Multiple measurements by a pendulum test improve the spasticity assessment in SCI subjects

Nikola Babić, Radoje Čobeljić, Slađana Kostić-Smith, Lana Popović-Maneski

***Abstract*— We present the variability of the spasticity scores during three consecutive days using the case series clinical study data with spinal cord injured (SCI) subjects. We assessed the spasticity by the Pendulum Test (PT) and Ashworth Scale (AS) scores. We measured the spasticity on the three consecutive days before and after the period of the treatment. Three subjects with SCI participated in the study. We found large variability from day to day. The PT score had more significant variability compared with the AS. The results suggest that the three consecutive testing by using the pendulum test and PT score on different days provide a better assessment of spasticity being essential in evaluating the treatment protocol.**

***Index Terms*— Spasticity assessment; Pendulum test; PT score; Ashworth Scale; Spinal cord injury.**

I. Introduction

UPPER motor neuron lesions lead to hypertonia resulting in paralysis/paresis of extremities [1]. Spasticity caused by a spinal cord injury (SCI) affects the quality of life of subjects with paralysis. Since neurological recovery is a long process, precise information on spasticity changes could assist in selecting the optimal treatment procedures. A research study that included 110 subjects after SCI shows a significant role in the severity of spasticity of the quality of life when using the Quality of life scores [2].

The validated, most often used methods for assessing the severity of spasticity use the Ashworth scale (AS) and modified Ashworth scale (MAS). AS and MAS score the reaction of manipulating the segment of the body that stretches the muscles responsible for the flexion and extension of the specific joint analyzed. The reaction is assessed physically by the examiner. The fact that the score reflects the examiners' perception of paralyzed muscles' involuntary response makes it inter-rater dependent; therefore, subjective.

The pendulum test (PT) was introduced to get an objective measure of the severity of spasticity. In the PT, the examiner stretches the muscles to bring the body segment into the position where gravity will cause the pendulum-like movement when the examiner lets the body segment free. The PT is convenient for the knee and elbow joints. The PT was used in the severity of spasticity scoring in subjects with spinal cord injuries [3, 4]; cerebral palsy [5, 6]; cerebrovascular insults [3, 7]; and sclerosis multiplex [8].

The PT increases the precision, objectivity, reliability, and validity of the spasticity measures [8]. The essential fact is that spasticity varies; hence, even the quantified PT gives results that change with repetitions and change from one to the next assessment session. We decided to analyze the variability of AS and PT scores by determining those in three consecutive days.

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II. Methods and Materials

A. Subjects

The inclusion criteria for entering the study were complete or incomplete SCI above Th12 level (American Spinal Cord Injuries Association (ASIA) A and B), no other trauma or neurological diseases, and the ability to follow the test protocol.

The Ethics Committee of the Clinic for Rehabilitation "Dr. Miroslav Zotović," Belgrade, Serbia, approved a protocol prepared along with the Helsinki declaration. All participants signed the informed consent before entering the study. The basic demography of participants in the study is in Table 1.

TABLE I
BASIC DATA FOR THE SUBJECTS

Subject N^{o}	ASIA	SCI lesion (motor/sensory)
1	A	Th6/Th6
2	B	C6/Th10
3	A	Th8/Th8

B. Instrumentation

We used an instrument that consists of two units fixed at the thigh and shank. Each unit has the inertial measurement unit (IMU) measuring the acceleration and angular rate of the thigh and shank. The unit at the thigh has a two-channel electromyography (EMG) amplifier system connected to surface electrodes over the knee extensors (Quadriceps m.) and knee flexors (Hamstrings m.) (https://www.3-x-f.com/products.html#121) The reference electrode was placed at the bony part in the vicinity of the knee joint.

C. Protocol

The experienced examiner (one of the authors of this paper) assessed both legs' flexion and extension spasticity by applying the Ashworth scale (AS). After the AS assessment, the physiatrist performed the pendulum test, and the computer calculated the PT score.

All tests were done before the intake of medications for the reduction of spasticity.

The subject's position was between the lying and sitting position, with the shanks hanging over the table edge. Hips angles were set to about $3\pi/4$ degrees in all tests. The pelvis and the thighs were fixed with tape to the table. The clinician extended the knee joint to bring the shank to the horizontal position (full knee extension) and let the shank swing about the knee joint caused only by gravity force. The oscillations stopped in less than 15 seconds in all subjects.

IMUs and EMG signals were simultaneously recorded during the pendulum-like movements until the lower leg stopped swinging. The EMG recordings allow the analysis of the timing and strength of spastic reflexive contractions of the paralyzed knee extensors and flexors. The kinematics recordings were used to calculate the PT score [7]. The pendulum measurements were repeated three times at approximately 15-second intervals. The AS and pendulum tests were repeated on three consecutive days.

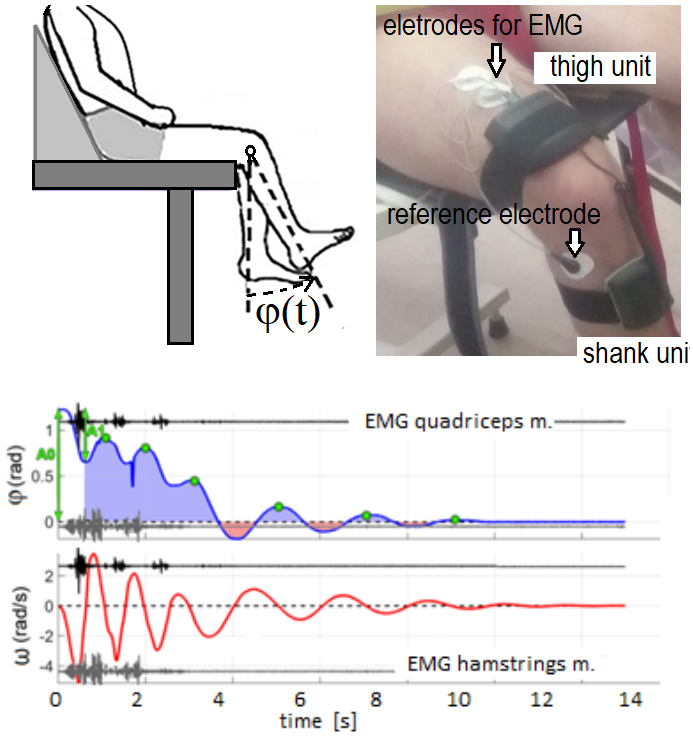

Fig. 1. The setup for the pendulum test with EMG recordings electrodes (upper panel). An example of signals estimated from the recordings: goniogram, tachogram, and the recorded EMG signals (bottom panel).

Fig. 1 shows the knee joint φ(t) and the shank angular rate ω(t) during the pendulum test. The resting position of the shank was vertical (φ = 0). The starting position of the shank in the pendulum test was horizontal (φ = π/2). The blue areas show intervals when the knee joint angle was positive (φ ≥ 0), and the red areas show the intervals when the knee joint was negative (φ < 0). The φ(t) and ω(t) recordings show apparent asymmetry, more precisely, the knee angle is mostly above zero, and there is a significant change in the frequency of oscillations.

EMG signals from the knee extensors (black) and flexors (grey) are shown above and below the goniogram and the tachogram. Fig. 1 shows that the spastic EMG activity stops much before the shank stops oscillating.

The PT score was calculated using the formula defined in Popović Maneski et al. [4]:

$$PT_i = \left|\frac{\left(\bar{R}_{2n_i} - \hat{R}_{2n_H}\right)}{7*\hat{R}_{2n_H}}\right| + \left|\frac{(\bar{N}_i - \hat{N}_H)}{7*\hat{N}_H}\right| + \left|\frac{(\bar{\varphi}_i - \hat{\varphi}_H)}{7*\hat{\varphi}_H}\right| + \left|\frac{\left(\bar{\omega}_{max_i} - \hat{\omega}_{max_H}\right)}{7*\hat{\omega}_{max_H}}\right| + \left|\frac{\left(\bar{\omega}_{min_i} - \hat{\omega}_{min_H}\right)}{7*\hat{\omega}_{min_H}}\right| + \left|\frac{(\bar{f}_i - \hat{f}_H)}{7*\hat{f}_H}\right| + \left|\frac{\left(\left|\frac{\overline{P^+ - P^-}}{P_{total}}\right|_i - \left|\frac{\widehat{P^+ - P^-}}{P_{total}}\right|_H\right)}{7*100}\right| \quad (1)$$

The index H is used for the values of healthy subjects. "i" denotes a subject N°, $\bar{}$ represents a mean value of three trials in the same subject, and ^ represents the mean value for the whole population (i.e., H group population). To normalize PT, each member in the equation is divided by the total number of parameters used to calculate PT (i.e., seven parameters). N is the number of oscillations, $R_{2n} = A_1/1.6A_0$ relaxation index, φ and ω are the knee joint angle and angular rate of the shank, f frequency of oscillations, $P+$ and $P-$ positive and negative area between the knee joint and the neutral value (φ=0), respectively.

III. Results and Discussions

From day to day, we found significant differences in the PT scores. Goniograms with the most significant differences found in the three days of testing are presented (Fig. 2).

Fig. 3 shows the PT and AS scores for three participants in the study for the left and right leg.

The bars indicate that PT scores were different on three subsequent days, while the AS showed more negligible, and in some cases, no variation. We found no rule related to the variability of the PT scores, but this is most likely because the sample of only three subjects is too small. The possible answer will come after a planned randomized clinical study where the statistics are meaningful, and the comparison can be made before and after the treatment.

Figure 4 shows the variability of the results for the measurements on three consecutive days. Although the standard deviation for the left leg in the first and the right in the second day is close to the mean, compared to overall, the data dispersion in the PT scores indicates a higher level of the test sensibility comparing to the AS.

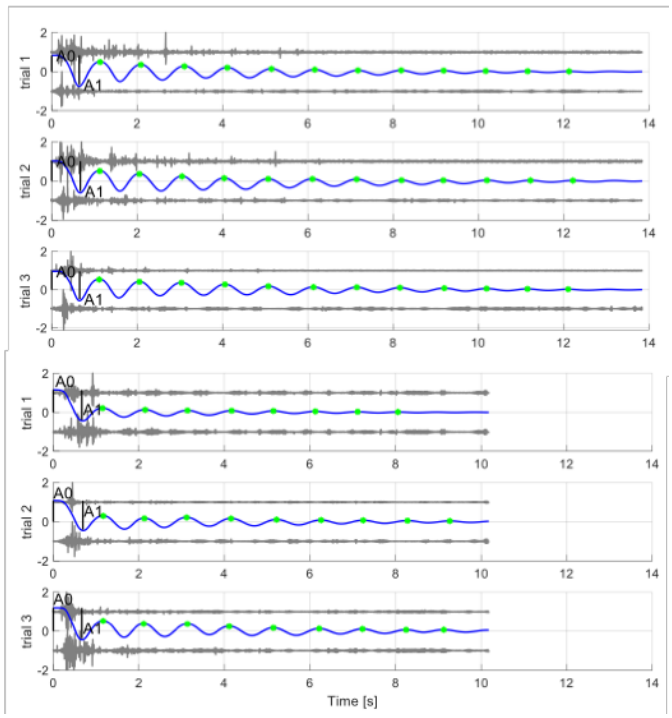

Fig. 2. Goniogram for Subject 1 recorded during the pendulum (right leg). The top three traces are three repetitions during the 1st day, and the bottom three traces are the repetitions on the 2nd day.

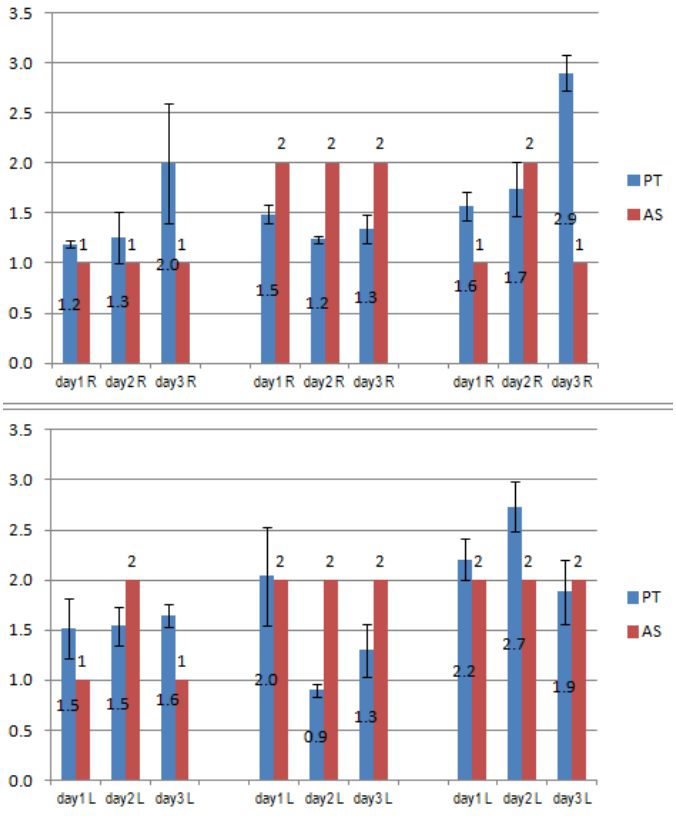

Fig. 3. The PT scores and AS for the right leg (top panel) left and the left leg (bottom panel) for three subjects on three subsequent days.

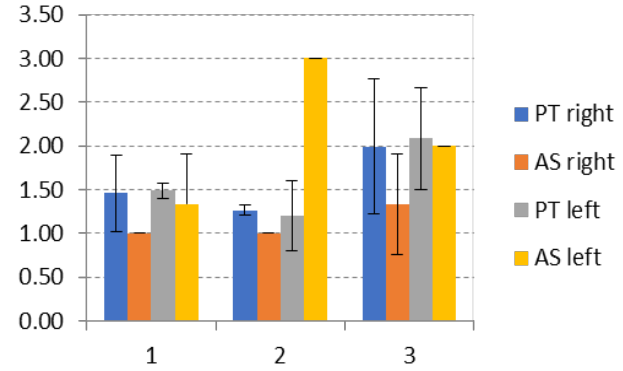

Fig.4. Variability of the PT and AS scores were measured on three consecutive days. The bars show the average score on each day, and the lines are standard deviations.

The size of the study made us present the results by using the means and standard deviations instead of the box-plot presentation.

IV. Conclusion

This case series confirms that precisely detected variability of the spasticity is to be considered in assessing achievements in the rehabilitation progress. Although the variability of the assessment was seen with the Ashworth scale, the precision obtained by the PT score shows that the three consecutive testings on different days are meaningful for the better judgment of spasticity. PT score obtained this way gives precise insight into the spasticity variability, which enables the detection of improvements or deterioration of the subject's condition, thus the nature and extent of effects of a different way of the treatment of spasticity in SCI subjects. The Covid19 pandemic made impossible the inclusion of a more significant number of subjects in the sample and the implementation and evaluation of FES-assisted biking. The findings presented in this paper calls for a more extensive randomized clinical study to be validated.

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