

Clinical Usefulness of the Pendulum Test Using a NK Table to Measure the Spasticity of Patients with Brain Lesions

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Abstract. [Purpose] The purpose of the present study was to investigate the clinical usefulness (reliability and validity) of the pendulum test using a Noland-Kuckhoff (NK) table with an attached electrogoniometer to measure the spasticity of patients with brain lesions. [Subjects] The subjects were 31 patients with stroke or traumatic brain injury. [Methods] The intraclass correlation coefficient (ICC) was used to verify the test–retest reliability of spasticity measures obtained using the pendulum test. Pearson’s product correlation coefficient was used to examine the validity of the pendulum test using the amplitude of the patellar tendon reflex (PTR) test, an objective and quantitative measure of spasticity. [Results] The test–retest reliability was high, reflecting a significant correlation between the test and the retest (ICCs = 0.95–0.97). A significant negative correlation was found between the amplitude of the PTR test and the four variables measured in the pendulum test ($r = -0.77$ – -0.85). [Conclusion] The pendulum test using a NK table is an objective measure of spasticity and can be used in the clinical setting in place of more expensive and complicated equipment. Further studies are needed to investigate the therapeutic effect of this method on spasticity.

Key words: NK table, Pendulum test, Spasticity

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INTRODUCTION

Patients with brain lesions such as those associated with stroke and traumatic brain injury often suffer from a permanent disability¹⁾. Although the clinical features of such disabilities are diverse, more than 80% of patients with brain lesions have a motor deficit due to neurological injuries involving the pyramidal and para-pyramidal tracts^{2, 3)}. Significant spasticity occurs in the antigravity muscles of the four extremities of such patients when spastic paralysis replaces flaccid paralysis⁴⁾. Because the mechanisms underlying spasticity have not been clearly identified, a wide variety of definitions of this condition exist⁵⁾. However, the most commonly used definition was developed by Lance⁶⁾, who defined spasticity as “a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes with exaggerated tendon jerks resulting from hyperexcitability of the stretch reflex as one component of the upper motor neuron syndrome”⁷⁾.

Although spasticity provides stability of the lower extremities while standing and walking, and muscle mass and bone marrow density are maintained, its negative effects, such as limiting motion, joint contracture, pain, and muscle spasm, make spasticity the major factor preventing active rehabilitation of patients with brain lesions^{8, 9)}. Thus, therapy to minimize the negative effects of spasticity resulting from brain lesions is of primary concern for physical ther-

apists and clinicians^{10, 11)}. The complexities of the factors underlying spasticity make accurate assessment difficult; however, an objective, quantitative measure of spasticity is essential for the development and validation of an effective treatment regime¹²⁾.

Previous studies have used indirect measures of spasticity such as those addressing global functioning or ability to perform activities of daily living (e.g., the Barthel index), or have used specific motor ability scales such as the Motor Club Assessment¹³⁾. Methods that directly quantify spasticity include the biomechanical approach, which analyzes torque generated during passive or active movement of a joint, electrophysiology, which uses electromyography (EMG) indices such as the H-reflex and F-wave, and the pendulum test^{9, 14)}.

The pendulum test, introduced by Wartenberg, in 1951, involves observing the pendular movement at the knee joint when patients in the sitting position drop their lower leg from a horizontal position¹⁵⁾. Later, Bajd and Vodovnik used an electrogoniometer to quantitatively measure spasticity in the pendulum test¹⁶⁾. The instruments used to quantify vibration in the knee joint as the leg drops in the pendulum test include an electrogoniometer, video recorder, and isokinetic dynamometer. Each instrument has disadvantages. Video recording requires expensive equipment and special facilities, and it is time consuming to perform. The design of the isokinetic dynamometer may hinder free movement of the knee joint, and the leg support frame, which limits excessive knee flexion, may not allow sufficient flexion

in the pendulum movement. Finally, because the electrogoniometer is attached directly to the knee joint, it may yield varying results due to spatial twist, depending on the change in its position¹⁷⁾.

We developed a pendulum test that uses the Noland–Kuckhoff (NK) table with an electrogoniometer attached to a table leg, which overcomes the disadvantages of other tests. The clinical usefulness of this device has not been investigated; thus, the purpose of the present study was to test the reliability and validity of the pendulum test using a NK table with an attached electrogoniometer in quantitatively measuring the spasticity of patients with brain lesions.

SUBJECTS AND METHODS

Subjects

The research subjects were 31 patients diagnosed with a stroke or traumatic brain injury at a University Hospital in Korea. The subjects understood the study procedure and provided their written informed consent prior to participation. The Local Research Ethics Committee of Yonsei University approved the study and measurement protocol.

The inclusion criteria were: absence of musculoskeletal disability, such as knee osteoarthritis or knee joint contracture; a rectus femoris muscle spasticity score above grade 1 according to the Modified Ashworth Scale (MAS); stable spasticity for at least 6 months; sufficient cognitive function to understand instructions; and not taking medication directly influencing spasticity. Initially, 38 subjects were enrolled; however, seven subjects were excluded from the data analysis because five were diagnosed with severe osteoarthritis of the knee joint, and two were unable to understand the researchers' instructions because of cognitive deficit.

Methods

The NK table is a therapeutic exercise device developed to strengthen various muscles of the lower extremity through concentric, eccentric, and isometric contraction training. The NK table consists of a seat, a back rest for leaning comfortably, a lower-leg support frame, a weight-hanging frame, and an axis connecting the two frames at a variety of angles. To allow free pendulum movement at the knee joint, the pendulum test was conducted with the proximal thigh fixed so as not to move, and the distal calf attached to the lower-leg support frame for performance of the pendulum movement. A molded plastic frame, made from a lightweight material to minimize interference with the test, was attached between the calf and the lower-leg support frame.

An electrogoniometer (Autogon II, J Tech Inc. Torrance, CA, USA) was attached to the NK table to measure real-time angular variation in the knee joint during the pendulum test. The fulcrum of the electrogoniometer was synchronized to the axis of the NK table. The moving arm of the electrogoniometer was set to match the lower-leg support frame of the NK table, and the fixed arm was vertically attached to the moving arm at 90° so that angle changes were measured according to the movement of the lower-leg supporting frame. Measurements taken during the pendu-

lum test of four variables yielded the following data: the relaxation index (RI), the ratio between the amplitude of the first swing angle and the difference between starting and resting angles; the number of oscillations (NO), the number of sinusoidal waves evoked by the swinging leg; the duration of oscillation (DO), the duration of the pendulum swing from start to stop of the lower-leg swing movements; and the first-swing excursion angle (FSEA), the difference between the angle at the start and the maximum angle of the initial downward swing.

The amplitude in the patellar tendon reflex (PTR) test, frequently used in the electrophysiological evaluation of spasticity, was used to verify the validity of the spasticity measures produced by the pendulum test using the NK table. An electric reflex hammer (Medelec Corp., Germany) was used for the PTR test, and a surface electrode was attached to the spastic rectus femoris muscle. AE-131 circular surface electromyography (EMG) electrodes (NeuroDyne Medical Corp., MA, USA) were used to measure EMG signals. The electrodes were arranged in an equilateral triangular pattern in which the center-to-center distance of the three round 12-mm-diameter metal discs was 20 mm. A MP150 data-acquisition system (Biopac System Inc., Santa Barbara, CA, USA) was used to process EMG amplitude signals during the PTR test. The MP150 system is a multifunctional biometric device that analyzes analog signals such as those in EMG, electrocardiography, nerve conduction velocity, and the angle of human joint motion¹⁸⁾. Rectus femoris muscle spasticity of all the subjects with brain lesions was evaluated using a modified version of the Ashworth scale¹⁹⁾. This instrument uses a five-point rating scale (0 indicates "no increase in muscle tone" and 4 indicates "rigid in flexion or extension") to measure muscle tone, and it is the most common clinical rating scale used for the assessment of spasticity.

After the patient was seated and her/his calf was fastened to the lower-leg support frame of the NK table, the pendulum test was conducted using the method developed by Bajd and Vodovnik²⁰⁾. A 0.4-kg molded plastic frame was designed to guide the pendulum motion in a two-dimensional plane and to fit the joint axis. Changes in the angle during the pendulum motion were recorded and analyzed using the MP150 system. The electrical signals from the electrogoniometer were converted into angles using the MP150 system. The electrical signals generated by the electrogoniometer were 0.7995 V at 90° and 1.315 V at 180°. The RI, defined as the ratio between the amplitude of the first swing and the difference between the starting and resting angle, was used to measure spasticity during the pendulum test. The RI was measured 10 times at 30-s intervals in each trial. The normal RI rating is ≥ 1.6 and an RI < 1 is considered to indicate severe spasticity¹⁶⁾. The PTR test was performed using the method developed by Kuruoglu and Oh²⁰⁾. After the patient was seated on the NK table with the knee joint flexed at 90°, a surface electrode was attached to the skin at the center of the spastic rectus femoris muscle on the line connecting the anterior superior iliac spine and the patellar superior border, and the reference electrode was placed on the patellar superior border. The test was conducted by tapping the quadriceps tendon with an electric reflex hammer and

recording the compound muscle action potentials 10 times, with 10-s intervals between taps to avoid habituation. The maximal amplitude of 10 compound muscle potentials was selected for the latency and amplitude values²⁰. Amplitude was defined as the peak-to-peak voltage difference between two positive and negative EMG signals.

The intraclass correlation coefficient (ICC) was used to verify the test–retest reliability of spasticity measures during the pendulum test using the NK table. Pearson's product correlation coefficient was used to determine the validity of the spasticity measures using the amplitude of the PTR

test. The Statistical Package for the Social Sciences version 20.0 (SPSS Inc., Chicago, IL, USA) was used to conduct the statistical tests. *p* values <0.05 were deemed statistically significant.

RESULTS

Of the 31 subjects, 21 (67.7%) males and 10 (32.3%) females, 23 (74.2%) were diagnosed as having stroke and eight (25.8%) were diagnosed as having traumatic brain injury. Most patients showed mild to moderate spasticity: 14 (45.2%) patients were assessed as having a MAS grade of 1, and 10 (32.3%) were assessed as having a MAS grade of 1+. The subjects' general and medical characteristics are presented in Table 1.

Although previous studies have found the pendulum test to be a reliable measurement of spasticity for patients with brain lesions, it was necessary to verify the reliability and clinical usefulness of the novel pendulum test method used in the present study. The intra-rater reliability of the spasticity measurements was determined by testing a subset of 25 subjects on two occasions separated by 5 days. We found no difference in the spasticity measurements taken on the 2 days, and the intrarater ICC values ranged from 0.95 to 0.97 (*p*<0.05). Thus, the spasticity measurements made using the pendulum test with the NK table showed a high degree of reliability (Table 2). The spasticity measurements (means \pm SD) taken in the pendulum and the PTR tests are shown in Table 3.

We found a significant negative correlation between the amplitude of the PTR and each variable measured in the pendulum test (DO: *r*=−0.78, *p*<0.01; NO: *r*=−0.78, *p*<0.01; FSEA: *r*=−0.85, *p*<0.01; and RI: *r*=−0.84, *p*<0.01; Table 4).

Table 1. Descriptive characteristics of the participants (n=31)

Characteristics	n (%)
Sex	
Male	21 (67.7)
Female	10 (32.3)
Paralysis	
Right	11 (35.5)
Left	15 (48.4)
Both	5 (16.1)
Causes of injury	
Stroke	23 (74.2)
TBI	8 (25.8)
MAS	
Grade 1	14 (45.2)
Grade 1+	10 (32.3)
Grade 2	6 (19.3)
Grade 3	1 (3.2)
Age (yrs)	61.2 \pm 11.6*
Period of illness (mon)	24.7 \pm 9.4*

TBI, traumatic brain injury; MAS, modified Ashworth scale

*mean \pm SD

Table 2. Test-retest reliability of spasticity measures of the pendulum test using a NK table (n=46)

Spasticity measures	First test		Second test		ICC (2,1)	95%CI
	Mean \pm SD	Range	Mean \pm SD	Range		
DO (sec)	5.0 \pm 1.4	2.3–6.7	5.1 \pm 1.2	2.4–6.7	0.96	0.93–0.99
NO (no)	10.0 \pm 2.5	6.0–14.0	9.9 \pm 2.1	6.0–14.0	0.95	0.89–0.98
FSEA (°)	94.3 \pm 21.4	51.2–120.3	93.6 \pm 20.2	58.6–114.8	0.97	0.94–0.99
RI	1.9 \pm 0.2	0.8–1.5	1.2 \pm 0.2	0.9–1.4	0.97	0.93–0.99

DO, duration of oscillation; NO, number of oscillation; FSEA, first swing excursion angle; RI, relaxation index; SD, standard deviation; ICC, intraclass correlation coefficient; NK, Noland Kuckhoff; CI, confidence interval

Table 3. Spasticity measures of the pendulum test and the patellar tendon reflex test (n=31)

Spasticity measures	Mean \pm SD
Pendulum test	
DO (sec)	4.97 \pm 1.36
NO (no)	10.03 \pm 2.42
FSEA (°)	94.10 \pm 20.96
RI	1.18 \pm 0.17
PTR test	
Amp (mV)	0.82 \pm 0.30

DO, duration of oscillation; NO, number of oscillation; FSEA, first swing excursion angle; RI, relaxation index; Amp, amplitude; PTR, patellar tendon reflex; SD, standard deviation

Table 4. Correlations of the spasticity measures of the pendulum test and the patellar tendon reflex test (n=31)

Variables	NO	FSEA	RI	Amp
DO	0.91*	0.84*	0.89*	−0.77*
NO		0.81*	0.87*	−0.78*
FSEA			0.93*	−0.85*
RI				−0.84*

DO, duration of oscillation; NO, number of oscillation; FSEA, first swing excursion angle; RI, relaxation index; Amp, amplitude

**p*<0.01

Significant positive correlations were found among the four measures of the pendulum test ($p < 0.01$; Table 4).

DISCUSSION

The muscle stretch used to assess spasticity can be quantified physiologically using the pendulum test or the tendon reflex test. A previous study of the stretch reflex measured tonic and phasic properties using the pendulum test and the tendon reflex test, respectively²². The pendulum test can be performed using an electrical goniometer, video recorder, or an isokinetic dynamometer²³. Each of these techniques has certain limitations. The electrogoniometer is attached directly over the knee joint; however, proper placement is difficult, and results may vary according to the attachment technique and position. Techniques relying on a video recorder or isokinetic dynamometer require expensive equipment, specialized facilities, and are time-consuming and costly. To overcome these disadvantages, the present study performed the pendulum test using a NK table with an electrogoniometer attached directly to the table frame rather than to subjects' knees.

The results show that this novel method has high test–retest reliability (ICCs=0.95–0.97; $p < 0.01$). A previous study investigating the reliability of the pendulum test with 30 brain lesion patients showed high inter-tester reliability using a Cybex II Dynamometer (ICCs=0.96)²⁴. Furthermore, a study using the three-dimensional pendulum test with 10 cerebral palsy patients reported high test–retest reliability (ICCs=0.98)²⁵. Although our experimental equipment and subjects differed from those of the previous studies, the high test–retest reliability found in this study is consistent with those of previous studies, indicating that the pendulum test using the NK table to quantify spasticity is a reliable method for the evaluation of the spasticity of patients with brain lesions.

The PTR test is an objective measure of spasticity, and the present experiment used the PTR test with EMG recording to verify the validity of the pendulum test using the NK table. The results show a significant negative correlation between the amplitude of the PTR test and the four indices of spasticity measured in the pendulum test ($r = -0.77$ – -0.84 ; $p < 0.01$). According to the definition of spasticity, increased amplitude in the deep tendon reflex and stretch reflex indicates an increase in spasticity. Alternatively, when relaxation occurs as a result of decreased spasticity, the amplitude of the PTR test diminishes, and the value of the four variables measured by the pendulum test increases. The significant negative correlation between amplitude and the four variables measured, on the one hand, and the results of the pendulum test, on the other, indicates that the four indices of spasticity measured in the present study using the pendulum test with a NK table provide a valid evaluation of spasticity. Of the four measures, FSEA and RI showed the highest negative correlation with amplitude (amplitude and FSEA, $r = -0.85$; amplitude and RI, $r = -0.84$), possibly because RI sensitively reflects the degree of spasticity as a limitation of knee-joint movement. Several previous studies have used RI to evaluate spasticity. RI ≥ 1.6 indicates

normal relaxation, whereas RI < 1 indicates severe spasticity²¹. The mean RI in the present study was 1.18 ± 0.17 , indicating that the spasticity of our patients was moderate; this may be related to the fact that the MAS grade of most of our subjects was 1 or 1+. We were not able to use the results of previous studies to verify the validity of our method because they are not directly comparable; however, Smith et al.²⁶ used the pendulum test with an electrogoniometer to measure passive angular movement of the joints of 22 patients with spinal cord injuries and reported a significant correlation ($r = 0.64$; $p < 0.05$), which is consistent with the results of the present study.

Similar to the results of previous studies^{12, 23}, I found a significant correlation among the variables measured using the pendulum test. In particular, the correlation between FSEA and RI ($r = 0.93$; $p < 0.01$) was the highest among the variables measured, possibly because FSEA is a component of the RI formula. In contrast to our results, previous studies have reported that NO is not a valid measurement of spasticity in the pendulum test. This difference may be attributable to the fact that the mechanical axis in previous studies was not aligned with the anatomical axis of the knee joint; thus, free pendular movement was limited²⁷. NO is an objective measure of spasticity in the pendulum test when these limiting factors are controlled for, as in the present study. Because repeated trials of the pendulum test may affect relaxation status, the inter-test interval was more than 30 s to reduce measurement error attributable to a carry-over effect.

The present study demonstrated that the pendulum test using a NK table is a simple and safe method of objectively quantifying spasticity and can be readily used in a clinical setting. However, the present study had several limitations. First, the study population was limited to adult patients with brain lesions owing to the difficulty of finding suitable patients with spasticity accompanying an upper motor neuron syndrome, such as cerebral palsy or spinal cord injury. Second, we were not able to conduct a sufficient number of relaxation checks on the spastic muscles via electromyography; thus, tests of spasticity relied on verbal requests to relax. Additional studies that incorporate sufficient relaxation checks via EMG and a wider variety of patients, including those with cerebral palsy and spinal cord injuries, are needed to verify the reliability and validity of the pendulum test using a NK table, and to investigate its therapeutic effect on spasticity.

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