Biomechanical Models for Modified Pendulum Test of the Upper Limb

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Abstract

The main goal of this study was to develop and evaluate biomechanical models for interpreting the results of pendulum test of the elbow. Three biomechanical models with different degrees of complexity were proposed. Model 1 consisted of simple spring and damping elements. In model 2, non-linear damping element was added. In model 3, a structure of thixotropic effect was added. By using optimization techniques, we estimated parameters from these models as the candidate indicators of spasticity. In model 1, the estimated stiffness constant and damping coefficient were larger in stroke patients with spasticity. In model 2, though adding a non-linear damping term marginally improved the optimization, the added non-linear damping effect was not more prominent in the stroke patients. In model 3, no unique solution could be obtained. We concluded that, for analyzing the results of upper limb pendulum test, increasing the complexity of models did not increase the capability to differentiate spasticity from normotonus. From the simple linear model, both stiffness constant and damping coefficient were increased in the stroke patients with spasticity.

Keywords: Pendulum test, Spasticity, Elbow, Biomechanical model

Introduction

Though spasticity is a common symptom in spinal cord injury and stroke patients, there was no simple quantitative method to evaluate the severity of spasticity. The commonly used Ashworth scale [1] was a semi-quantitative scale. Pendulum test developed initially by Wartenberg [2] was modified and refined by several researchers and became a quantitative measurement method. These researchers also proposed many different parameters for quantifying the severity of spasticity. The simpler parameters included calculating ratios of peaks and troughs of the angle trajectory [3-5]. More complicated parameters were derived from estimating proprietarily proposed models of the knee joint. The proposed models ranged from linear models [6-7] to more complicated models incorporating physiological details [8-9].

However, the test was only natural for the knees and it was cumbersome to apply the test to the elbows. The main difficulties included the smallness of forearm inertia and the uncomfortable posture. We designed a simple accessory apparatus, which solved both above-mentioned difficulties, to assist performing pendulum test in the upper limbs [10]. Although the evaluation methods developed for lower limbs were good candidates to be transferred to the upper limbs, the properties of knee and elbow joints were not identical and the characteristics of the pendulum test results were not identical. We tried to develop a new model and a new approach for the upper limbs.

The main goal of this study was to develop an appropriate model for analyzing the experimentally derived results. We formulated three biomechanical models with different levels of complexity. The first one was a simple linear additive stiffness-damping model; the second one included a nonlinear velocity-dependent term, representing the effects of velocity-dependent stretch reflex; and the third model incorporated both non-linear position- and velocity-dependent terms for stretch reflex. Model parameters were estimated with the optimization techniques. The advantages and disadvantages among the three models were compared and discussed.

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