024m diameter). Each task was repeated 3 times and the objects were held for 5 seconds at the arm position of 90°shoulder flexion, 0°elbow flexion and 0°wrist flexion.

After obtaining approval from the University Human Subjects Ethics Sub-Committee, we recruited two subjects after stroke for the study. Subjects were identified as suitable if they met the inclusion criteria: subjects were in the chronic stage (at least 6 months after the onset of stroke), ischemic or hemorrhagic stroke, normal communication/cognitive skills (Mini-Mental-State-Examination (MMSE) > 21), no significant contractures or spastic of the UE (Modified Ashworth Scale (MAS) < 3) and no pain in the hand, wrist, elbow or shoulder.

Two chronic ischemic stroke patients were recruited in this study:

Patient A (male, 60 years old) was affected by a first-time ischemic stroke 11 months before being recruited in this study. Patient A was independent in all ADL's before and after onset of stroke, only the fine motor skills were affected. Before the clinical trial, he showed inability to lift delicate objects without assistance. FM score was 61 and ARAT was 41.

Patient B (male, 53 years old) had a first-time ischemic stroke 6 months prior from joining this study. After the stroke, he was affected in the lower and upper extremity, which restricted his independence in ADL (FIM 64). FM score was 23 and ARAT was 3.

III. RESULTS AND DISCUSSION

Two chronic ischemic stroke patients with arm and hand impairment completed the 20-session of fine motor skill training by integrating 10 minutes physical therapy, 20 minutes robotic rehabilitation and 15 minutes functional training tasks with delicate objects. Both patients showed improvement in the natural hand and finger functions, such as active coordination between fingers, voluntary muscle contraction and individually finger flexion/extension.

Subject A: At the end of the 20th session, the fingers were slightly bent during the clenched fist and opposition of the thumb to the ring finger could be achieved. The distal phalanges of the thumb could be extended independently. The muscle coordination pattern has been improved during fine motor function tasks without the robotic hand. The results showed that the co-contraction index was reduced for agonist-antagonist muscle pairs of the hand, wrist and elbow (FDI-ED from 0.013 to 0.007, ED-FD from 0.022 to 0.015 and BIC-TRI from 0.037 to 0.028). Patient A progressed gradually by improving the arm function of the fine and gross motor skills in the ARAT from 41 to 49 and FM from 61 to 63.

Subject B: The FM showed an improvement from 23 up to 36 and the ARAT score showed a profound increase from 3 to 27. FIM had increased from 64 to 68 (full score), which enables him to accomplish bathing and stairs climbing independently. The co-contraction index showed no significant changes.

In addition, no adverse effect was shown during and after the intervention program. The patients were satisfied with the achieved results and the training procedures.

The results from this case report showed a positive effect on the fine motor skills by combing conventional rehabilitative techniques and robot assisted training. The fine motor skill was difficult to train, since the patients did not know how to control the finger movement after stroke, and they had difficulty in using the hand to interact with an object during the conventional training. With the robotic hand, the system could sense the patient's intention from the residual finger force to trigger the robotic hand movement to assist hand opening/closing. This approach will amplify the weak muscle and residual control signal to generate hand functions by the robotic system. Physical therapy and fine motor function task training were also important to allow the patients to practice the finger motor-relearned skill, reduce joint stiffness and spasticity.

This is a preliminary study, the results need to be evaluated in randomized controlled studies. Nonetheless, the results showed that robot-assisted therapy will be a potential area to further improve the training effects in stroke rehabilitation in the future in the finger and hand functions.

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