Examination of Spasticity of the Knee Flexors and Knee Extensors Using Isokinetic Dynamometry With Electromyography and Clinical Scales in Children With Spinal Cord Injury

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Abstract

Background/Objective: To examine the role of reflex activity in spasticity and the relationship between peak passive torque, Ashworth Scale (AS), and Spasm Frequency Scale (SFS) of the knee flexors and extensors during the measurement of spasticity using an isokinetic dynamometer in children with spinal cord injury (SCI).

Methods: Eighteen children with chronic SCI and 10 children of typical development (TD) participated. One set of 10 passive movements was completed using an isokinetic dynamometer at 15, 90, and 180 degrees per second (deg/s) while surface electromyographic data were collected from the vastus lateralis (VL) and medial hamstrings (MH). Spasticity was clinically assessed using the AS and SFS.

Results: There were no significant differences in peak passive torque of the knee flexors and extensors at any velocity for children with SCI compared to children with TD. Children with TD demonstrated significantly more reflex activity of the MH during the assessment of knee flexor spasticity at all movement velocities than did children with SCI. Children with TD demonstrated significantly more reflex activity of the VL during the assessment of knee-extensor spasticity with movements at 180 deg/s. The relationship between peak passive torque, AS, and SFS was significant during movements at a velocity of 90 deg/s only.

Conclusions: The role of increased reflexes in spasticity needs further examination. Isokinetic dynamometry may be measuring a different aspect of spasticity than the AS and SFS do in children with SCI.

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Key Words: Spinal cord injuries; Spasticity; Reflexes; Pediatrics; Isokinetic dynamometry; Electromyography

INTRODUCTION

Spasticity may be defined as a velocity-dependent increase in muscle tone with exaggerated stretch reflexes (1). Spasticity is a common impairment in children with spinal cord injury (SCI). Vogel et al reported that approximately 50% of children with SCI exhibit spasticity (2). The management of spasticity in children may be especially critical to prevent long-term orthopedic

complications associated with spasticity such as joint contractures and hip dislocation (3). Despite the importance of spasticity management in children with SCI, there has been little research examining spasticity and its measurement in this patient population.

One tool that may be useful in studying spasticity in children with SCI is isokinetic dynamometry. Spasticity may be measured by using the dynamometer to passively move a limb through a defined range of motion while the peak resistive torque (4) is calculated. The reliability of isokinetic dynamometry to measure spasticity in adults with SCI has been supported (5,6). Lamontagne et al (6) found good reliability intraclass correlation coefficient [ICC] > 0.75 for plantar-flexor spasticity measurements of peak torque in adults with SCI at velocities of 10 and 190 degrees per second (deg/s). Kakebeeke et al (5) reported Spearman correlation coefficients ranging from

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0.22 to 0.88 when examining the test-retest reliability of knee flexor and knee extensor peak torque in adults with SCI, with the variation in reliability attributed to the different testing positions.

One advantage of isokinetic dynamometry is that muscle stretch reflexes measured by electromyography (EMG) may be assessed in conjunction with the passive movements imposed on the limb by the dynamometer. By using a dynamometer with EMG, clinicians and researchers may be able to evaluate the contributions of increased muscle reflexes as evidenced by an increase in EMG activity with stretch or increased intrinsic muscle resistance in the absence of EMG activity to spasticity (7). The relative contribution of changes in muscle reflexes to spasticity has been debated in the literature for diagnoses such as stroke (8) and cerebral palsy (9). In adults with SCI, there is less available literature, but Skold et al (10) reported that a majority of adults with chronic SCI did not demonstrate increased stretch reflexes with passive movement by a dynamometer and suggested that passive muscle properties played a major role in the spasticity of their subjects. An increase in the understanding of the contribution of muscle reflexes to spasticity may lead to the development of improved assessments and interventions for adults and children with SCI.

However, the use of isokinetic dynamometry to measure spasticity in people with SCI has been limited in clinical situations. Ordinal scales such as the Ashworth Scale (AS) (11), Modified Ashworth Scale (MAS) (12), and Spasm Frequency Scale (SFS) (13) are more commonly used to assess spasticity in people with SCI due to their ease of use, despite studies suggesting inconsistent reliability with the AS and the unknown reliability of the SFS (14). Investigations in children with cerebral palsy and adults with spasticity that have correlated measurements of peak torque by a dynamometer with the AS have reported a moderate but inconsistent relationship between these measures (15,16). Literature in adults with SCI has reported significant relationships between the AS and peak torque of lower extremity muscle groups ranging from $r = 0.30$ to 0.82 (17). Additional research examining the relationship of the clinical scales of spasticity and isokinetic dynamometry may provide further support for the use of isokinetic dynamometry in clinical practice.

Our objective was to examine the role of reflex activity in spasticity of the knee flexors and knee extensors during the measurement of spasticity using an isokinetic dynamometer in children with SCI and to examine the relationship between peak passive torque, AS, and SFS.

METHODS

Participants

A university-affiliated institutional review board approved this investigation. Written informed consent from each child's parents along with verbal or written assent from

each child was obtained prior to participation. A convenience sample of 18 children (11 boys, 7 girls) with chronic SCI (mean age = 9.3 years, $SD = 2.7$; range = 5 to 13 years; mean duration since injury = 5.3 years) was recruited. Fifteen children were classified as American Spinal Cord Injury Association (ASIA) Impairment Scale A, and 3 children were classified as ASIA B. The inclusion criteria for the participants with SCI were: (a) 12 months post injury to allow for a plateau in neurological status; (b) cervical or thoracic level SCI with an ASIA A or ASIA B classification; (c) intact lower motor neurons in the lower extremities as assessed by electrical stimulation; (d) from age 5 to 13 years; (e) no history of lower limb stress fractures or heterotopic ossification; (f) no greater than a 15-degree knee flexion contracture; (g) no use of antispasticity medications. Additionally, 10 children (7 boys, 3 girls) of typical development (TD) (mean age = 10.0 years, $SD = 1.6$; range = 7 to 12 years) with no history of orthopedic or neurological disease were recruited for comparison to the children with SCI.

Methodology

The left limb was tested for each child with SCI due to involvement in another research study, while the limb was randomly selected for children with TD. Two signal-conditioning electrodes (DE-2.3; DelSys Inc, Boston, MA) with a parallel-bar arrangement (contact area 1×10 mm, 10-mm interelectrode distance) were used to detect electrical activity of the vastus lateralis (VL) and medial hamstrings (MH). These electrodes contain a built-in gain of 1000 V/V, a Common Mode Rejection ratio of greater than 80 decibels at 60 Hz, noise of $1.2 \mu V$, and a bandpass filter of 20 to 450 Hz. The electrode on the VL was placed at a point one half of the distance from the greater trochanter to the superior-lateral pole of the patella. The electrode on the MH was placed at a point one half of the distance from the ischial tuberosity to the medial condyle. The VL and MH were palpated to confirm proper electrode placement. The area was lightly abraded and cleaned with alcohol prior to the placement of the electrode on the skin. Coflex wrap (Andover Coated Products, Salisbury, MA) was used to secure the electrodes to the thigh to prevent movement of the electrodes on the skin during testing.

The children were seated on the isokinetic dynamometer (Kincom, Chattex Corp, Chattanooga, TN) in a position of 80 degrees of hip flexion, 90 degrees of knee flexion, and with the ankle unrestricted. The trunk and leg were stabilized using straps across the chest and waist and upper thigh, respectively. The axis of the dynamometer was visually aligned with the knee joint's axis, which was defined as a line between the medial and lateral condyles of the femur. Distal attachment of the lower limb to the lever of the dynamometer was made approximately 3 cm above the lateral malleolus. The distance from the force transducer to the axis of rotation was recorded.

Baseline EMG data were collected for at least 5 seconds while the children were instructed to relax as much as possible and not move the limb or trunk on the dynamometer. One set of 3 continuous passive movements at a velocity of 5 deg/s from 90 degrees of knee flexion to 25 degrees of knee flexion and back to 90 degrees of knee flexion was collected for gravity correction calculation of the limb's weight during data processing. The children were instructed to relax as much as possible and to not assist the passive movement of the limb. The EMG signals were visually assessed during gravity correction to ensure that no voluntary or spastic muscle activity was present. EMG output from the amplifier as well as force, velocity, and position data were collected using a personal computer and custom software written in Labview 5.1 (National Instruments Corporation, Austin, TX) for data analysis. The EMG signals were displayed on a computer monitor for visual assessment. One set of 10 continuous passive movements from 90 degrees of knee flexion to 25 degrees of knee flexion was completed at 15, 90, and 180 deg/s with a return speed of 5 deg/s to assess knee flexor spasticity. One set of 10 continuous passive movements from 25 degrees of knee flexion to 90 degrees of knee flexion was completed at 15, 90, and 180 deg/s with a return speed of 5 deg/s to assess knee-extensor spasticity. The order of muscles tested and velocity of movement were randomized. The acceleration during movement reversals was set for high, which is equivalent to approximately 9,000 deg/s². A 60-second rest break occurred after each movement velocity was assessed.

Prior to attachment of the child's lower extremity to the dynamometer, a physical therapist assessed the child's spasticity using the AS (11). The AS is an ordinal measurement of a muscle group's resistance to passive movement. Each child's left leg was grasped proximal to the ankle joint with the knee in the position obtained due to gravity. The limb was quickly moved for approximately 1 second throughout the full passive range of motion of knee extension and knee flexion that was available. Each movement was repeated 3 times, and the median AS was reported for the knee flexors and knee extensors. The child or the child's parent (if the child was unable to comprehend the scale) then completed the SFS (13). The SFS is a self-rated assessment of the how often spasms occur, which is measured using an ordinal scale.

A custom Matlab program (The MathWorks, Natick, MA) was used for postprocessing and analysis of the torque and EMG data. The gravity-corrected knee flexor and knee extensor peak passive torque was calculated for each repetition while the knee was extended between 85 and 30 degrees to measure knee flexor spasticity and while the knee was flexed between 30 and 85 degrees of knee flexion to measure knee extensor spasticity. Peak passive torque was not calculated until the limb was moving at a constant velocity. The EMG data were full wave rectified and processed using a second order

Butterworth 10-Hz low pass filter with phase correction to create a linear envelope. The EMG onset and offset were defined as muscle activity, which was 3 standard deviations above baseline and occurred for a minimum of 50 milliseconds. The mean percentage of each movement repetition that exhibited reflex activity of the MH and VL was calculated.

Data Analysis

The peak passive torque data were nonnormally distributed for children with SCI and children of TD. The velocity dependence of peak passive torque data for both subject groups separately was assessed by a Friedman 2-way ANOVA by ranks for each muscle group across movement velocities (15, 90, and 180 deg/s). Post-hoc testing to determine the differences in peak torque between each movement velocity was completed using the Wilcoxon signed ranks test with the alpha level set at ($P \leq 0.017$) using a Bonferroni correction. Mann-Whitney *U* tests were calculated on the median peak torque for each muscle group and each movement velocity to test the differences between children with SCI and children of TD. Mann-Whitney *U* tests were also calculated on the median percentage of the movement repetition, which exhibited reflex activity of the MH and VL for each muscle group and each movement velocity to test the differences between children with SCI and children of TD. The relationships for children with SCI for each muscle group with measurements of peak passive torque at 15, 90, and 180 deg/s, AS, and SFS were assessed by correlation coefficients with 95% confidence limits. For peak torque values, Pearson product moment correlation coefficients were used to compare peak passive torque at the 3 angular velocities. Spearman rho correlation coefficients were used to examine the relationships between peak passive torque, AS, and SFS. For all statistical analyses with the exception of post-hoc testing for the velocity dependence of data, the alpha level was set at $P \leq 0.05$.

RESULTS

Table 1 shows the median peak passive torque data for children with SCI and TD. The Mann-Whitney *U* test between children with SCI and TD indicated no significant differences in peak passive torque in any muscle group at any movement velocity. Using separate Friedman 2-way ANOVA for ranks indicated for the both the children with SCI and children of TD, velocity-dependent increases in peak passive torque were found for the knee flexors ($P < 0.001$) and knee extensors ($P \leq 0.001$). Post-hoc testing found that all comparisons between peak passive torque at 15, 90, and 180 deg/s were significantly different from each other for both children with SCI and children of TD for the knee flexors ($P < 0.017$) and knee extensors ($P < 0.017$).

Tables 2 and 3 present the median percentage of each movement repetition that exhibited muscle activity

Table 1. Median Peak Torque of the Knee Flexors and Knee Extensors of Children With SCI and TD

Muscle Group	Velocity (deg/s)	Peak Torque		<i>P</i> Value
		SCI	TD	
Knee flexors	15	0.50	0.33	0.65
	90	1.79	2.11	0.80
	180	4.93	7.47	0.87
Knee extensors	15	1.14	0.71	0.15
	90	2.89	3.06	0.87
	180	4.92	7.11	0.31

of the MH and VL during the assessment of knee flexor and knee extensor spasticity, respectively, for each movement velocity. For these variables, there were a large number of repetitions with no reflex muscle activity, and median values were low. Children with TD demonstrated significantly more reflex activity of the MH during the assessment of knee flexor spasticity at all movement velocities than did children with SCI ($P < 0.05$). There were no significant differences in VL reflex activity between groups at any movement velocity during the assessment of knee flexor spasticity. However, children with TD demonstrated significantly more reflex activity of the MH during the assessment of knee extensor spasticity with movements at 15 deg/s and 180 deg/s and significantly more reflex activity of the VL during the assessment of knee extensor spasticity with movements at 180 deg/s ($P < 0.05$).

Tables 4 and 5 present the correlation coefficients with 95% confidence intervals illustrating the relationships between peak passive torque, AS, and SFS for the knee flexors and knee extensors, respectively, for children with SCI. For AS of the knee flexors, 8 children were scored as 0, 8 children were scored as 1, 1 child was scored as 2, and 1 child was scored as 3. For AS of the knee extensors, 12 children were scored as 0, and 6 children were scored as 1. For the SFS, 4 children were scored as 1, 10 children were scored as 2, and 4 children were scored as 3. No significant relationships were found between the quantitative measurements of spasticity

(peak passive torque at 15, 90, and 180 deg/s) and the clinical measurements (AS and SFS) for either muscle group with the exception of a significant relationship found between the SFS and peak passive torque of both the knee flexors and knee extensors with movements at 90 deg/s ($P < 0.05$). During the assessment of knee flexor spasticity, positive correlations were found between comparisons of peak passive torque at 15 to 90 deg/s and 90 to 180 deg/s ($P < 0.05$). During the assessment of knee extensor spasticity, positive correlations were found between measurements of peak passive torque at all movement velocities ($P < 0.05$). There were no significant correlations between AS and SFS during the assessment of knee flexor and knee extensor spasticity.

DISCUSSION

This investigation examined the role of reflex activity in spasticity and the relationship between peak passive torque and clinical scales during the measurement of spasticity of the knee flexors and knee extensors using an isokinetic dynamometer in children with SCI. To our knowledge, these issues have not been examined in children with SCI. Peak passive torque of the knee flexors and knee extensors for children with SCI demonstrated a velocity-dependent increase, which is consistent with common definitions of spasticity (1). A velocity-dependent increase in torque with passive movement has also been reported by Perell et al (18), while later research by Akman et al (17) found no effect of velocity on torque in adults with SCI. However, our finding of a velocity-dependent increase in passive torque in children of TD suggests that a velocity-dependent increase in passive resistance is not exclusive to patients with spasticity, which has also been found by other authors (19). The small amount of EMG activity elicited in the VL and MH during passive movements with a velocity up to 180 deg/s is inconsistent with definitions of spasticity, which include increased reflexes (1), and suggests that the role of muscle reflexes in spasticity needs further examination.

One interesting finding was no differences were found between peak passive torque values during the assessment of spasticity of knee flexors and knee extensors between children with SCI and children of TD regardless of the movement velocity. The literature

Table 2. Reflex Activity During the Assessment of Knee Flexor Spasticity*

Velocity of Movement (deg/s)	Median Percentage of the Movement With Medial Hamstring Activation			Median Percentage of the Movement With Vastus Lateralis Activation		
	SCI	TD	<i>P</i> Value	SCI	TD	<i>P</i> Value
15	0	0.4	0.009	0	0	0.16
90	0	2.6	0.009	0	0	0.33
180	0	1.1	0.04	0	0	0.33

*SCI indicates spinal cord injury; TD, typical development.

Table 3. Reflex Activity During the Assessment of Knee Extensor Spasticity*

Velocity of Movement (deg/s)	Median Percentage of the Movement With Medial Hamstring Activation			Median Percentage of the Movement With Vastus Lateralis Activation		
	SCI	TD	<i>P</i> Value	SCI	TD	<i>P</i> Value
15	0	0.3	0.009	0	0	0.41
90	0	0	0.29	0	0	0.33
180	0	13.9	0.001	0	11.3	0.002

*SCI indicates spinal cord injury; TD, typical development.

regarding differences in peak torque in adults with SCI and control subjects is inconclusive, with some authors reporting either an increase (17,20), decrease (18), or mixed results (21) when comparing passive torque in adults with SCI to control subjects. However, the reliability of the use of isokinetic dynamometry to measure passive torque in children with SCI has not been established; consequently, our study's results should be interpreted cautiously. The lack of reflex EMG responses found in the children with SCI in this investigation may have affected our torque results since reflexive activity may have increased the passive torque of the stretched muscle groups. One confounding factor when measuring spasticity and passive torque in children with SCI is the possible role of muscle mass since atrophy may reduce the stiffness of the quadriceps (22), which may cause a decrease in peak passive torque. Future investigations directly assessing the relationship between muscle mass using magnetic resonance imaging and peak torque may be helpful in determining the influence of muscle mass on spasticity.

The significant decreases in reflex activity of the MH and VL during the assessment of spasticity in children with SCI when compared to children with TD were surprising. A selection bias may have been introduced in this study since only children who were not using

antispasticity medications were included in this investigation. The decision not to include children who were currently using antispasticity medication was made to avoid the confounding variables associated with the different types of medications and the effectiveness of the medications on the subject's reflexive responses. Lower motor neuron injury in the children with SCI was not the cause of this finding since the inclusion criteria for the study for the children with SCI included intact lower motor neurons for the knee extensors and knee flexors as measured by electrical stimulation. Volitional movement in the children with TD was also an unlikely source of EMG activity since the children were visually monitored for active movements during testing. One hypothesis for the increase in reflex activity in the children with TD was that a startle reflex was generated during the initiation of passive movement in the children with TD (23). The startle reflex may be elicited with a variety of auditory, visual, or somatosensory stimuli in children (23,24). The combination of the proprioceptive and auditory stimuli provided by the start of passive movement by the dynamometer may have been sufficient to generate a startle response. Gross flexion of the extremities has been reported as part of the startle response (23), which may be an explanation of our finding of MH activity in children with TD during assessments of knee flexor and

Table 4. Correlation Coefficients and 95% Confidence Intervals for Relationships Between Peak Torque, the Ashworth Scale (AS), and the Spasm Frequency Scale (SFS) for the Assessment of Knee Flexor Spasticity in Children With Spinal Cord Injury

	Correlation Coefficient	<i>P</i> Value	95% Confidence Interval
Peak torque 15 deg/s vs peak torque 90 deg/s	0.66	0.003	0.29–0.86
Peak torque 15 deg/s vs peak torque 180 deg/s	0.46	0.054	0.00–0.76
Peak torque 90 deg/s vs peak torque 180 deg/s	0.88	<0.001	0.71–0.96
AS vs SFS	0.43	0.08	–0.05–0.74
AS vs peak torque 15 deg/s	0.20	0.40	–0.29–0.62
AS vs peak torque 90 deg/s	–0.01	0.97	–0.48–0.46
AS vs peak torque 180 deg/s	0.05	0.83	–0.43–0.51
SFS vs peak torque 15 deg/s	0.39	0.11	–0.10–0.72
SFS vs peak torque 90 deg/s	0.48	0.05	0.02–0.78
SFS vs peak torque 180 deg/s	0.47	0.054	0.00–0.77

Table 5. Correlation Coefficients and 95% Confidence Intervals for Relationships Between Peak Torque, the Ashworth Scale (AS), and the Spasm Frequency Scale (SFS) for the Assessment of Knee Extensor Spasticity With Spinal Cord Injury

	Correlation Coefficient	P Value	95% Confidence Interval
Peak torque 15 deg/s vs peak torque 90 deg/s	0.78	<0.001	0.50–0.91
Peak torque 15 deg/s vs peak torque 180 deg/s	0.66	0.003	0.28–0.86
Peak torque 90 deg/s vs peak torque 180 deg/s	0.95	<0.001	0.86–0.98
AS vs SFS	0.00	1.00	–0.47–0.47
AS vs peak torque 15 deg/s	–0.02	0.93	–0.48–0.45
AS vs peak torque 90 deg/s	0.00	1.00	–0.47–0.47
AS vs peak torque 180 deg/s	0.30	0.22	–0.20–0.67
SFS vs peak torque 15 deg/s	0.43	0.07	–0.04–0.75
SFS vs peak torque 90 deg/s	0.48	0.05	0.02–0.78
SFS vs peak torque 180 deg/s	0.42	0.09	–0.06–0.74

knee extensor spasticity. The children with SCI would not have been able to generate a startle reflex in the lower extremities since the reflex is thought to originate from the reticulospinal and vestibulospinal tracts, which would have been disrupted by the SCI (23).

There is limited literature in adults with SCI and no literature in children with SCI that investigates reflexive EMG during passive movements. Skold et al (10) found that 60% of adults with chronic SCI demonstrated no increase in EMG activity during passive movements of the knee flexors and knee extensors. In patient populations such as adults with hemiplegia due to stroke or traumatic brain injury (25,26) and children with cerebral palsy (27), increases in muscle reflexes have been commonly reported. The different mechanisms of injury for these conditions may result in different clinical presentations of spasticity. In addition, comparison between studies is difficult due to differences in spasticity assessment protocols, EMG data collection methodology, and EMG analysis between these investigations. The velocity of the movement used to assess spasticity may be especially critical since research suggests that the movement velocities used in some isokinetic dynamometry protocols may not be fast enough to elicit a reflexive response (6,10,28). The lack of EMG responses in the current investigation may be influenced by our protocol, which assessed spasticity with passive movements at a speed below 180 deg/s in order to minimize the risk of pathological fracture of the femur in children with SCI. In addition, the testing of the knee extensors without these muscles being maximally stretched with the hip extended may have reduced the amount of reflex activity elicited. The decision to test both the knee flexors and knee extensors in the same position was made to minimize the time requirements for data collection for our study participants and to more closely simulate the position in which many individuals have their spasticity initially assessed, which is seated in a wheelchair.

Our results, which found little relationship between the AS, SFS, and peak passive resistance torque, suggest

that these tools may measure different aspects of spasticity in children with SCI. The multifactorial nature of spasticity in people with SCI has been discussed previously in the literature (13); thus, it may not be surprising that peak passive resistance torque and the clinical measures demonstrated few significant relationships (Tables 4 and 5). The cause of the significant relationship found between the SFS and passive torque of the knee flexors and knee extensors with movements at a velocity of 90 deg/s is unknown, especially since little EMG activity was found with movements at this speed and the SFS presumably would be associated with EMG activity related to spasms. There is limited literature that addresses the relationship between quantitative measures of passive torque and clinical scales in people with SCI. Akman et al (17) reported significant positive relationships between AS scores and passive torque of the knee flexors, knee extensors, hip adductors, and ankle plantar flexors in adults with SCI. The literature examining the relationship between the AS and peak passive resistive torque in patients with stroke or cerebral palsy is inconclusive, with some authors reporting significant relationships between these variables (15), while others found no significant correlations (28,29). The differences in the range of motion assessed for the AS (full range available) and the isokinetic testing (25° to 90° of flexion) may have also influenced the correlation, but the range of motion tested on the dynamometer was limited for safety reasons. The finding of no correlation between SFS and the AS found in our study and others (30) also suggests that these clinical scales may be measuring different facets of spasticity. Measurement issues with the clinical scales may have influenced these results because the reliability of the AS has been questioned (14), while the reliability of the SFS has not been reported.

CONCLUSION

The current study suggests that the role of muscle reflexes in spasticity needs further examination because children with SCI demonstrated significantly less EMG of

the knee flexors and knee extensors than did children of TD during passive movements. Also, passive movements by an isokinetic dynamometry may be measuring a different aspect of spasticity than AS and SFS in children with SCI, as indicated by the finding of little correlation between these measures.

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