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Usefulness of the Tendon Reflex for Assessing Spasticity After Botulinum Toxin-A Injection in Children With Cerebral Palsy

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Abstract

This study sought to investigate the relationships between clinical and neurophysiologic assessments of spasticity after injection of botulinum toxin-A in children with cerebral palsy. A total of 40 children were recruited. Clinical assessments included the modified Ashworth scale and modified Tardieu scale parameters R1, R2, and D. Neurophysiologic assessment included compound motor action potential, Hoffmann, and tendon reflex. Children showed significant decreases in modified Ashworth scale, R1, and R2 at 2, 4, and 12 weeks and in D at 2 and 4 weeks. Amplitude of compound motor action potential decreased at 2 weeks, Hoffmann reflex amplitude decreased at 4 weeks, and tendon reflex amplitude decreased at 2 and 4 weeks. At 12 weeks, none of the neurophysiologic parameters differed from baseline. The correlations among R2, D, and the amplitude of tendon reflex were significant. Neurophysiologic tests could be used to evaluate reduced spasticity after botulinum toxin-A injection. The amplitude of tendon reflex showed the highest correlation with severity of spasticity.

Keywords

cerebral palsy, spasticity, botulinum toxin type A

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Spasticity is a component of upper motor neuron syndrome that is characterized by a velocity dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks. It has been thought to result from the hyperexcitability of the stretching reflex and can often interfere with mobility, positioning, and self-care in children with cerebral palsy.[1] Botulinum toxin-A has become increasingly utilized in the management of focal spasticity in children with cerebral palsy. Intramuscular injection of botulinum toxin-A inhibits the release of acetylcholine at the neuromuscular junction, resulting in a temporary and reversible reduction in excessive muscle activity and is believed to decrease the spasticity by affecting the fusimotor system.[2,3]

To date, outcome measures for reduced spasticity after injection of botulinum toxin-A have focused on the body structure and function domains of the International Classification of Functioning, Disability and Health and have used various clinical scales, neurophysiologic measurements, and methods of gait analysis.[4-6] Clinical assessments commonly used to measure spasticity include active range of motion, the modified Ashworth scale and the modified Tardieu scale. Neurophysiologic methods include the compound motor action potential, Hoffman reflex, and tendon reflex.[7,8] Clinical and neurophysiologic assessments of spasticity, however, may show discrepancies. Clinical assessments are related not only to the neural component of spasticity but also biomechanical factors such as soft tissue compliance and joint integrity. In contrast, neurophysiologic assessments are concerned solely with the neural component. Moreover, since each type of neurophysiologic assessment measures different pathways involved in spasticity, the relationship of each with clinical parameters may differ. In particular, the tendon reflex involves not only α-motoneuron excitability but also fusimotor system, making this parameter possibly more sensitive to spasticity.[8] Therefore, it is important to establish relationships between these 2 categories of outcome measures for correct application

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in the clinic; however, there have been just a few studies and no studies after botulinum toxin-A injection, until now. We have therefore investigated the relationships between clinical and neurophysiologic assessments of spasticity after injection of botulinum toxin-A into children with spastic cerebral palsy.

Methods

Subjects

A total of 40 children aged 2-18 years with spastic unilateral/bilateral type cerebral palsy were prospectively recruited from the outpatient clinic of the Department of Physical Medicine and Rehabilitation (Table 1). The children with more than spasticity of modified Ashworth scale 1 and spastic equinus foot deformity were recruited for our study. Patients were excluded if they had undergone surgery, serial casting, or botulinum toxin-A injection within 6 months before enrollment. Because their medical conditions could affect previous level of spasticity, 2 patients who failed to attend the 12-week follow-up assessment were not included in the analysis. The study was approved by our Institutional Research Review Board, and the children and their parents provided informed consent.

Table 1. General Characteristics of the Study Population

Variable		
Age (y)		5.5 ± 2.4 (2-14)
Gender		
	Male	26 (65)
	Female	14 (35)
Distribution		
	Unilateral	15 (37.5)
	Bilateral	25 (62.5)
Injected legs		65
GMFCS level		
	I	17 (42.5)
	II	4 (10.0)
	III	2 (5.0)
	IV	4 (10.0)
	V	13 (32.5)

Abbreviation: GMFCS, Gross Motor Function System. Age is reported as mean ± standard deviation (range); all other values are reported as number (percentage) of patients.

Injection Technique

All injections were performed by one experienced pediatric physiatrist. Each child was sedated by administering chloral hydrate orally (0.5 mL/kg, 100 mg/mL), followed by topical application of lidocaine cream to the injection site 1 hour before the procedure. Anatomic landmarks were utilized to determine standard injection sites.[9] Botulinum toxin-A (200 UI diluted in 2 mL of 0.9% sodium chloride, normal saline; Meditoxin) was obtained from Medytox, Ochang-eup, Cheongwongun, Chungcheongbuk-do, Korea, and 4 UI/kg body weight botulinum toxin-A was injected into the gastrocnemius of each child at 4 to 6 points. Meditoxin average dose for cerebral palsy is 4 UI/kg body weight for unilateral and 6 UI/kg for bilateral cerebral palsy. The single dose should not exceed 200 UI in both children and adults. One unit of Meditoxin corresponds to the calculated median intraperitoneal lethal dose (LD 50) in mice and pH is 6.3-7.3. All children were injected into only gastrocnemius with the same 4 UI/kg body weight botulinum toxin-A per leg.

Outcome Measures

Clinical and neurophysiologic assessments were performed by another pediatric physiatrist, an American board certified physician of electrodiagnostic medicine, before injection and at 2, 4, and 12 weeks after injection.

Clinical assessments included modified Ashworth scale[10] and modified Tardieu scale.[11] The scoring of modified Ashworth scale was changed to 1, 2, 3, 4 and 5 (0 = *no increase in muscle tone*, 5 = *limb rigid in ankle dorsiflexion*) for statistical analysis. All clinical assessments were performed with the patient in the supine position with the knee flexed to 90° and fully extended. Dynamic ankle range of motion and passive range of motion were measured by modified Tardieu scale with a manual goniometer. The ankle was dorsiflexed as fast as possible, and the catch angle at which the stretch reflex started or the point angle at which a clonus felt was designated R1. The ankle was dorsiflexed as slow as possible, the angle of full passive range of motion was designated R2, and R1 minus R2 was designated D (dynamic range).[12] The fulcrum was aligned with the lateral malleolus. The stationary arm was in line with the midline of the lower leg, using the head of the fibula for reference. The moving arm was parallel to the fifth metatarsal. We checked the angle between the stationary and moving arm, and the angle of the neutral ankle joint was defined as 90°.

Neurophysiologic assessment included compound motor action potential, Hoffman reflex, tendon, reflex and Hoffman reflex$_{max}$ amplitude/compound motor action potential$_{max}$ amplitude ratio and was performed through the 5-channel electromyography equipment (Medelec synergy, VIASYS Healthcare, Surrey, UK) with anti-aliasing filtering in the 20 Hz to 10 000 Hz band. All neurophysiologic assessments were measured while the children were in an alert state and their head was the neutral position. All parameters were recorded over the most prominent belly of medial gastrocnemius muscle, and we measured the recording point from popliteal line to assure the same location when the children would be followed up. Disposable 4-disc electrodes with leads (VIASYS Healthcare 019-400400) were used for active and reference electrode. We controlled the skin temperature greater than 32°C and used the disposable alcohol cottons for the skin preparation. Disposable ground plate electrode with lead (VIASYS Healthcare 019-400500) was applied proximal to the recording sites and reference electrode distal to the Achilles tendon. Compound motor action potential was obtained via supramaximal stimulation with 0.1 ms simulation and Hoffman reflex was obtained via submaximal stimulation with 0.5 ms simulation of the tibial nerve at the popliteal fossa in the prone position with knee fully extended (Deluex Bipolar Stimulator, VIASYS Healthcare 031K074). The stimulus intensity was increased by 1 or 2 mA of the current to obtain the largest compound motor action potential (from 20 mA of the current) and Hoffman reflex (from 0 mA of the current). Tendon reflex was obtained via a tendon hammer (Tendon Hammer–synergy, VIASYS Healthcare 084C001) connected to electrodiagnostic machine, and maximal amplitude was obtained through 10 stimulations of the Achilles tendon in the prone position with knee flexed to 90°. The tendon was tapped manually at constant strength, and there was an irregular pause of more than 30 seconds between stimulations to avoid habituation. We collected the tendon reflex that showed a constant latency and removed the tendon reflex that showed a shorter latency induced by muscle background activity. All neurophysiologic assessments were performed

Table 2. Results of clinical assessment.

	Preinjection	2 Weeks	4 Weeks	12 Weeks
KE MAS	2.9 ± 0.9	2.5 ± 1.0**	2.3 ± 1.1**	2.3 ± 0.9**
KF MAS	2.5 ± 0.9	2.0 ± 0.9**	1.7 ± 0.9**	2.0 ± 1.0**
KE R1	106.3 ± 14.0	96.7 ± 15.0**	93.3 ± 18.7**	96.8 ± 14.3**
KE R2	81.6 ± 15.3	76.0 ± 14.6**	75.2 ± 14.4**	75.2 ± 16.0**
KE D	24.6 ± 13.2	20.9 ± 12.1*	19.5 ± 8.8**	21.9 ± 11.6
KF R1	93.6 ± 13.2	85.3 ± 17.7**	84.9 ± 15.9**	86.8 ± 16.9**
KF R2	69.8 ± 15.9	65.0 ± 17.1**	65.4 ± 15.4**	65.4 ± 16.6**
KF D	24.5 ± 12.8	20.5 ± 10.2*	19.3 ± 10.5**	22.3 ± 12.6
P	55.6 ± 10.2	56.2 ± 9.8	56.2 ± 9.8	56.3 ± 9.0

Abbreviations: KE, knee extension; KF, knee flexion; MAS, modified Ashworth scale; P, plantarflexion. Values are mean ± standard deviation. The ankle was dorsiflexed as fast as possible, and the catch angle at which the stretch reflex started was designated R1. The ankle was dorsiflexed as slow as possible, the angle of full passive range of motion was designated R2, and R1 minus R2 was designated D (dynamic range). The angle of the neutral ankle joint was defined 90°. If the ankle was dorsiflexed than the neutral, then the angle got toward 0° and plantarflexion was toward 180°.
*$P < .05$, significant difference between preinjection and postinjection. **$P < .01$, significant difference between preinjection and postinjection.

Table 3. Results of Neurophysiologic Assessment

	Preinjection	2 Weeks	4 Weeks	12 Weeks
C-lat.	2.27 ± 0.36	2.52 ± 0.63*	2.56 ± 0.66**	2.29 ± 0.40
C-amp.	12.45 ± 4.52	9.41 ± 4.39**	10.80 ± 12.01	11.42 ± 4.62
H-lat.	19.23 ± 2.28	19.52 ± 2.78	19.34 ± 2.32	19.23 ± 2.52
H-amp.	4.34 ± 2.66	3.88 ± 3.01	3.44 ± 2.11*	4.06 ± 2.20
H/M ratio	52.13 ± 41.27	52.56 ± 33.44	55.79 ± 38.14	53.42 ± 25.74
T-lat.	20.60 ± 3.18	21.09 ± 3.08	21.17 ± 3.18	20.13 ± 3.17
T-amp.	5.13 ± 2.47	3.42 ± 1.77**	3.65 ± 1.91**	4.78 ± 2.58

Abbreviations: C-amp., amplitude (mV) of compound motor action potential (CMAP); C-lat, onset latency (ms) of the CMAP; H-amp., amplitude (mV) of Hoffman reflex (H-reflex); H-lat., latency (ms) of H-reflex; H/M ratio, H_{max} amplitude/$CMAP_{max}$ amplitude ratio; T-amp., amplitude (mV) of tendon reflex (T-reflex); T-lat., latency (ms) of T-reflex. Values are mean ± standard deviation
*$P < .05$, significant difference between preinjection and postinjection. **$P < .01$, significant difference between preinjection and postinjection.

using the same room, light, table, position of patient, machine, electrode, and time between test weeks to maintain the reliability of neurophysiologic assessments. Parameters measured included the onset latency (ms) and amplitude (mV) of compound motor action potential, the latency (ms) and amplitude (mV) of the T- and Hoffman reflexes, and the Hoffman reflex max amplitude/compound motor action $potential_{max}$ amplitude ratio.

Statistical Analysis

The software program SPSS for Windows, version 18.0 (SPSS, Chicago, IL), was used for statistical analyses. Parameters were compared using repeated measures ANOVA with a post hoc test except modified Ashworth scale. *Pearson correlation coefficient* was used to determine the correlation between clinical and electrophysiologic parameters except modified Ashworth scale. Friedman's test, Wilcoxon signed–rank test, and Spearman correlation coefficient were used to analysis modified Ashworth scale. Significance was defined as $P < .05$.

Results

The characteristics of the 40 children are presented in Table 1. Of these, 26 were boys and 14 were girls; the mean age of these 40 patients was 5.5 ± 2.4 years. A total of 25 patients showed bilateral and 15 showed unilateral involvement, with 65 legs injected.

Clinical Assessments

Clinical measures, including modified Ashworth scale, R1 and R2, were significantly lower 2, 4, and 12 weeks after botulinum toxin-A injection than at baseline, whereas D was significantly lower at 2 and 4 weeks but not at 12 weeks. In general, the largest declines were observed at 4 weeks (Table 2).

Neurophysiologic Assessments

The latencies of compound motor action potential were significantly higher at 2 and 4 weeks, whereas the latency of Hoffman reflex, tendon reflex, and the Hoffman $reflex_{max}$ amplitude/compound motor action $potential_{max}$ amplitude ratio did not change. Compound motor action potential amplitude was significantly lower only at 2 weeks, Hoffman reflex amplitude was significantly lower only at 4 weeks, and tendon reflex amplitude was significantly lower at 2 and 4 weeks, but lower at 2 than at 4 weeks. None of the neurophysiologic parameters was significantly lower at 12 weeks than at baseline (Table 3).

Table 4. Correlations Among Neurophysiologic and Clinical Assessments

	KE MAS	KF MAS	KE R1	KE R2	KE D	KF R1	KF R2	KF D
Pre C-amp.	0.069	0.069	–0.037	–0.002	–0.041	0.149	0.058	0.108
Pre H-amp.	0.135	0.131	–0.136	–0.044	–0.086	–0.112	0.035	–0.209
Pre T-amp.	0.166	0.125	0.060	–0.255*	0.350**	–0.038	–0.227*	0.331**
2 wks C-amp.	–0.126	–0.072	0.054	–0.071	0.139	–0.061	0.018	–0.135
2 wks H-amp.	–0.030	0.018	0.151	–0.033	0.215	0.069	–0.036	0.189
2 wks T-amp.	0.330**	0.237	0.071	–0.190	0.321**	0.060	–0.126	0.299*
4 wks C-amp.	–0.002	0.074	–0.043	–0.106	0.024	–0.010	–0.021	0.020
4 wks H-amp.	0.225	0.122	–0.169	–0.158	0.192	–0.033	–0.257*	0.327**
4 wks T-amp.	0.289*	0.204	–0.150	–0.123	0.267*	0.138	–0.159	0.442**
12 wks C-amp.	0.020	0.038	0.027	0.017	0.000	–0.021	–0.050	–0.005
12 wks H-amp.	–0.011	0.155	–0.096	–0.116	0.052	–0.078	–0.120	0.031
12 wks T-amp.	0.296*	0.252	0.042	–0.315**	0.517**	–0.046	–0.297*	0.441**

Abbreviations: C-amp., amplitude (mV) of compound motor action potential; H-amp., amplitude (mV) of Hoffman reflex; KE, knee extension; KF, knee flexion; MAS, modified Ashworth scale; T-amp., amplitude (mV) of tendon reflex. The ankle was dorsiflexed as fast as possible, and the catch angle at which the stretch reflex started was designated R1. The ankle was dorsiflexed as slow as possible, the angle of full passive range of motion was designated R2, and R1 minus R2 was designated D (dynamic range). Values are Pearson's correlation coefficients, except MAS values, which are Spearman's correlation coefficients.
*$P < .05$. **$P < .01$.

Correlations Between Clinical and Neurophysiologic Assessments

In evaluating the correlation between clinical assessments and the amplitude of compound motor action potential, Hoffman reflex, and tendon reflex, we found that only D of modified Tardieu scale and the amplitude of tendon reflex consistently showed correlations from baseline to 12 weeks after injection. Modified Ashworth scale with knee extension and R2 of modified Tardieu scale showed several correlations with the amplitude of the tendon reflex. No other correlation was observed (Table 4).

Discussion

Modified Ashworth scale and modified Tardieu scale are the most frequent outcome measures of reduced spasticity after botulinum toxin-A injection in children with cerebral palsy. And neurophysiologic assessments are considered as a direct measure of spasticity. Prior to the present work, however, there had been no studies on the correlations between these clinical and neurophysiologic measures in response to botulinum toxin-A injection. We found that neurophysiologic changes generally peaked and returned to baseline earlier than clinical changes, suggesting that different components may influence each assessment. Clinical measures, including modified Ashworth scale and modified Tardieu scale, are affected by both neural and peripheral components, whereas neurophysiologic assessments are affected only by neural components.[13-15] Intrinsic and extrinsic factors, including physical therapy, ordinary walking ability, type of paralysis, and cognitive level, may influence peripheral components after botulinum toxin-A injection, resulting in longer maintenance of clinical improvements. It may be of note that D of modified Tardieu scale returned to baseline earlier than other clinical parameters. Although there are questions about the validity and reliability of the modified Tardieu scale, this scale may be more reliable and sensitive than the modified Ashworth scale for measuring spasticity because modified Tardieu scale assesses the response of the muscle to passive movement at both slow and fast speeds.[16-18] We believe that D of modified Tardieu scale was more valuable at assessing spasticity and differentiating spasticity from peripheral components than the modified Ashworth scale because of an earlier return to baseline.

We also found that the latency of the Hoffman reflex and the Hoffman reflex_{max} amplitude/compound motor action potential_{max} amplitude ratio did not change after botulinum toxin-A injection. In contrast, a previous study showed that the Hoffman reflex_{max} amplitude/compound motor action potential_{max} amplitude ratio was reduced after botulinum toxin-A injection.[5] One drawback in measurements of the Hoffman reflex is its variability resulting from many factors, including muscle activity, sensory input, age, and state of consciousness, all of which can affect children who are not sedated.[8,19] Change in Hoffman reflex_{max}/compound motor action potential_{max} ratio after botulinum toxin-A injection may also be a questionable parameter because an intramuscular injection of botulinum toxin-A reduces the amplitude of both compound motor action potential and the Hoffman reflex because of presynaptic block at the extrafusal motor end plate.[20] Moreover, the amplitude of the Hoffman reflex and the Hoffman reflex_{max} amplitude/compound motor action potential_{max} amplitude ratio have been considered to have large intersubject variability.[21] The present study also showed that the amplitude of the Hoffman reflex and the Hoffman reflex_{max} amplitude/compound motor action potential_{max} amplitude ratio had large standard deviations and were poorly correlated with modified Ashworth scale and modified Tardieu scale except at 4 weeks. Our finding is consistent with that of Pisano et al, who reported that latency and amplitude of Hoffman reflex and Hoffman reflex_{max} amplitude/compound motor action potential_{max} amplitude ratio were not correlated with modified Ashworth scale.[22] Indeed a broad

overlapping of Hoffman reflex measurements has been described in patients with spasticity and controls; the poor correlation between these values and spasticity scales limits the use of this test in clinical practice.[22,23] However, we found the consistency of the latency of Hoffman reflex, and it is interesting. The reason for the consistency is not clear, but we believe that botulinum toxin type A may decrease spasticity primarily by affecting the fusimotor system and does not affect I-a afferent fiber. Because the afferent pathway of Hoffman reflex is considered via only I-a fiber, the latency of Hoffman reflex could be constant after botulinum toxin type A injection.

Although the main pathways of the tendon reflex are not clear, they are thought to include α- and γ-motor neuron excitability and presynaptic inhibition, suggesting that the tendon reflex may be more sensitive than the Hoffman reflex for measuring spasticity.[24] Botulinum toxin-A injection decreases spasticity by affecting the fusimotor system and muscle spindle (γ-motor neurons), as well as α-motor neurons.[3] Thus, the amplitude of the tendon reflex can be well correlated to D of modified Tardieu scale because the latter is a better measure of spasticity because of its velocity component. However, it is unclear whether the amplitude of the tendon reflex is correlated with R2 of modified Tardieu scale. This may be the result of the contribution of increased tightness of the peripheral component for a long period to the severity of spasticity because R2 was defined as the angle of full passive range of motion when the ankle was dorsiflexed as slow as possible. In addition, the amplitude of the tendon reflex is poorly correlated with R2 of modified Tardieu scale at the 2 and 4 weeks; we believe this means R2 of modified Tardieu scale does not reflect the reduced spasticity after injection of botulinum toxin-A.

Our study had several limitations. Because of the small size of our study population, we could not classify patients according to sex, age, or the severity or type of cerebral palsy. Moreover, we did not follow up patients until clinical assessments returned to baseline. Unfortunately, we did not assess outcome measures blindly and use calculating limb weight for dosage decision of botulinum toxin-A.

Conclusion

Clinical improvements were maintained longer than neurophysiologic improvements after botulinum toxin-A injection in children with cerebral palsy. Therefore, aftercare such as serial casting and physiotherapy is important to maintain the response of botulinum toxin-A treatment on spasticity in cerebral palsy. Neurophysiologic tests, including the latency of compound motor action potential and the tendon reflex, and the amplitude of compound motor action potential, the Hoffman reflex, and the tendon reflex, can be used to measure reduced spasticity after botulinum toxin-A injection. Amplitude of tendon reflex showed the best correlation with the D of modified Tardieu scale; we believe this can be used to evaluate the severity of spasticity in children with cerebral palsy. A further study for validation and reliability of tendon reflex is needed for clinic settings and standardization.

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Author Contributions

DHJ wrote the article, critically reviewed the article, and contributed to data collection. IYS contributed to study design and analyzed and interpreted the data and takes responsibility for the study as a whole. YJK contributed to data collection.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Ethical Approval

Medytox Inc. provided 40 bottles of botulinum toxin-A (200 UI; Meditoxin).Our Institutional Research Review Board approved this prospective study.

References

1. Lance JW. Pathophysiology of spasticity and clinical experience with baclofen. In: Lance JW, Young RR, Koella WP, eds. *Spasticity: Disorder Motor Control*. Chicago, IL: Year Book; 1980:185-204.
2. Edgar TS. Clinical utility of botulinum toxin in the treatment of cerebral palsy: comprehensive review. *J Child Neurol*. 2001;16(1):37-46.
3. On AY, Kirazli Y, Kismali B, et al. Mechanisms of action of phenol block and botulinus toxin type A in relieving spasticity: electrophysiologic investigation and follow-up. *Am J Phys Med Rehabil*. 1999;78(4):344-349.
4. Baird MW, Vargus-Adams J. Outcome measures used in studies of botulinum toxin in childhood cerebral palsy: a systematic review. *J Child Neurol*. 2010;25(6):721-727.
5. Frascarelli F, Di Rosa G, Bisozzi E, et al. Neurophysiological changes induced by the botulinum toxin type A injection in children with cerebral palsy. *Eur J Paediatr Neurol*. 2011;15(1):59-64.
6. Lannin N, Scheinberg A, Clark K. AACPDM systematic review of the effectiveness of therapy for children with cerebral palsy after botulinum toxin A injections. *Dev Med Child Neurol*. 2006;48(6):533-539.
7. Pauri F, Boffa L, Cassetta E, et al. Botulinum toxin type-A treatment in spastic paraparesis: a neurophysiological study. *J Neurol Sci*. 2000;181(1-2):89-97.
8. Voerman GE, Gregoric M, Hermens HJ. Neurophysiological methods for the assessment of spasticity: the Hoffmann reflex, the tendon reflex, and the stretch reflex. *Disabil Rehabil*. 2005;27(1-2):33-68.
9. Kim MW, Kim JH, Yang YJ, et al. Anatomic localization of motor points in gastrocnemius and soleus muscles. *Am J Phys Med Rehabil*. 2005;84(9):680-683.
10. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. *Phys Ther*. 1987;67(2):206-207.

11. Boyd RN, Graham HK. Objective measurement of clinical findings in the use of botulinum toxin type A for the management of children with cerebral palsy. *European Journal of Neurology*. 1999;6: s23-s35.
12. Yam WK, Leung MS. Interrater reliability of modified Ashworth scale and modified Tardieu scale in children with spastic cerebral palsy. *J Child Neurol*. 2006;21(12):1031-1035.
13. Cousins E, Ward AB, Roffe C, et al. Quantitative measurement of poststroke spasticity and response to treatment with botulinum toxin: a 2-patient case report. *Phys Ther*. 2009;89(7):688-697.
14. Pandyan AD, Gregoric M, Barnes MP, et al. Spasticity: clinical perceptions, neurological realities and meaningful measurement. *Disabil Rehabil*. 2005;27(1-2):2-6.
15. Vattanasilp W, Ada L, Crosbie J. Contribution of thixotropy, spasticity, and contracture to ankle stiffness after stroke. *J Neurol Neurosurg Psychiatry*. 2000;69(1):34-39.
16. Fosang AL, Galea MP, McCoy AT, et al. Measures of muscle and joint performance in the lower limb of children with cerebral palsy. *Dev Med Child Neurol*. 2003;45(10):664-670.
17. Haugh AB, Pandyan AD, Johnson GR. A systematic review of the Tardieu scale for the measurement of spasticity. *Disabil Rehabil*. 2006;28(15):899-907.
18. Patrick E, Ada L. The Tardieu scale differentiates contracture from spasticity whereas the Ashworth scale is confounded by it. *Clin Rehabil*. 2006;20(2):173-182.
19. Jusic A, Baraba R, Bogunovic A. H-reflex and F-wave potentials in leg and arm muscles. *Electromyogr Clin Neurophysiol*. 1995; 35(8):471-478.
20. Priori A, Berardelli A, Mercuri B, et al. Physiological effects produced by botulinum toxin treatment of upper limb dystonia: changes in reciprocal inhibition between forearm muscles. *Brain*. 1995;118(pt 3):801-807.
21. Levin MF, Hui-Chan C. Are H and stretch reflexes in hemiparesis reproducible and correlated with spasticity? *J Neurol*. 1993; 240(2):63-71.
22. Pisano F, Miscio G, Del Conte C, et al. Quantitative measures of spasticity in post-stroke patients. *Clin Neurophysiol*. 2000;111(6): 1015-1022.
23. Milanov I. Clinical and neurophysiological correlations of spasticity. *Funct Neurol*. 2000;14(4):193-201.
24. Delwaide PJ. Clinical neurophysiology in spasticity: contribution to assessment and pathophysiology. In: Delwaide PJ, ed. *Electrophysiological Testing of Spastic Patients: Its Potential Usefulness and Limitations*. Amsterdam, The Netherlands: Elsevier; 1985:185-203.