Muscle Tone of Upper Limbs Evaluated by Quantitative Pendulum Test in Patients with Acute Cerebellar Stroke

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Abstract- The main objective of this study was to quantify the muscle tone of upper limbs in patients with acute cerebellar stroke. Quantitative pendulum test was conducted, and model analysis was performed. Four parameters (number of swings, relaxation index, stiffness coefficient and damping coefficient) were formulated and the differences between the intact and affected sides were documented. In total, 8 subjects were recruited. While the number of swings, relaxation index and stiffness coefficient showed no difference, damping coefficient on the affected side was significantly smaller than that on the intact side by Wilcoxon signed rank test. The results indicated that the relatively lower muscle tone on the affected side of patients with acute cerebellar stroke was mainly ascribable to the smaller velocity-dependent component.

Key Words: Muscle tone, Cerebellar stroke, Pendulum test

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INTRODUCTION

Hypotonia is usually described in the textbook as one of the major manifestations of cerebellar lesions and is more apparent in the acute stage[1]. However, hypotonia is seldom accurately recorded in the patients with cerebellar lesions because it usually is subtle and difficult to be graded by manual tests. In the modified Ashworth scale (MAS), the lowest score is zero and defined as normal when no resistance detected. To the best of our knowledge, there is no report quantitatively investigating the muscle tone of patients with cerebellar lesions. Physical examinations or tests commonly used for the demonstration of the existence of hypotonia include increased passive range of motion, asymmetry of posture, and impairment of check reflex. The pendulum test developed initially by Wartenberg[2] was a semi-quantitative test for the assessment of spasticity of the knee joint. In the original pendulum test, the number of swings was the only parameter, which decreased in hypertonia and increased in hypotonia. The test was modified and refined later by several researchers and became a quantitative measurement.

In previous studies[3,4], we designed a simple apparatus to facilitate the pendulum test in the elbow joint and also proposed a biomechanical model of the elbow to

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formulate parameters for quantification. Initial results indicated that the parameters could differentiate spasticity in stroke patients from normal muscle tone in intact subjects[4]. In another study, we established the effects of age, gender and body weight on muscle tone of normative subjects[5]. We have also applied pendulum test to investigate the muscle tone of patients with diabetic polyneuropathy[6]. The main purpose of the present study was quantitative investigation of the effect of acute unilateral cerebellar stroke on muscle tone.

METHODS

Subjects consisted of patients admitted to National Cheng Kung University Hospital due to an acute cerebellar stroke. Inclusion criteria were clear consciousness and cooperativity, first episode of clinical stroke, stable medical condition, not taking anti-spasticity medication and unilateral cerebellar sign. The study protocol was approved by the NCKUH ethics committee on human subject study. Before an experiment, the purpose, potential hazards, and test procedure were fully explained to the subjects. A written consent form was signed. The body weight, forearm length and maximal forearm circumference were measured for the estimation of mass, center of mass, center of gyration and inertia of the forearm and hand[7,8].

The experimental setup and procedures were identical to those in the previous studies[6]. In brief, an apparatus was specifically designed to facilitate the pendulum test in the elbow joint (Fig. 1A). The apparatus consisted of a pendulum and a wrist fastening part. The steel pendulum was connected at the mid point to the test bed through a pure rotary joint with an electronic goniometer to measure the rotatory angle. A weight was added to the lower end of the pendulum to increase the total inertia. The subject lay comfortably on the test bed. The wrist was fixed to the apparatus through the wrist fastening part. The upper part of the pendulum was hooked to the test bed with a chain of pre-designed length, such that the initial elbow joint angle was 130˚ (with full extension defined as 0˚). Data collection was started and the chain was released swiftly without informing the subject. The forearm swung passively due to the weight at the lower part of the pendulum. After the swing motion was stopped by visual inspection, the data collection was terminated. Six successful trials were collected. The signals were sampled at 600 Hz for 15-25 seconds according to the duration of swing and stored in a personal computer for off-line analyses.

In order to quantify the results, four parameters were formulated. Number of swings (S) and relaxation index (R) were calculated from the averaged angle trajectory[9], where R was the ratio of maximal swing angle to the

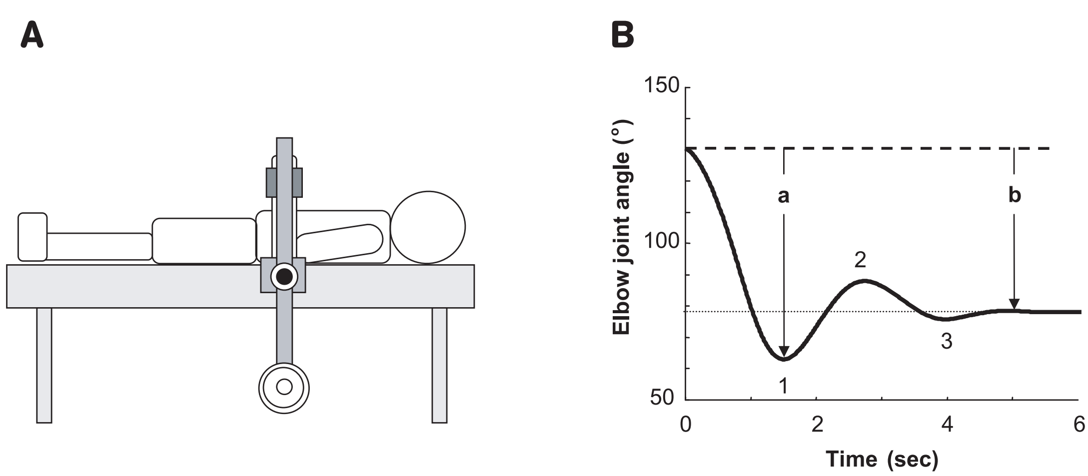

Figure 1. (A) A schematic drawing of the upper limb pendulum test. (B) An explanatory drawing of angle trajectory during the pendulum test. Symbol a is the maximal swing angle and symbol b is the final steady-state angle, both being neasured relative to the initial position.

final steady-state angle and S was the number of peaks and troughs during the swing (Fig. 1B). In general, both S and R increased as the muscle tone decreased. Then, the angle trajectory was fitted to a previously proposed biomechanical model of the elbow joint to derive K (the stiffness coefficient) and C (the damping coefficient). The full mathematical model and algorithm about the derivation of C and K from experimental data is described elsewhere[3]. In general, K was related to joint position and tissue stiffness, but not muscle tone. C was related to the angular velocity, and would increase with increased muscle tone.

For each of the four formulated parameters (S, R, K and C), we tested the significance of difference between the intact and affected sides by Wilcoxon signed rank test with a significance level of $\alpha = 0.05$. The software package, Statview (www.statview.com), was used for statistical analyses.

RESULTS

Eight subjects completed the pendulum test. The basic data of the subjects are listed in Table 1. The cause of stroke was infarction in 7 subjects and hemorrhage in 1 subject. The lesion was in the right hemisphere in 2 subjects and in the left hemisphere in 6 subjects. Muscle power of the affected side was mildly decreased (4+) in three subjects and normal in the others. There was no detectable difference in muscle tone by manual test in all subjects.

An example of the angle trajectory during the pendulum test along with the simulated results of both the intact and affected sides is shown in Fig. 2. Because the first trough (~60˚) of the angle trajectory on the affected side (thick line) is not as deep as that on the intact side (~50˚) and both trajectories reach approximately the same steady angle, the relaxation index on the intact side is larger than that on the affected side. At 10 seconds, the trajectories of both sides have almost reached the steady state. The simulated results from the biomechanical model match the experimental data well. A summary of

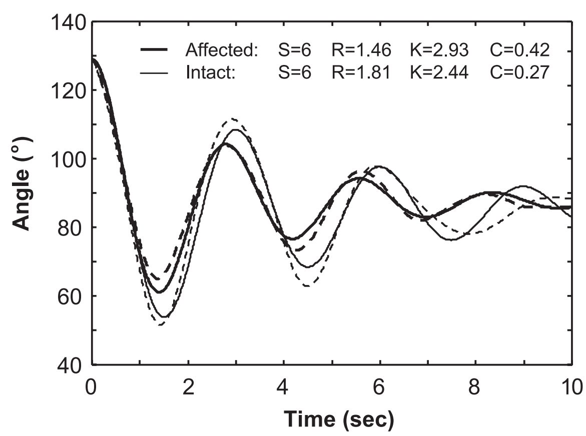

Figure 2. Typical results of the pendulum test on both the intact (thin line) and the affected (thick line) sides. The dashed lines are experimental results and the solid lines are simulated results.

***Table 1.** Anthropometric data of subjects*

	Sex	Age (y)	BW (kg)	Side of stroke	MRC scale*		MAS†	
					I‡	A	I	A
S1	M	86	54	L	5	5	0	0
S2	M	63	85	L	5	5	0	0
S3	F	69	69	L	5	5	0	0
S4	F	63	48	L	5	4+	0	0
S5	F	64	74	R	5	4+	0	0
S6	M	65	55	L	5	5	0	0
S7	F	77	55	R	5	5	0	0
S8	M	73	73	L	5	4+	0	0

*Medical Research Council scale. † Modified Ashworth scale. ‡ I: infact; A: affected.

the parameters are listed in Table 2. The trend of smaller S, K, and C, but larger R on the affected side was compatible with a relatively lower muscle tone. Yet, only the difference of C between the two sides was statistically significant.

DISCUSSION

The main result of this study is that, in the 4 formulated parameters, only the difference of damping coefficient (C) between the intact and affect sides was statistical significant. It implies that the conventional pendulum test may not detect the difference of muscle tone caused by acute cerebellar stroke, because the number of swings (S) is the only index available in the conventional pendulum test. S of both the intact and the affected sides were smaller than that of normal subjects and was not statistically significant. It is also noted that the muscle tone of both the intact and affected sides in these patients tended to be higher than that in the normal population[5], according to the larger S and R but smaller C in the normal subjects (Table 2). These results are unexpected, because the common concept predicts the opposite. There are several possible explanations. First, the mechanical terms that we used to describe muscle tone may not be exactly correlated with clinical hypotonia. Clinically, hypotonia is usually described by indirect methods such as hyperextensibility, pendular tendon reflex, impaired check, and excessive rebounds, because mild-to-moderate hypotonia cannot be perceived by manual stretch like hypertonia. Second, stroke syndromes affecting the cerebellum are heterogenous and may involve different parts of the cerebellum or even structures of the brainstem. The effects on the muscle tone might therefore be different in different syndromes. For example, a lesion at the midline anterior cerebellar lobe tends to cause disinhibition of ipsilateral extensor tone[9], whereas a lesion affecting the facilitatory pathways (eg. medial reticulospinal tract in the brainstem) would reduce muscle tone[10]. It is possible that hypotonia is more prominent in some syndromes but hypertonia might appear in the others. In this study, we did not observe hypotonia either by manual stretch or by other indirect methods. It is possible that the cerebellar stroke in our patients did not cause hypotonia, because we recruited subjects based only on cerebellar signs in the limbs. A larger-scale study is needed to investigate the effects of different cerebellar stroke syndromes on muscle tone. Third, the lesion size and severity of deficit may have further confounding effects on muscle tone. We only recruited patients with clear consciousness, stable condition and pure cerebellar symptoms. Fourth, the physical and medical condition of the recruited patients before stroke might not be identical to that of the normal subjects recruited in the previous study[5]. The patients recruited in this study might have a higher risk of metabolic dysfunction, leading to cerebrovascular insufficiency or changes in connective tissue properties[11]. Our previous study on stroke patients with spasticity showed that the muscle tone on the intact side was higher than that of the normal subjects[3]. Because the muscle tone on the intact side in the patients with cerebellar stroke may be higher than that in the normal subjects, the hypotonia in cerebellar stroke could be relative. This conjecture also echoes the results of this study that only paired comparison between sides showed significant difference, while simple group comparison did not.

Table 2. *Comparison of the parameters on the intact and affected sides*

	Normal [b]	Intact	Affected	*P* [c]
S	4.76 ± 2.14	3.62 ± 2.32	3.50 ± 1.31	0.79
R	1.48 ± 0.19	1.36 ± 0.16	1.45 ± 0.18	0.16
K (N·m·s)	2.47 ± 0.97	3.43 ± 1.23	3.18 ± 1.23	0.13
C (N·m·s/rad) [a]	0.65 ± 0.40	1.11 ± 0.54	0.88 ± 0.40	0.04

a: N·m·s/rad: Newton · meter· second/radiance; b: Data from Lin et al.[4]; c: *P* value of Wilcoxon signed rank test between sides.

CONCLUSIONS

The present study showed that muscle tone, defined as the passive resistance in the tested range, was lower on the affected side than on the intact side in patients with cerebellar stroke. The difference was mainly ascribable to the velocity-dependent component.

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