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Measurement of Elbow Spasticity in Stroke Patients Using a Manual Spasticity Evaluator

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Abstract— **Spasticity is often seen in patients with central nervous system lesion, such as stroke. It hinders functional movement and may induce pain. Current measures for assessing spasticity are either quantitative but not convenient to use or convenient to use in clinics but lack of objective quantification. We developed a manual spasticity evaluator (MSE) to evaluate the spasticity quantitatively and potentially suitable for a clinical setting. Joint position and torque from 10 subjects with right hemiplegia and 9 healthy subjects were measured conveniently and used to evaluate spasticity and determine the catch angle. EMG signal was obtained from the biceps brachii and triceps brachii to corroborate the mechanical measurement of the MSE. Results showed that the MSE provided a convenient and quantitative measurement of spasticity, including presence of catch angle, increase in joint stiffness, and decrease in joint range of motion in the stroke patients, as compared with healthy subjects. EMG signals corroborated MSE assessment of the catch angle.**

I. INTRODUCTION

Spasticity, a complex symptom, is usually seen in patients with upper motor neuron (UMN) dysfunctions such as cerebral vascular accidents (CVA), spinal cord injuries (SCI), multiple sclerosis, etc. [1,2]. The mechanism of spasticity is commonly thought of as an exaggerated stretch reflex which is a velocity-dependent increase in the resistance to the passive movement [3,4] and the property change of the muscle or related soft tissue. Spasticity in conjunction with excessive muscle tone frequently interferes with the voluntary motor function in patients with residual muscle power, causing difficulties with daily activities. Muscle pain or discomfort, reduction in joint range of motion (ROM) as well as contracture, may also occur at the joint crossed by spastic muscles [5,6].

Several measures have been used to assess the reflex hyperexcitability or hypertonus associated with spasticity, including the modified Ashworth scale, tendon reflex scale, pendulum test, Tardieu scale, passive joint ROM in clinics and mechanical perturbations in laboratory setting. However the measures adopted in clinical setting are usually not quantitative and is more or less subjective, depending on the testers, which decrease the inter-rater and intra-rater reliability. In the laboratory setting, motor-driven device provide accurate measurement nevertheless its bulk size is not convenient for clinical uses. Recently Lee et al developed portable device for assessing spasticity by derived viscosity [7]. Although it could be more convenient to use in clinical setting then motor-driven device, it could not reflect the condition of ROM and catch angle which are mostly used in clinical.

Determining the joint ROM with the “end-feel” and Tardieu angles [8] are simple and convenient ways to examine contracture and catch angle in clinics. In patients with spasticity, the resistance increases at the end of ROM, but it is quite subjective to determine the end point, which may vary considerably in a patient during different assessments and from patient to patient. Catch angle recording is also influenced by different movement velocities and errors from naked eye reading of the joint angle during the movement. Hence, the accuracy of these two measurements is depended on the clinician’s experience.

In order to provide an accurate and convenient tool to assess spasticity and contracture, we developed a manual spasticity evaluator (MSE) suitable for clinical setting [8]. In this study, we used the MSE to measure the elbow ROM at controlled terminal resistance torque, elastic stiffness, and the Tardieu R1 catch angle at the elbow joint of stroke survivors.

II. METHODOLOGY

A. Subjects

Ten stroke patients (57.2 ± 10.9 years old, 9 males and 1 female) and nine healthy subjects (50±20 years old, nine males) were recruited. Each patient had history of right side hemiplegia for more than one year. The healthy subjects were volunteers in our research group and elderly subjects from a registry.

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B. Instrument design

As shown in Fig 1, the MSE measured the joint torque and angle using a torque sensor and a potentiometer respectively. Besides, special attachment was designed for appropriate alignment to maintain consistent measurement, including forearm and upper arm brace supports. An extended handle allowed the clinician to evaluate the spastic elbows easily with joint torque measured by a torque sensor. The elbow flexion axis, torque sensor and potentiometer were aligned with each other. Two mechanical stops at the extreme ends were used to limit the movement range for safety (avoid over-stretching the spastic elbow joint).

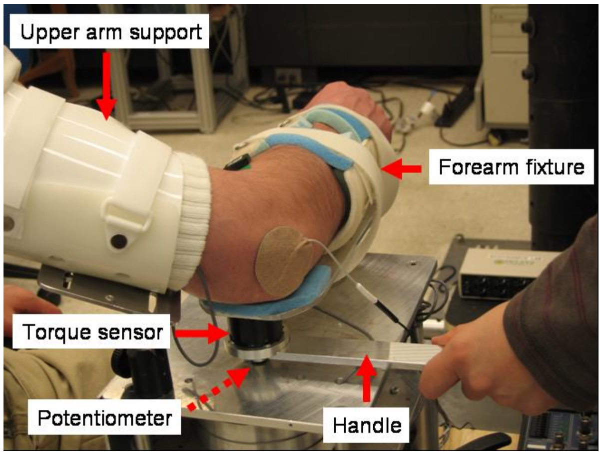

Fig. 1 Setup of Manual Spasticity Evaluator

The torque and position signals were sampled at 1000 Hz and sent to a laptop computer through an analogue-to-digital (A/D) converter (National Instruments, Austin, TX) with a 16-bit resolution. Interfacing programs of data acquisitions and visual/audio feedback were made in Visual C++ and MATLAB (The MathWorks, Natick, Massachusetts), and data were further processed and analyzed using MATLAB [8]. Figure 2 shows the Graphic user interface (GUI) for the data collection with real-time feedback.

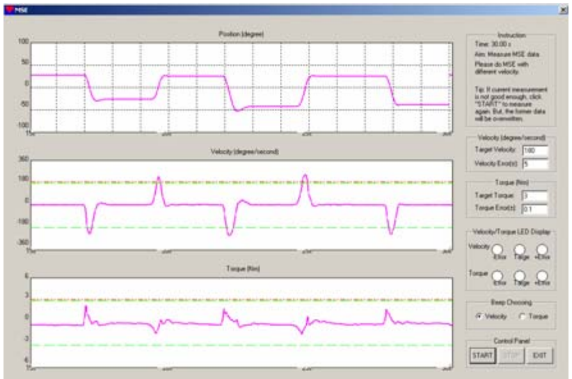

Fig.2 Graphic user interface (GUI) used in data acquisition and feedback control of movement velocity and terminal torque.

C. Experimental setting and procedures

At the beginning of the experiment, the stroke patients were evaluated by the therapist manually and graded by the modified Ashworth scale (MAS). With the patient's arm mounted onto the device, surface electrodes (DE-2.1, Delsys Inc., MA, USA) were placed on the biceps brachii and triceps brachill. The flexion axis of the elbow joint was aligned with the rotation center of the device. The forearm was held at the neutral position using a brace. The shoulder was kept at around 75° of abduction and strapped to the upper arm support.

First, the elbow passive ROM and stiffness were determined under a slow velocity of 30 degrees/sec. Next, three trials of back and forth movements were performed at the velocity of 90, 180, and 270 degrees/sec.

D. Data analysis

The biomechanical data were fed through lowpass filters with a cutoff frequency of 50 Hz. The EMG data were filtered with passband at 10- 450 Hz. In order to determine the onset time for verifying the catch angle, the EMG were presented as liner envelope form (LE). The raw EMG were full wave rectified and filtered at 10 Hz. Derivative of torque (τ (t)) with respect to time, dτ(t)/dt, and the velocity were calculated from the acquired torque and position signals respectively to determine the catch angle [9]. First, the instant of negative peak velocity was detected. Within the window of 80 points preceding this point, the peak of dτ(t)/dt located was determined, which gave the corresponding catch angle.

III. RESULTS

A. ROM AND STIFFNESS

Using the MSE, we measured the elbow ROM and elastic stiffness at the controlled low velocity. The results show that ROMs of stroke patients (ROM2= 3° ~ 104° and ROM3= 36° ~ 93°) are smaller than those of the healthy subject (ROM1= -1° ~ 106°). The stiffness at given elbow position of stroke patients are larger than that of the healthy subjects (slopes of line B (0.035 Nm/deg) and C (0.7 Nm/deg) are larger than the slope of line A (0.11 Nm/deg) at the same elbow angle, 70° of flexion, and the slope in patient with sever spasticity is steeper).

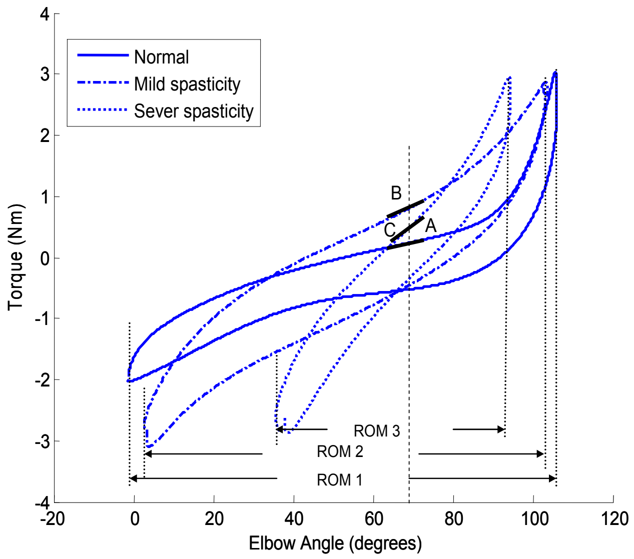

Fig.3. Representative torque-angle curves of stroke patients (mild and sever) and a healthy subject. 0 degree means full extension of elbow. Line B and C are the elastic stiffness of stroke patients with mild and sever spasticity, line A is the elastic stiffness of healthy subject recorded from the same angle as that of the patients.

B. TARDIEU R1 CATCH ANGLE AND EMG

A catch was felt during stretching and reflected in the changes of torque, velocity, and $d\tau(t)/dt$. Fig 4(a), (b) and (c) show the typical curves of these parameters in stroke patients with mild and sever spasticity and in a healthy subject, respectively. While reaching the catch position during passive elbow extension, $d\tau(t)/dt$ increased in the flexion direction (the value became more negative), as indicated by Point B in Fig 4(a) and 4(b). Besides, the velocity decreased then increased near the catch angle (Point A in Fig 4(a) and (b)). We also can see the change of the torque shown in point C in Fig 4(a) and 4(b). Correspondingly we could see the jerk occurring in the position curve (Point D in Fig 4(a) and (b)). In contrast, there was no obvious difference in $d\tau(t)/dt$ during the elbow movement in healthy subject (Fig. 4(c)). Because the $d\tau(t)/dt$ was influenced by the inertial, the first negative peak in the $d\tau(t)/dt$ curve, we chose the decrease point of instant velocity as the first indicator. Negative peak of $d\tau(t)/dt$ in the 80-points window (80 milliseconds) preceding the change of instant velocity (Point A) was detected as the catch angle.

EMG was used to verify the accuracy in determining catch angle using instant velocity change and $d\tau(t)/dt$. As shown in Fig. 5. (c), EMG firing occurred before the instant velocity decreased abruptly (Fig. 5(b)) because of the electromechanical delay. Again, this did not happen in normal subjects. And Fig. 5(a) shows the clear jerk in position change.

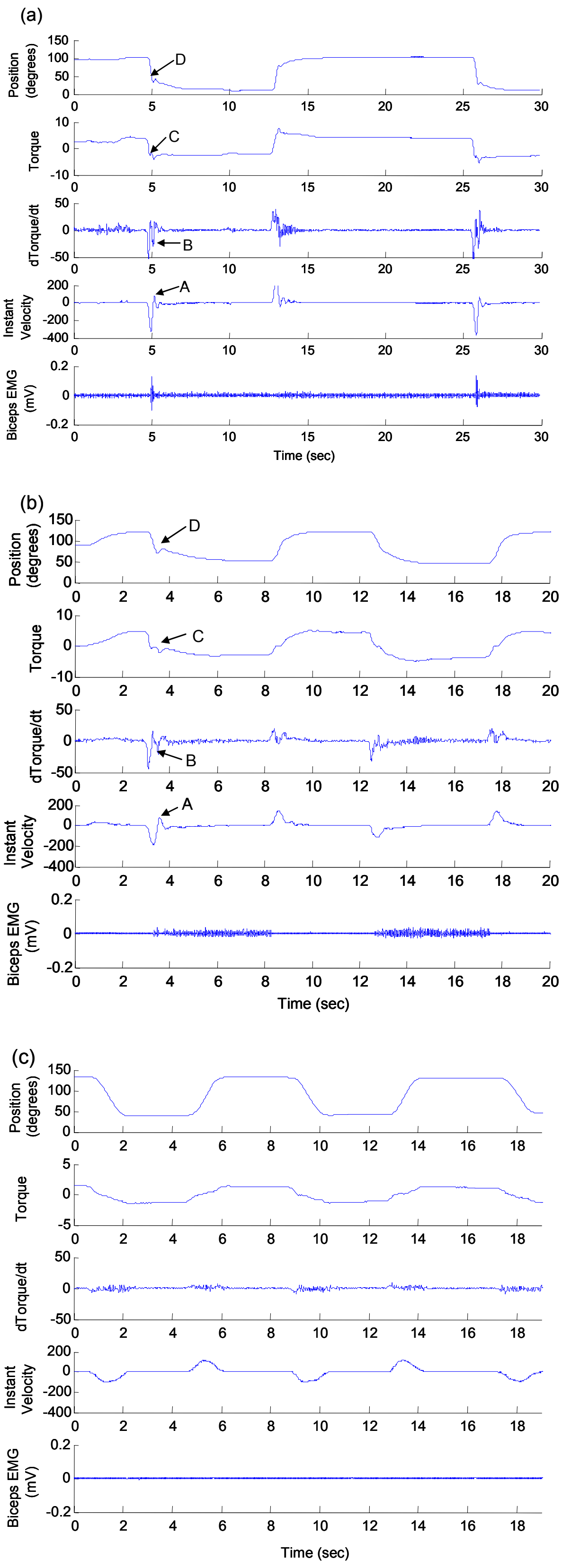

Fig. 4. (a) and (b) Typical catch results at the elbow of a stroke patient with hypertonic elbow flexors. (b) Similar test on a normal subject with no neurological disorder. dTorque/dt in the figure corresponds to $d\tau(t)/dt$ in the text content.

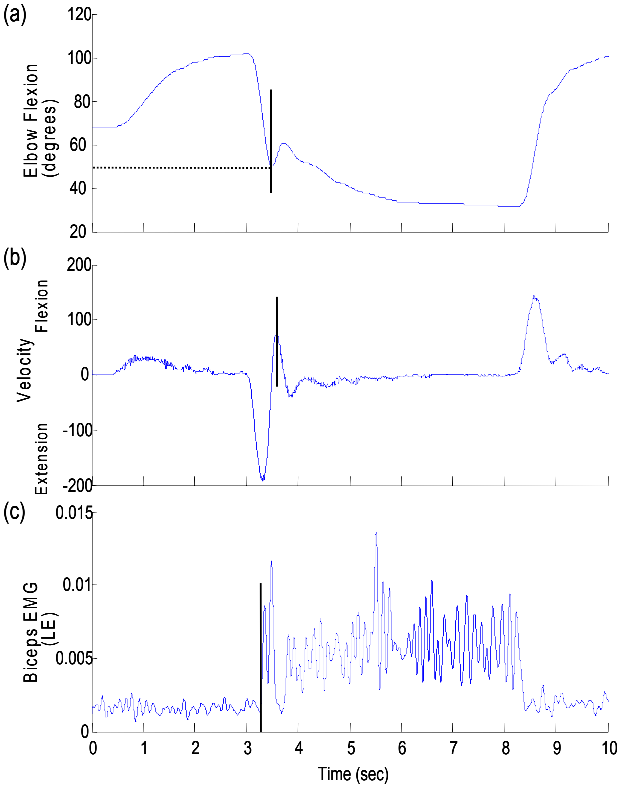

Fig. 5. Reflex EMG of biceps brachii (c) and changes of instant velocity (b) during passive elbow extension in a stroke patient and corresponding catch angle in (a).

IV. DISCUSSION AND CONCLUSION

Stroke patients showed changes in both biomechanical and reflex properties of their elbow. The changes can be evaluated quantitatively using the MSE which allowed a convenient control in the resistance torque and movement velocity through real-time feedback, and provided us quantitative evaluations of the joint stiffness, range of motion, and catch angle.

Instant velocity change combined with $d\tau(t)/dt$ can be used to determine the catch angle reliably. When the operator moves the elbow to the catch position, he/she feels sharp increase in the resistance torque, which is reflected in the abrupt change in $d\tau(t)/dt$. Of note is that we should ignore the torque used to overcome the resistance from the limb inertia.

In conclusion, the MSE provided quantitative and convenient measures of spasticity, and it is suitable for clinical setting. Furthermore, with validation from EMG signal, we showed that using instant velocity and $d\tau(t)/dt$ is a reliable measure to determine the catch angle quantitatively.

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