Clinical Assessment of Forearm Pronation/Supination Torque in Stroke Patients

Bing-Cheng Kung Ming-Shaung Ju* Chou-Ching K. Lin[1] Shu-Min Chen[2]

Department of Mechanical Engineering, National Cheng Kung University, Tainan, Taiwan, 701 ROC
[1]*Department of Neurology, University Hospital, National Cheng Kung University, Tainan, Taiwan, 701 ROC*
[2]*Department of Physical Medicine & Rehabilitation, University Hospital, National Cheng Kung University, Tainan, Taiwan, 701 ROC*

Received 13 Nov 2004; Accepted 16 Dec 2004

Abstract

The main goal of this study was to quantify the pronation/supination torque of the forearm during the planar circular motion of the whole upper limb. One of the synergy patterns of the stroke patients was the involumtary pronation/supination of forearm while they were moving their elbow joints. A new torque measurement system was designed and installed on a previously built shoulder-elbow rehabilitation robot. The robot could apply either resistant or assistant force on the subject's wrist when the upper limb was performing a circular movement. The pronation/supination torque and the trajectory of tracking movement were recorded during the treatment procedure, and the pronation and supination torque of forearm were analyzed offline. The experimental results revealed that the forearm pronation/supination torque of stroke subjects could be detected and quantified while the subjects were performing the tracking movement on the transverse plane. The able-bodied subjects provoked less forearm pronation/supination torque during similar movements.

Keywords: Rehabilitation robot, Elbow joint, Synergy pattern

Introduction

In recent years, there have been many important breakthroughs on developing the technology of robots which can imitate the human being's movements, such as grasp and grip in upper limb and walk, squat and standing in lower limb. Since the number of patients is large and the treatment is time-consuming, it is a big advance if robots can assist in performing treatment. Therefore, there have been many researches on how to use robots in assisting patients in rehabilitation [1-5]. The results indicated that the ability of movements was improved and pain was reduced.

By clinical observation, when stroke patients moved their upper limbs voluntarily, involuntary contraction was observed in irrelevant muscles. For example, when the elbow joint was flexed or extended, the forearm tended to pronate or supinate spontaneously. O'Sullivan et al. [6] used a custom-built T-bar configuration to measure forearm pronation and supination torque at different upper limb postures. Their research showed that the maximum forearm supination torque occurred at 135° and the maximum forearm pronation occurred at 45° (referring full elbow extension as 0°). Yang et al. [7] used a VICON 3D motion analysis system with four cameras to record the movements. Each subject was asked to perform six reaching tasks at various levels of difficulty. The normalized results revealed that the angle trajectory of elbow flexion was similar to that of forearm pronation. The results could be applied widely in biomechanical modeling, orthoses design, control theory and rehabilitation evaluation.

The purpose of this study was to investigate the forearm pronation/supination torque of the subjects during rehabilitation exercise, and to objectively quantify this phenomenon. Subjects were asked to perform planar circular movements of upper limbs along a predetermined circular trajectory with a neuromuscular rehab robot. The movement trajectory and forearm pronation/supination torque were recorded. The results were analyzed and discussed.

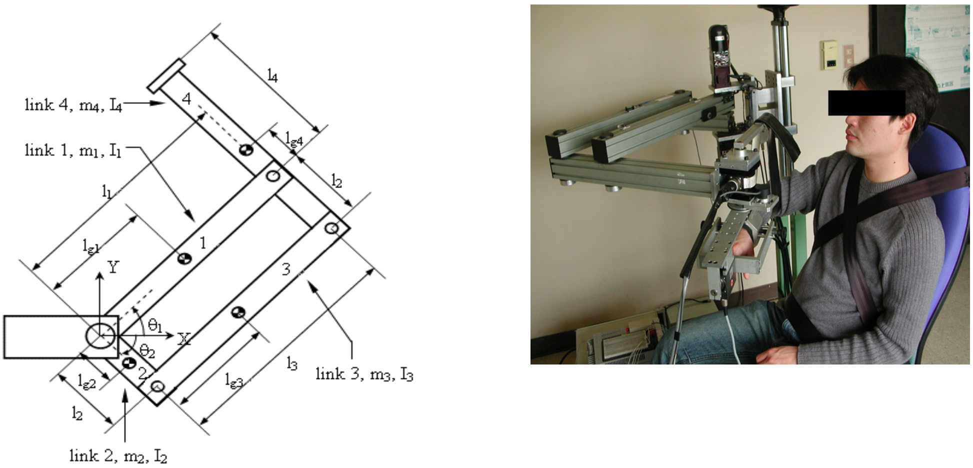
Methods

Robot system

The experimental setup consisted of a robot mechanism, a command generating sub-system that controlled the movement of the robot, an input sub-system that received signals from the robot and a personal computer. The robot was designed to perform a two-dimensional motion in a planar workspace. A fuzzy logic controller was employed to realize the position and force control such that the robot could apply either resistant or assistant force on the subject's wrist when the upper limb was

---

* Corresponding author: Ming-Shaung Ju
Tel: +886-6-2757575 ext. 62163; Fax: +886-6-2352973
E-mail: msju@mail.ncku.edu.tw



[redacted]

(a) (b)

Figure 1. A schematic drawing of robot mechanism (a) and a photograph of the robot-aided rehabilitation system with a subject (b).

performing a circular movement. For the command generation, the commands calculated by the personal computer were converted into analog signals through a D/A card (PCL726, Advantech Inc., www.advantech.com) and sent to the drivers of two AC motors of the robot.

The inputs to the controller consisted of end-point force and position information. End-point force was detected by a force sensor (MC3A-S1000, Advanced Mechanical Technology Inc., Watertown, MA, USA) attached on the robot between the wrist-fixing part and link 4 (Fig. 1a). The forearm pronation/supination torque was detected by a single axis load cell (Model 1702 series, Lebow) attached on the wrist-fixing part. The signal from the force sensor, amplified by a custom made amplifier, was digitized by an A/D board (PCL818HD, Advantech Inc., www.advantech.com). The rotation of each AC motor was detected by an encoder attached to the motor and counted by using a counter board (PCL833, Advantech Inc., www.advantech.com). From the joint angles of the robot, Cartesian coordinates of the end effector could be calculated. The force and position data were used both for closed-loop control and for later off-line analyses.

Experimental procedure

The subjects included able-bodied subjects and stroke patients. Young subjects were 20~30 year-old without any neuromuscular diseases. The stroke subjects having Brunnstrom's stage greater then 3, could limitedly voluntarily move their affected limbs. All the subjects spent approximately 30~40 minutes per day in this study. With a wide strip attached to the robot mechanism, the upper limb of the subject was suspended at a horizontal position (Fig. 1b). The hand was put into an elastic glove attached to the base of a crooked clamp, which was able to rotate horizontally relative to other parts of the robot mechanism. The clamps positioned at the wrist level, when tightened with an elastic band, further stabilized the wrist with the robot mechanism. The subjects moved their hands along a circular trajectory centripetally (left hand clockwise, right hand counterclockwise) or centrifugally (left hand counterclockwise, right hand clockwise) in different trials. The motion included passive movements and active constraint movements, and both of the subject's intact and affected hands were tested.

The passive movements meant that the subject was asked to relax his upper limb and the robot applied an assistant force along the tangential direction of the movement to drive a centripetal or centrifugal motion. In the active constraint movements, the subject had to move actively and the robot applied a resistant force along the tangential direction of the movements. For the able-bodied subjects, the robot applied a resistant force of 7 Newtons and, for the stroke patients, the robot applied an adaptive resistance. The subjects were asked to conform to the planned movement trajectory at their best. The robot recorded endpoint position, velocity, force, elbow rotary angle and forearm pronation/supination torque during the circular movements.

Quantification Index

The present research developed an index, IADT (Integration of Absolute Deviation of Torque, Equ. 1), to summarize the forearm pronation or supination torque trajectory.

$$IADT = \int_{0}^{360} \left| \left| \bar{M}_f \right| - AVG\left(\left| \bar{M}_f \right| \right) \right| d\theta \qquad (1)$$

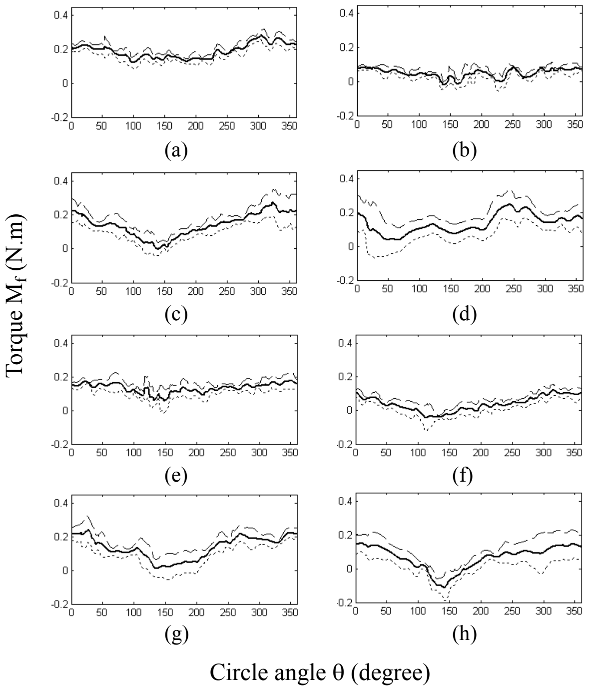
where $\bar{M}_f$ was the forearm pronatin/supination torque, AVG was the average of forearm pronatin/supination torque, θ was the angular displacement of circular movements. The purpose of this quantification index was to estimate the total variation of forearm pronatin/supination torque. The larger the IADT was, the larger the forearm pronation/supination torque the subject produced. T test with alpha=0.05 was utilized to test the significance of difference between groups.

Results

The subjects included six able-bodied subjects and three stroke patients. (Table 1), in which N1~N6 were able-bodied subjects and S1~S3 were stroke patients. S2 showed the largest muscle tone and S3 had the lowest Brunnstorm's stage.

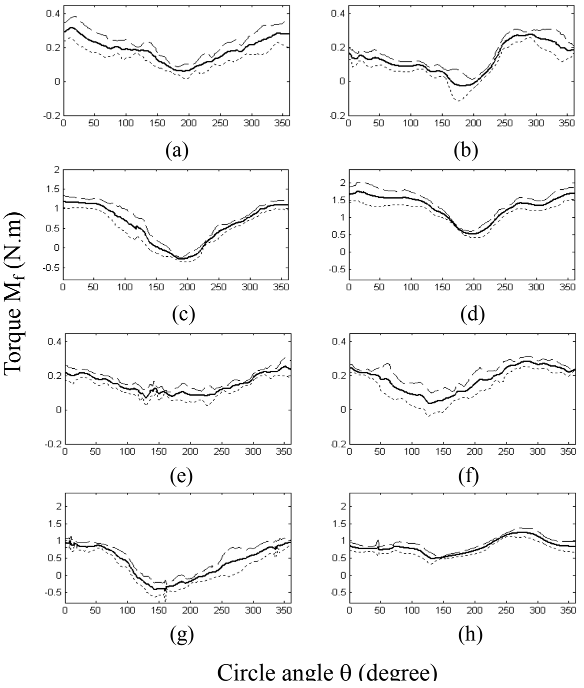
Table 1 Basic characteristics.

	Subject No.	Age	Sex	Affected	Brunnstorm's stage	Modified Asworth scale
able-bodied	N1	25	F		7	0
	N2	21	F		7	0
	N3	24	M		7	0
	N4	23	M		7	0
	N5	23	M		7	0
	N6	23	M		7	0
Stroke	S1	37	M	Left	5	1^+
	S2	67	F	Left	4	2
	S3	71	F	Left	3	1



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 2. The measured forearm pronation/supination torque in circular movements of subject N2. The solid line is the mean of the forearm pronation/supination torque and the dashed lines are one positive and negative standard deviation of the mean, respectively.



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 3. The measured forearm pronation/supination torque in circular movements of subject S2. The solid line is the mean of the forearm pronation/supination torque and the dashed lines are one positive and negative standard deviation of the mean, respectively.

In measuring forearm pronation/supination torque in circular movements, taking N2 and S2 for example (Fig. 2, 3), there were different conditions (a)~(h). Conditions (a) and (e) were the measured results of passive movements for centripetal and centrifugal motion respectively. The able-bodied subjects used non-dominate and the stroke patients used affected side. Conditions (b) and (f) were the measured results in passive movements for centripetal and centrifugal motion respectively. The able-bodied subjects used dominate and the stroke patients used intact side. Conditions (c) and (g) were the measured results in active constraint movements for centripetal and centrifugal motion respectively. The able-bodied subjects used non-dominate and the stroke patients used affected part. Conditions (d) and (h) were the measured results in active constraint movements for centripetal and centrifugal motion respectively. The able-bodied subjects used dominate and the stroke patients used intact part. In both centripetal and centrifugal motion, the forearm produced larger pronation/supination rotary variation in active constraint movements than in passive movements and stroke patients produced larger variation phenomenon than able-bodied subjects (Fig. 2, 3).

Ⅰ. ***Centripetal and centrifugal motion***

Centripetal and centrifugal movements of able-bodied subjects and stroke patients in passive movements and active constraint movements were compared, respectively. The results of statistical analyses for the mean IADT index ($t_{18,0.975}$=2.101) of torque generated in centripetal and centrifugal movements revealed that there was no significant difference between able-bodied subjects and stroke patients (Fig. 4, 5) in centripetal and centrifugal movements neither in passive nor in active constraint movements. Since the forearm pronation/supination torque generated in centripetal and

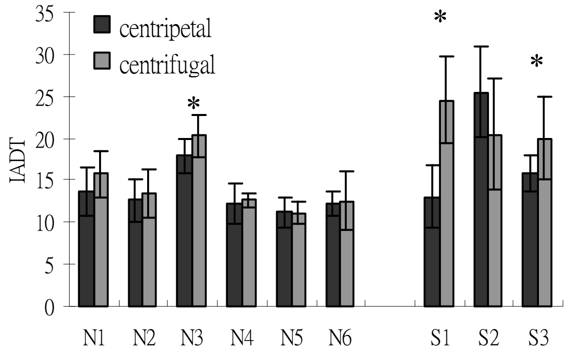


Figure 4. IADT of centripetal and centrifugal motions for able-bodied subjects and stroke patients in passive movements.

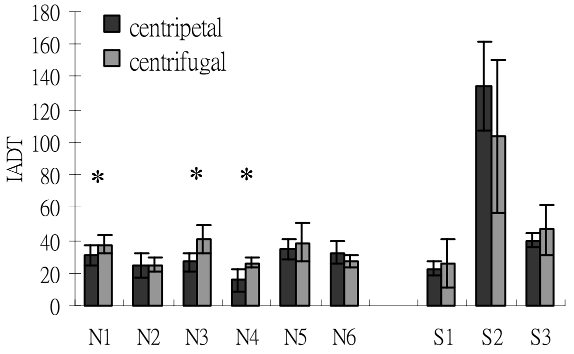


Figure 5. IADT of centripetal and centrifugal motions for able-bodied subjects and stroke patients in active constraint movements.

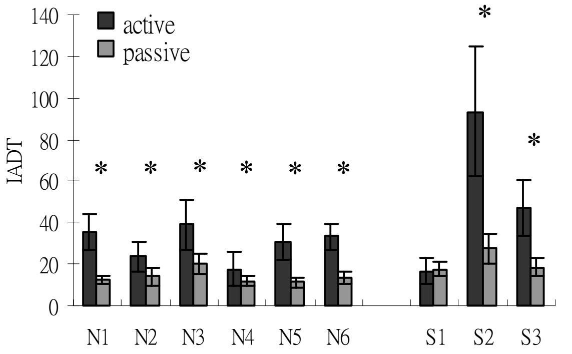


Figure 6. IADT of passive movements and active constraint movements of able-bodied subjects' non-dominate hand and stroke patients' affected hand.

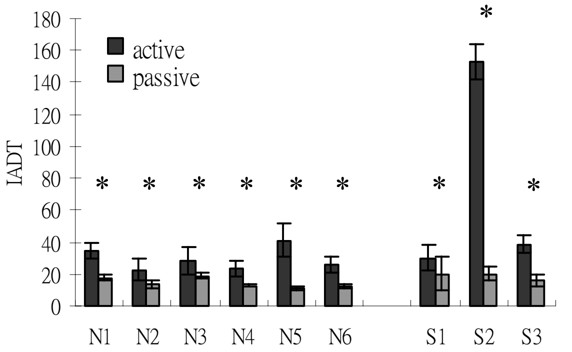


Figure 7. IADT of passive movements and active constraint movements of able-bodied subjects' dominate hand and stroke patients' intact hand.

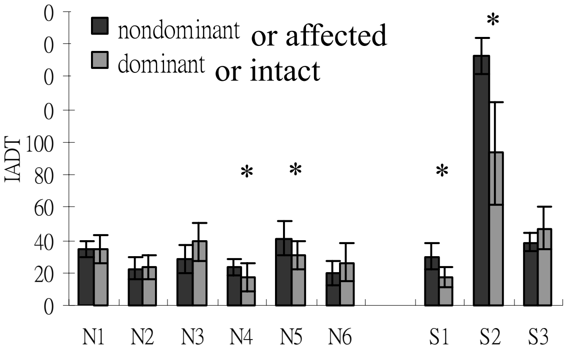


Figure 8. IADT of able-bodied subjects' non-dominate and dominate hands and stroke patients' affected and intact hands in active constraint movements.

centrifugal movements showed no significant difference, they were merged into one single set in the following statistical analyses.

Ⅱ. Passive movements and active constraint movements

Passive movements and active constraint movements of each side of able-bodied subjects and stroke patients were compared, respectively. The results of statistical analysis for the mean IADT index ($t_{18,0.95}$=1.734) of passive movements and active constraint movements showed significant differences (Fig. 6, 7) for both sides of all able-bodied subjects and stroke patients, except S1's affected side.

Ⅲ. Between two sides

The results of two sides of each subjects were compared. The results of statistical analysis for mean IADT index ($t_{18,0.95}$=1.734) revealed that the forearm pronation/supination torque generated by dominate and non-dominate hands of able-bodied subjects had no significant difference (Fig. 8). On the contrary, in storke patients, the affected side generated larger forearm pronation/supination torque.

Discussion

The circular trajectory predetermined in the rehab robot was an integral movement for shoulder and elbow joints including flexion and extension of the elbow joint, horizontal adduction and abduction of the shoulder joint. The elbow joint exerted similarly, though in different order, in centripetal and centrifugal motions. Though the exercise of the shoulder was different, shoulder joint did not affect the pronation or supination of the forearm. Since IADT was the integral of absolute values of pronation/supination torque, it was insensitive to the temporal order of torque and was expected to have similar values for centripetal and centrifugal motions.

For able-bodied subjects and stroke patients, the rotary moments of the forearm were all positively biased (Fig. 2, 3), probably due to the posture that the forearm was fixed at the clamps. Different postures would produce different background values. However, the trend of the forearm pronation/supination torque would be the same, because different backgrounds would not alter the IADT index.

Observing the results in able-bodied subjects and stroke patients during active motion, one would found the same trend that the forearm rotary torque descended first and was followed by ascending. Forearm supination occurred when the elbow flexed between $0^\circ \sim 180^\circ$ in the circular trajectory. Contrarily, forearm pronation occurred when the elbow extended between $180^\circ \sim 360^\circ$ in the circular trajectory. Naito and Yajima [8] applied electrical stimulation to brachioradialis and biceps brachii, which produced flexion of the elbow and supination of the forearm. These results were similar to our results of forearm pronation/supination torque. It indicated that brachioradialis and biceps brachii contraction, producing elbow flexion during circular movements, were also responsible for the accompanied forearm supination.

Conclusion

On the basis of a previously developed rehab robot, an add-on part and an associated quantification index IADT was developed to evaluated the pronation/supination torque of the forearm during the planar circular movements. The preliminary results in six able-bodies subjects and three stroke patients indicated that (1) the index could quantify the pronation/supinatipn torque trajectory and (2) the affected sides of stroke patients generated a larger pronation/supination torque and a large IADT value.

Acknowledgment

The research is supported by the Grant of National Science Council (NSC 92-2320-B-006 -074).

References

[1] P. S. Lum, C. G. Burgar, P. C. Shor, et al., ”Robot-assisted Movement Training Compared with Conventional Therapy Techniques for the Rehabilitation of Upper-limb Motor Function After Stroke”, *Arch Phys Med Rehabil*, 83: 952-959, 2002.

[2] H. I. Krebs, B. T. Volpe, M. L. Aisen, W. Hening, S. Adamovich, H. Poizner, K. Subrahmanyan, N. Hogan, ”Robotic Applications in Neuromotor Rehabilitation”, *Robotica*, 21: 3-11, 2003.

[3] S. E. Fasoli, H. I. Krebs, J. Stein, W. R. Frontera, N. Hogan, ”Effects of Robotic Therapy on Motor Impairment and Recovery in Chronic Stroke”, *Arch Phys Med Rehabil*, 84: 477-482, 2003.

[4] S. Coote, E. K. Stokes, ”Robot mediated therapy: Attitudes of patients and therapists towards the first prototype of the GENTLE/s system”, *Technology and Disability*, 15: 27-34, 2003.

[5] S. Hesse, G. Schulte-Tigges, M. Konrad, A. Bardeleben, C. Werner, ”Robot-Assisted Arm Trainer for the Passive and Active Practice of Bilateral Forearm and Wrist Movements in Hemiparetic Subjects”, *Arch Phys Med Rehabil*, 84: 915-920, 2003.

[6] L. W. O’Sullivan, T. J. Gallwey, ”Upper-limb Surface Electro-myography at Maximum Supination and Pronation Torques: the Effect of Elbow and Forearm Angle”, *Journal of Electromyography and Kinesiology*, 12 : 275-285, 2002.

[7] N. Yang, M. Zhang, C. Huang, D. Jin, ”Synergic analysis of upper limb target-reaching movements”, *Journal of Biomechanics*, 35: 739-746, 2002.

[8] A. Naito, M. Yajima, M. Chishima, Y.-J. Sun, ”A motion of forearm supination with maintenance of elbow flexion produced by electrical stimulation to two elbow flexors in humans”, *Journal of Electromyography and Kinesiology*, 12 : 259-265, 2002.