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Clinical Study

Flexor and extensor muscle tone evaluated using the quantitative pendulum test in stroke and parkinsonian patients

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ABSTRACT

The aim of this study was to evaluate the flexor and extensor muscle tone of the upper limbs in patients with spasticity or rigidity and to investigate the difference in hypertonia between spasticity and rigidity. The two experimental groups consisted of stroke patients and parkinsonian patients. The control group consisted of age and sex-matched normal subjects. Quantitative upper limb pendulum tests starting from both flexed and extended joint positions were conducted. System identification with a simple linear model was performed and model parameters were derived. The differences between the three groups and two starting positions were investigated by these model parameters and tested by two-way analysis of variance. In total, 57 subjects were recruited, including 22 controls, 14 stroke patients and 21 parkinsonian patients. While stiffness coefficient showed no difference among groups, the number of swings, relaxation index and damping coefficient showed changes suggesting significant hypertonia in the two patient groups. There was no difference between these two patient groups. The test starting from the extended position constantly manifested higher muscle tone in all three groups. In conclusion, the hypertonia of parkinsonian and stroke patients could not be differentiated by the modified pendulum test; the elbow extensors showed a higher muscle tone in both control and patient groups; and hypertonia of both parkinsonian and stroke patients is velocity dependent.

1. Introduction

Muscle tone is the passive resistance of muscle and is the collaborative effort of neural control, muscle status and connective tissue properties. More attention has been paid to hypertonia, because it is manifested in common neurological diseases, such as stroke, spinal cord injury and parkinsonism. In clinical practice, hypertonia is evaluated semi-quantitatively using manual tests, which are crude and prone to inter-examiner variability and experience effect [1]. Many quantitative tests, including the electronic pendulum test and mechanical passive stretch, have been developed [2,3].

Hypertonia includes many subtypes, including spasticity, rigidity and catatonia. The differentiation between spasticity and rigidity is clinically essential, because spasticity is caused by lesions of the pyramidal tracts, such as strokes and myelopathies, while rigidity is caused by extrapyramidal etiologies, represented here by parkinsonism [1]. Both stroke and parkinsonism are very common diseases in the elderly. Manually, rigidity is characterized by passive resistance in both agonist and antagonist muscles, while spasticity shows resistance mainly in the anti-gravity muscles, that is, flexor muscles in the upper and extensor in the lower extremity. Most of the quantitative tests can only measure hypertonia and are not able to differentiate spasticity and rigidity.

In previous studies, we developed a quantitative pendulum test for evaluating muscle tone of the elbow joints. The results indicated that the derived parameters could quantify hypertonia in strokes affecting the pyramidal tracts [4] and hypotonia in strokes affecting cerebellar circuits [5]. In these studies, the test started from a flexed elbow position and, therefore, flexor muscles would have larger influence on the testing results. It was reasoned that if the starting point was changed to an extended joint position, the extensor properties could also be evaluated. Therefore, in this study, the pendulum test was performed twice, once with the elbow initially fixed at a flexed position and once with the elbow at an extended position. The main purpose of the present study was to investigate the difference in muscle tone contributed respectively by the elbow flexors and extensors in patients with spasticity and rigidity. We hypothesized that the technique could assist in differentiating spasticity and rigidity.

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2. Methods

2.1. Subjects

Subjects were recruited from the outpatient clinic of National Cheng Kung University Hospital (NCKUH), Taiwan. The diagnosis of stroke and Parkinson's disease (PD) was confirmed initially by both clinical manifestations and imaging studies. The medical and neurological condition of the patients were stable for at least 3 months. We intentionally chose patients without elbow contracture. For the control group, subjects were chosen randomly from our database of normal subjects, matching the age range and sex. Inclusion criteria for the control group included the ability to cooperate. No subject was taking anti-spasticity medication or muscle relaxant at the time of study. The study protocol was approved by the NCKUH Ethics Committee on Human Subject Study. Before an experiment, the purpose, the potential hazards and the procedure of the experiment were fully explained to the subjects. A written permission form was signed. Muscle power according to the Medical Research Council scale and muscle tone according to the Modified Ashworth Scale (MAS) of the elbow joint was evaluated by one of the two neurologists. The body weight, forearm length and maximal forearm circumference were measured for the estimation of mass, center of mass and inertia of the forearm and hand.

2.2. Study design

While the experimental setup was identical to previous studies and is described elsewhere [6], the experimental procedure was modified. In brief, an accessory apparatus was specifically designed to facilitate performing the pendulum test at the elbow joint (Fig. 1). The accessory apparatus was similar to a pendulum in an old-fashioned clock. The subject's wrist was fixed to the upper part of the accessory apparatus. In previous studies, the upper part of the pendulum shaft was hooked to the test bed with a chain of pre-designed length, such that the elbow joint angle was 130° (referencing full extension as 0°). In this position, the test results were more influenced by the flexor muscles. In this study, the pendulum test was performed twice, one identical to the previous design and the other with the initial elbow joint angle set to 50°, that is, the mirror position of the original setting. It was expected that the test results of the latter would better reflect the extensor muscle tone, because the extensor muscle is stretched in the initial stage. The data collection of joint angle through an electro-goniometer was started when the chain was released swiftly without informing the subject. After the swing motion stopped by visual inspection, the data collection was terminated. Six successful trials were collected. The signal from the electro-goniometer were sampled at 600 Hz for 15–25 seconds depending on the duration of swing and stored in a personal computer for off-line analyses. The data collection was accomplished with the package software LabView (National Instruments, Austin, TX, USA).

2.3. Data analyses

In order to quantify the results, several parameters were formulated. The number of swings (S), the number of peaks and troughs during the swing, and the relaxation index (R) defined as the ratio of maximal swing angle to the final steady-state angle, were determined from the averaged angle trajectory [7]. Then, the angle trajectory was also fitted to a biomechanical model of the elbow joint,

$$I\ddot{\theta} = -\tau - K(\theta - \theta_0) - C\dot{\theta}$$

where θ is the elbow joint angle, τ is the gravitational torque, K is the stiffness coefficient/constant of the elbow joint, θ_0 is the threshold angle, and C is the damping coefficient. The desired parameters (K and C) were estimated using a recursive optimization technique. It is worthwhile to note that K is similar to a spring constant, whose strength (or stiffness) is related to tissue properties including mass. A tissue with a larger K is harder to be set into swing but is also harder to be stopped. On the contrary, C is similar to a damper constant. A damper is a device that resists movement proportional to the moving velocity. A higher velocity provokes a larger resistance. A tissue with a larger C is harder to move and tends to stop quickly when set into motion. In brief, K and C are an antagonistic pair and K maintains ongoing states (still or motion) and C reduces moving velocity. The full mathematical model and algorithm about the derivation of C and K from experimental data has been described elsewhere [4].

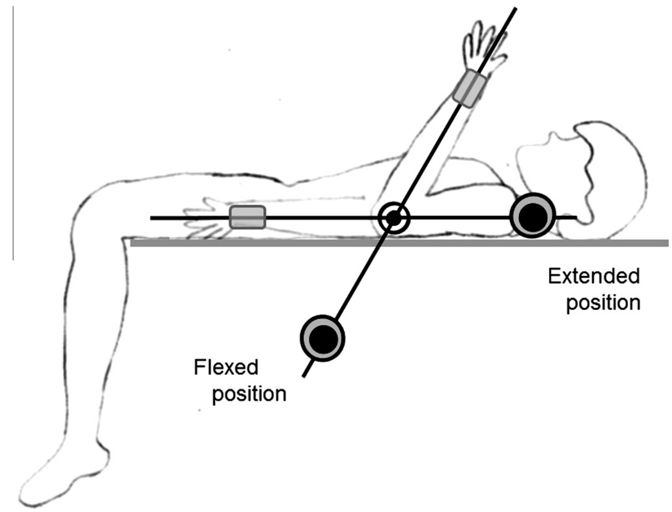

Fig. 1. Schematic drawing of the modified pendulum test for the upper limb. The test was repeated with the starting point from both the flexed and extended elbow positions.

2.4. Statistical analyses

First, we calculated the group means and standard deviations of the four quantitative parameters and tested the significance of difference between the three groups and the two postures by two-way analysis of variance (ANOVA) with a significance level of $p = 0.05$. If there was significant difference among groups, *post hoc* Tukey honest significant difference (HSD) test was used to determine the significance of difference between groups. The Statistical Package for the Social Sciences was used for the above mentioned statistical analyses (IBM, Armonk, NY, USA).

3. Results

Fifty-seven subjects successfully completed the pendulum test, including 22 controls, 21 PD patients and 14 stroke patients (Table 1). Descriptive analyses for S are summarized in Figure 2. Two-way ANOVA using group and posture (flexor and extensor) as the independent variables showed a significant difference ($F_{5,113} = 4.367$, $P = 0.001$) among the subgroups; both group ($P = 0.002$) and posture ($P = 0.018$) were significant variables, and there was no interaction between the two variables ($P = 0.493$). The *post hoc* Tukey HSD test indicated that while control group mean S was significantly larger than the stroke ($P = 0.001$) and PD ($P = 0.045$) groups, there was no significant difference between the means of stroke and PD groups ($P = 0.336$). Pooling all three