The Effect of Quadriceps Femoris Muscle Strengthening Exercises on Spasticity in Children With Cerebral Palsy

Background and Purpose. The Bobath neurodevelopmental treatment approach advised against the use of resistive exercise, as proponents felt that increased effort would increase spasticity. The purpose of this study was to test the premise that the performance of exercises with maximum efforts will increase spasticity in people with cerebral palsy (CP). Spasticity, in the present study, was defined as a velocity-dependent hyperexcitability of the muscle stretch reflex. Subjects. Twenty-four subjects with the spastic diplegic form of CP (mean age=11.4 years, SD=3.0, range=7–17) and 12 subjects without known neurological impairments (mean age=11.6 years, SD=3.5, range=7–17) were assessed. Methods. Knee muscle spasticity was assessed bilaterally using the pendulum test to elicit a stretch reflex immediately before and after 3 different forms of right quadriceps femoris muscle exercise (isometric, isotonic, and isokinetic) during a single bout of exercise training. Pendulum test outcome measures were: (1) first swing excursion, (2) number of lower leg oscillations, and (3) duration of the oscillations. Results. There were no changes in spasticity following exercise between the 2 groups of subjects. Discussion and Conclusion. These results do not support the premise that exercises with maximum efforts increase spasticity in people with CP. [Fowler EG, Ho TW, Nwigwe AI, Dorey F. The effect of quadriceps femoris muscle strengthening exercises on spasticity in children with cerebral palsy. *Phys Ther*. 2001;81:1215–1223.]

Key Words: *Cerebral palsy, Pendulum test, Spasticity, Strengthening exercises.*

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A widely used physical therapy intervention for children with cerebral palsy (CP) has been based on the Bobath neurodevelopmental treatment (NDT) approach.[1] This approach focused on consideration of abnormal tone and postures during treatment,[2] and interventions were not based on scientific research. The use of strengthening exercises was strongly discouraged by proponents of the approach because they believed that excessive effort would increase co-contraction, spasticity, and associated reactions.[2] The rationale for the NDT approach was based on a reflex-based or hierarchical view of motor control.[3] It was felt that the patient's primary problem in producing a voluntary movement was antagonist restraint, not agonist muscle weakness. Emphasis was placed on interventions to prevent abnormal postures and excessive muscle co-contraction. Clinicians following this treatment approach avoided exercises with maximum efforts in people with the spastic form of CP.

Investigators[4–9] have demonstrated the benefits of strengthening exercises in individuals with CP. Improvements in muscle performance have been demonstrated for people with CP using isometric exercise,[4] isotonic exercise,[4–6] isokinetic exercise,[7,8] and a combination of isotonic exercise and weight machines.[9] These programs were generally done 3 times a week for periods ranging from 6 to 8 weeks. Functional benefits, as a result of improved muscle performance, were reported for isotonic exercise using gait analysis[5] and for isokinetic exercise using the Gross Motor Function Measure.[8]

Although the benefits of strengthening exercises have been demonstrated, the potential negative effects of an associated increase in spasticity have not been critically examined. MacPhail and Kramer[8] used a modified version of the Ashworth scale[10] to measure the effect of spasticity on resistance to passive knee motion before and after an 8-week exercise program for subjects with mild spastic CP. They reported that the number of subjects exhibiting an Ashworth scale grade of at least 1 (slight increase in muscle tone) in the quadriceps femoris and hamstring muscles decreased after the completion of the exercise program. However, the authors stated that these results should be interpreted with caution. Many of the subjects had Ashworth scale grades of either 0 (normal) or 1. The investigators had difficulty making the differentiation between these 2 grades due to lack of sensitivity of the scale and inability to ascertain whether the subjects were truly relaxed. Healy[4] and Hovart[9] reported that range of motion increased, rather than decreased, after an 8-week strengthening exercise program, which they believed indicated no increase in spasticity.

The aim of our study was to assess spasticity before and after the performance of right quadriceps femoris muscle strengthening exercises. There exist varying definitions of spasticity in the literature. We defined *spasticity* as a velocity-dependent hyperexcitability of the muscle stretch reflex, consistent with the definition proposed by Lance[11] in 1980. Spasticity is often assessed by applying motion to the joint or tendon and measuring the response.[12] Factors such as central reflexes and biomechanical restraint from muscle or connective tissue also can contribute to this response; however, we believe that these factors would not be expected to change following interventions aimed at reducing spasticity. We believe that the most common method of measuring spasticity uses the Ashworth scale,[13] in which categories of "mild tone," "moderate tone," "severe tone," and "extreme tone"[10] are used to define an individual's level of spasticity. For detecting small changes in spasticity due to therapeutic interventions, alternative methods such as the pendulum test have been shown to be more sensitive.[14,15]

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Dr Fowler provided concept/research design and writing. Ms Ho provided data collection, and Ms Nwigwe and Dr Dorey provided data analysis.

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The pendulum test, first described by Wartenberg,[16] involves lifting the relaxed leg against gravity and releasing it, causing it to swing freely. The pendulum test has been reported to yield reliable measurements[17] and to be sensitive to variation in spasticity in people with CP.[18] Bohannon[17] assessed the reliability of measurements obtained with the pendulum test in people without known neurological impairments using an isokinetic dynamometer to quantify knee joint motion. He reported an intraclass correlation coefficient of .96 for 4 successive trials. The pendulum test is most sensitive to spasticity of the quadriceps femoris muscles, which is an important muscle group for functional activities[18] and the focus of many of the studies examining strengthening exercises in people with CP. The pendulum test is particularly suited to the evaluation of spasticity in children because it is not intimidating and can be administered in a relatively short period of time.[18]

The purpose of our study was to examine the premise that strengthening exercises will increase spasticity, as measured with the pendulum test, in people with CP. Spasticity was examined before and after a single bout of exercise training. Our aims were to examine the effect of quadriceps femoris muscle exercise on resistance to passive knee motion in: (1) the exercised limb, (2) the nonexercised limb, and (3) children with CP as compared with control subjects of similar ages with no known neurological impairments. Three different types of exercises were utilized: isometric, isotonic, and isokinetic.

Methods

Subjects

Human Subjects Protection Committee approval was obtained prior to subject enrollment in the study. Individuals with CP were recruited from the UCLA/ Orthopaedic Hospital Center for Cerebral Palsy clinics and referring clinicians. Participants without CP were recruited from friends and family of staff members and patient siblings. Written informed consent was obtained from all subjects and the parents or guardians of subjects who met the requirements for inclusion and agreed to participate in the study. Twenty-four subjects with CP and 12 subjects with no known neurological impairments were recruited. All subjects met the following criteria: (1) were between 7 and 18 years of age (to minimize the incidence of secondary conditions due to aging), (2) were in good general health, (3) were able to follow simple verbal directions, (4) had no surgical procedures to the lower extremities in the preceding 12 months, and (5) had the ability to actively extend the knee from 90 to 45 degrees in a sitting position. Additional criteria for subjects with CP were: (1) the diagnosis of spastic diplegia, (2) the ability to actively extend the knee without simultaneous hip extension, (3) the ability to walk with a maximum assistance of one hand held for the purpose of balance, and (4) not taking any pharmacological agents at the time of the study and had no previous surgical procedures for the purpose of reducing spasticity.

Because the severity of spasticity was a potential confounding variable, all subjects with CP were assessed for their degree of right quadriceps femoris muscle spasticity using a modified version of the Ashworth scale.[19] This version used the same methods to elicit spasticity as the original Ashworth scale[13] but added hypotonia as a possible grade. In this modified grading system, hypertonia was assessed as 0 and normal as 1, as opposed to 0 in the original grading system. Eight subjects with CP had grade 1 spasticity (no resistance to passive motion), 6 had grade 2 spasticity (mild resistance to passive motion), 6 had grade 3 spasticity (moderate resistance to passive motion), and 4 had grade 4 spasticity (substantial resistance to passive motion). A greater number of subjects with CP were recruited as compared with control subjects with no known neurological impairments in anticipation of the need for subgroups to test for a relationship between the level of baseline spasticity and changes that might occur with exercise. The mean age was 11.6 years (SD=3.5, range=7–17) for the control subjects and 11.4 years (SD=3.0, range=7–17) for the subjects with CP.

Instrumentation/Testing Protocol

Electrogoniometers can provide a record of pendulum test oscillations.[20] The electrogoniometer we used consisted of a potentiometer attached to both a stationary arm and a movable arm. The movable arm slid within a milled encasement that allowed the center of the potentiometer to maintain alignment with the knee joint center. Electromyographic (EMG) data were collected using disposable surface silver-silver chloride electrodes that were hardwired and attached to the remote unit of an EMG system.* The signal was differentially amplified and sent to a base unit via a fiber optic cable where it was sampled at 1 kHz and high-pass filtered (40 Hz). The EMG and electrogoniometer data were simultaneously displayed on a computer screen during collection using customized software.

All subjects wore shorts and were barefoot to prevent clothing from interfering with the instrumentation (EMG system and electrogoniometer) and to prevent variation in leg movement due to different types of shoes. Surface electrodes were placed over the vastus lateralis (VL), medial hamstring (MH), tibialis anterior (TA), and medial gastrocnemius (MG) muscles bilater-

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* Konigsberg Instruments Inc, 2000 E Foothill Blvd, Pasadena, CA 91107.

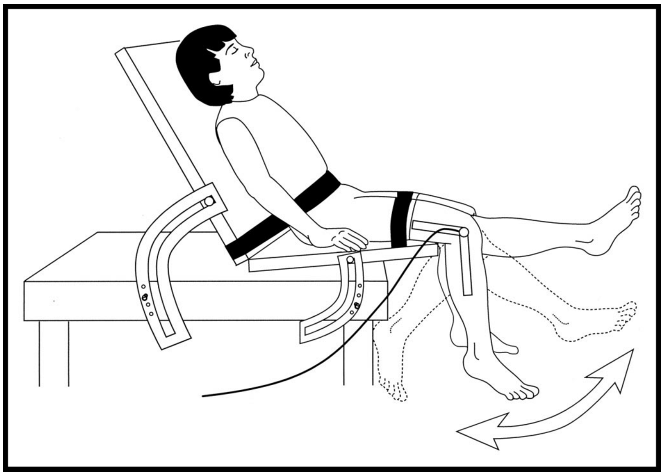

Figure 1.
Subject positioning, electrogoniometer placement, and representation of limb movement during the pendulum test. Reproduced with permission of MacKeith Press from Fowler EG, Nwigwe AI, Ho TW. Sensitivity of the pendulum test for assessing spasticity in persons with cerebral palsy. *Dev Med Child Neurol.* 2000;42:182–189.

ally, and a reference electrode was placed over the anterior medial aspect of the left lower leg. A maximum muscle contraction was elicited from the subjects, and the electrode was placed over the most prominent aspect of the muscle belly. Prior to electrode placement, the skin was prepared by shaving, when necessary, and rubbing with an alcohol wipe to cleanse and lightly abrade the skin. Subjects were seated in a specially designed chair with the trunk reclined between 20 and 40 degrees from vertical to minimize the effect of possible hamstring muscle tightness (Fig. 1). The trunk and thighs were secured to the chair with padded straps to maintain the position throughout the testing procedures, and a pillow was placed behind the subjects' head to promote comfort and relaxation.

The electrogoniometers were secured to the lateral aspect of each lower limb by placing the axis of rotation over the lateral aspect of the knee joint center (determined by palpation of the joint space) and taping the stationary arm and movable arm encasement securely to the midline of each thigh and shank, respectively. A calibration procedure was performed for each electrogoniometer by recording voltage data at varying positions throughout knee range of motion. The measurements were converted from volts to degrees.

The testing protocol is outlined in Table 1. Four pendulum tests were conducted bilaterally before and after each type of resistive exercise. Subjects were asked to relax and sit quietly during pendulum tests. The investigator (EGF or TWH) held each subject's heel and extended the knee from its resting position to the point of maximum knee extension (or the onset of an increase in passive hamstring muscle force for subjects with spasticity). The examiner then released the heel, allowing the leg to drop into flexion and swing freely (Fig. 1). In subjects without CP, the resulting motion is a series of oscillations that gradually diminish in amplitude.[12,16,18,20,21] In the presence of spasticity, the stretch reflex is elicited when the lower limb is released, causing muscle contractions that modify the swinging motion. The result is reduced excursions of the swinging limb, a fewer number of oscillations, and a shorter test duration.[18] A minimum of 15 seconds of rest occurred between successive pendulum tests for the same leg in order to ensure reliable measurements.[17]

Table 1.
Testing Protocol[a]

Exercised (Right) Limb		Nonexercised (Left) Limb
Pendulum tests		Pendulum tests
Exercise A		
Pendulum tests		Pendulum tests
	5-min rest	
Pendulum tests		Pendulum tests
Exercise B		
Pendulum tests		Pendulum tests
	5-min rest	
Pendulum tests		Pendulum tests
Exercise C		
Pendulum tests		Pendulum tests

[a] Exercises A, B, and C were isometric, isotonic, or isokinetic in randomized order.

Relaxation of subjects during the pendulum tests was confirmed by: (1) an absence of visible movement or quadriceps femoris muscle contraction, (2) an absence of EMG activity in the control subjects, and (3) EMG bursts occurring only during muscle lengthening in the subjects with CP (Fig. 2). Pendulum tests were conducted until a minimum of 4 successful tests using these criteria were obtained for each leg. Pendulum tests were repeated before and after each type of resistive exercise. There was a 5-minute rest period following the postexercise pendulum tests to minimize the effects of fatigue.

Subjects performed right quadriceps femoris muscle exercises as outlined in Table 1. Three different types of resistive exercise were done by each subject: isometric, isotonic, and isokinetic. The exercise order (A, B, C) was distributed evenly among the subjects using a Latin square randomized design. Each subject drew a number from an envelope that determined a particular exercise order. The exercises chosen for this study are commonly used by physical therapists to improve muscle force production and were the focus of studies demonstrating strength gains in children with CP.[4–9] Because spasticity is dependent on joint angular velocity, it was possible that these exercises, using different speeds of movement,

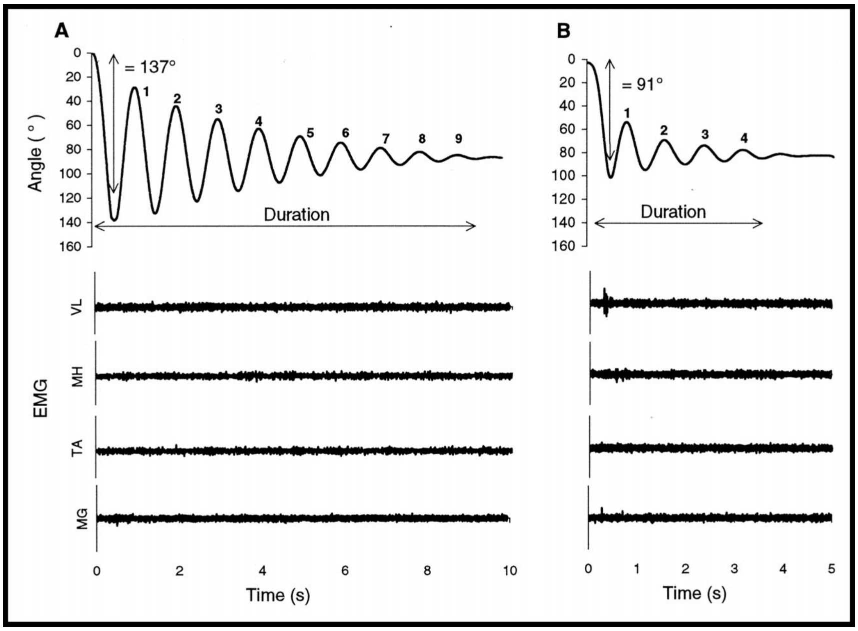

Figure 2.
Goniogram tracings and electromyographic (EMG) activity of the VL (vastus lateralis), MH (medial hamstring), TA (tibialis anterior), and MG (medial gastrocnemius) muscle during a pendulum test for (A) a subject without cerebral palsy and (B) a subject with cerebral palsy. Outcome measurements are illustrated for first swing excursion (vertical arrows), number of oscillations, and duration of oscillations. The subject with cerebral palsy did not exhibit quadriceps femoris muscle spasticity on clinical examination using a modified Ashworth scale; however, a burst of VL activity occurred during initial muscle lengthening after the limb was released. No evidence of voluntary interference was observed on any of the EMG channels. The subject with cerebral palsy exhibited a reduction in first swing excursion, number of oscillations, and duration of oscillations as compared with the subject without cerebral palsy.

might have different effects. Five repetitions of each type of exercise were performed by each subject following 2 or 3 practice repetitions to familiarize the subject with the testing protocol and apparatus. Using this protocol, the total number of exercises for the entire session were kept under 25 repetitions to minimize the effects of fatigue.

Isometric and isokinetic exercises were done using a Kin-Com dynamometer (Hardware Version 125E Plus, Software Version 3.20),[†] with verbal encouragement and visual feedback from the monitor to obtain maximum efforts. Isometric exercises were done with the knee positioned at 60 degrees of flexion, which was sustained to a count of 5 seconds. Isokinetic knee extension exercises were done at 60°/s. Starting from a relaxed, gravity-neutral position of approximately 90 degrees of knee flexion, the subjects were instructed to extend their knee as rapidly and as far as possible. The end positions set on the machine were the subjects' maximum joint range of motion for knee flexion and extension. Isotonic knee extension was performed using cuff weights around the ankle. Prior to the exercise session, the maximum amount of weight possible for 5 repetitions of isotonic exercises was determined for each subject. Varying weights were assessed until the maximum load that could be lifted through full range of motion for 5 repetitions was determined using subject feedback and the physical therapist's observations. The subject was instructed to extend his or her knee joint to a count of 5 seconds provided by the examiner. Following each repetition of knee extension exercise, the examiner held the ankle and passively flexed the knee to its starting position at approximately 90 degrees.

Data Analysis

Pre- and post-exercise resistance to passive motion was assessed for both the right (exercised) and left (non-exercised) knees using the pendulum test data. Electrogoniometer data (in volts) was converted to joint angular data (in degrees) using the conversion factor obtained during the calibration procedure. Outcome measurements obtained from the pendulum data were:

1. Number of oscillations: The number of sinusoidal waves produced by the swinging limb. The criterion for each oscillation was a flexion and extension wave with a minimum displacement toward extension of at least 3 degrees. This measurement is influenced by quadriceps femoris and hamstring muscle spasticity.

2. Duration of oscillations: The duration of pendulum swings (in seconds) from the release of the lower limb to completion of the final oscillation as determined by the above criterion. This measurement is influenced by quadriceps femoris and hamstring muscle spasticity.

3. First swing excursion: The difference between the angle of release and the maximum angle of the first initial downward swing (in degrees). This measurement is influenced by quadriceps femoris muscle spasticity, but not by hamstring muscle spasticity.

Measurements are illustrated for a control subject and a subject with CP in Figure 2. A decrease in any of these measurements following exercise would indicate an increase in spasticity. These measurements have been found to be sensitive to the severity of spasticity in

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[†] Chattanooga Group Inc, 4747 Adams Rd, Hixson, TN 37343.

people with CP, with first swing excursion exhibiting the greatest sensitivity to quadriceps femoris muscle spasticity.[18]

During the pendulum test, EMG data for the tested limb were examined for evidence of inappropriate muscle contractions. For a trial to be successful, there would have been an absence of muscle activity throughout the test in the control subjects. In the subjects with CP, VL activity was often visible during downward swings and MH activity was often visible during upward swings due to the elicitation of the stretch reflexes. All trials that did not exhibit evidence of voluntary muscle activity during data collection were evaluated further. The data were examined to determine that there was no increase over baseline activity for all subjects and that the EMG activity observed for subjects with CP occurred as a response to stretch (eg, during knee flexion for the VL and knee extension for the MH). Trials in which EMG activity was observed during muscle shortening, indicating voluntary activity, were excluded.

A main-effects repeated-measures analysis of variance (ANOVA) based on the Latin square randomized design was performed with a random subject effect and 4 fixed effects (order, subject group (subjects with CP versus control subjects), limb, exercise type). After pooling the data over exercise type, 2-sample *t* tests were used to examine the difference in pre- and post-exercise outcome measurements between the subjects with CP and the control subjects. A linear regression analysis was used to examine the effect of varying severity of quadriceps femoris muscle spasticity on each measure for the subjects with CP. Subjects with CP were placed into 1 of 3 groups based on their degree of quadriceps femoris muscle spasticity, as indicated by modified Ashworth scale scores[19]: (1) subjects with no resistance to passive movement, (2) subjects with mild or moderate spasticity, and (3) subjects with severe spasticity.

Results

Table 2 shows the means of the 3 outcome measures before and after exercise for both subject groups, the exercised leg, the nonexercised leg, and all types of exercise. Only slight changes in the mean values occurred following exercise. All of the observed changes in mean first swing excursion, our most sensitive measurement, were less than 5 degrees and more often were less than 2 degrees.

When we examined all 4 trials for each subject, we found that there was considerable overlap between pre- and post-exercise measurements of first swing excursion. For example, in 76% of the exercised limb trials, at least 1 of the 4 post-exercise first swing excursions was within the range of the pretest values. Only 3 subjects with CP exhibited decreases in mean first swing excursion for the exercised limb following all types of exercise. Three other subjects exhibited consistent increases. Changes in the mean number of oscillations were plus or minus one-tenth of an oscillation. The greatest change in mean duration was for the control subjects following the isokinetic exercise and was less than 1 second. All other changes were within 200 milliseconds.

The main-effects repeated-measures ANOVA revealed no differences in pre-exercise versus post-exercise data based on exercise order, exercise type, or subject group (subjects with CP versus control subjects) ($P>.05$). A suggestion of a difference was found between the exercised and nonexercised limbs. Because all subjects received all 3 exercises and there was no exercise type effect, the results were averaged and differences in means between pre- and post-exercise measurements were calculated (Tab. 2D). In order to determine whether the limb effect was similar for the subjects with CP and the control subjects, the differences in pre- and post-exercise measurements were calculated by subtracting the pre-exercise value from the post-exercise value.

Comparisons were made between the exercised limb and the nonexercised limb using a paired *t* test with 95% confidence intervals. No specific limb effects were found for number of oscillations or duration of oscillations ($P>.10$) for either subject group. There was no difference in first swing excursion for the nonexercised limb versus the exercised limb for the control subjects ($P=.07$) and the subjects with CP ($P=.06$). These results suggest that the limb effect was similar for both subject groups and illustrates the importance of including a control group.

Although the main-effects repeated-measures ANOVA did not find a difference in pre-exercise versus post-exercise data based on subject group (subjects with CP versus control subjects), further statistical analyses were performed to examine these data. Two-sample *t* tests were used to compare the differences between pre- and post-exercise outcomes between the 2 subject groups after averaging over the 3 types of exercise. Separate tests were done for the exercised and nonexercised limbs. Confidence intervals at 95% were calculated. No differences were found in outcome measures between the subjects with CP and the control subjects (Tab. 3). Confidence intervals were similar for the exercised and the nonexercised limbs and could be in the direction of increased or decreased resistance to passive motion for the subjects with CP versus the control subjects.

A difference was found in the mean values for all outcome measures between the control subjects and the subjects with CP ($P<.001$). The results of the linear

Table 2.
Results of the Three Outcome Measures Before and After Exercise for Both Subject Groups, Exercised and Nonexercised Limbs, and All Exercises

	Exercised (Right) Limb																	
	First Swing Excursion (°)						**No. of Oscillations**						**Duration of Oscillations (s)**					
	Pre-exercise			**Post-exercise**			**Pre-exercise**			**Post-exercise**			**Pre-exercise**			**Post-exercise**		
	$\overline{X}$	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**
A. Isometric exercise																		
Subjects without CP[a]	135	18.3	100–154	136	15.3	103–158	8.1	1.1	5–10	8.3	0.9	6–10	8.2	1.4	5.4–10.3	8.3	1.1	6.9–10.0
Subjects with CP	76	20.5	41–119	71	25.1	35–129	4.3	1.2	2–8	4.3	1.5	1–8	3.1	1.4	1.1–6.6	3.0	1.6	1.2–6.6
B. Isokinetic exercise																		
Subjects without CP	135	13.0	112–154	135	14.7	108–156	8.3	1.3	6–10	8.0	1.3	5–10	8.3	1.4	6.2–10.2	8.3	1.4	5.9–10.9
Subjects with CP	72	24.8	33–139	72	25.2	31–136	4.4	1.6	2–8	4.4	1.7	2–9	3.2	1.6	1.2–7.0	3.2	1.8	1.0–7.3
C. Isotonic exercise																		
Subjects without CP	133	14.6	105–152	134	12.7	115–152	7.8	1.3	5–10	8.1	1.0	6–10	8.0	1.4	6.1–10.7	8.2	1.2	6.7–10.3
Subjects with CP	72	24.3	33–137	71	22.3	37–135	4.3	1.4	2–8	4.3	1.4	2–10	3.0	1.6	1.2–6.8	3.0	1.5	1.4–6.8
D. All exercises																		
Subjects without CP	134	14.6	100–154	135	13.8	103–158	8.1	1.1	5–10	8.1	0.9	5–10	8.2	1.3	5.4–10.7	8.3	1.1	6.7–10.9
Subjects with CP	74	22.7	33–139	72	23.4	31–136	4.3	1.3	2–8	4.3	1.4	1–10	3.1	1.4	1.1–7.0	3.0	1.6	1.0–7.3

Table 2.
Continued

	Non-exercised (Left) Limb																	
	First Swing Excursion (°)						**No. of Oscillations**						**Duration of Oscillations (s)**					
	Pre-exercise			**Post-exercise**			**Pre-exercise**			**Post-exercise**			**Pre-exercise**			**Post-exercise**		
	$\overline{X}$	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**	**$\overline{X}$**	**SD**	**Range**
A. Isometric exercise																		
Subjects without CP[a]	134	9.9	115–145	138	9.6	124–149	8.4	0.9	6–10	8.5	0.9	7–10	8.4	1.1	6.1–10.5	8.6	1.1	6.3–10.8
Subjects with CP	77	20.8	39–121	76	24.1	36–127	4.4	1.6	1–10	4.5	1.6	1–8	3.3	1.7	0.9–8.3	3.4	1.7	0.7–6.9
B. Isokinetic exercise																		
Subjects without CP	134	14.4	109–149	136	11.1	117–155	8.3	1.3	6–10	8.3	1.1	5–10	8.4	1.4	6.2–10.7	8.4	1.2	7.1–10.3
Subjects with CP	74	23.0	37–134	75	22.7	35–132	4.6	1.8	1–11	4.6	1.5	1–9	3.4	2.1	1.2–9.5	3.4	1.7	1.0–8.1
C. Isotonic exercise																		
Subjects without CP	134	11.8	106–149	136	9.8	116–150	8.2	1.1	6–10	8.3	1.1	6–11	8.3	1.4	6.4–10.5	8.4	1.3	6.5–10.7
Subjects with CP	77	22.8	42–133	78	22.0	45–132	4.5	1.3	1–8	4.6	1.6	1–10	3.4	1.5	1.3–6.8	3.6	1.7	1.2–8.2
D. All exercises																		
Subjects without CP	134	10.9	106–149	137	9.4	116–155	8.3	1.0	6–10	8.4	0.9	5–11	8.4	1.2	6.1–10.7	8.5	1.1	6.3–10.8
Subjects with CP	76	21.4	37–134	76	22.1	35–132	4.5	1.5	1–11	4.6	1.5	1–10	3.4	1.7	0.9–9.5	3.5	1.6	0.7–8.2

[a] CP=cerebral palsy.

Table 3.
Two-Sample *t* Test: Comparison of the Pre-exercise to Post-exercise Differences Between Subjects Without Cerebral Palsy and Subjects With Cerebral Palsy

Outcome Measure	Mean Difference	*t*	*P*	CI[a] (95%)
Exercised (right) limb				
First swing excursion (°)	−2.59	−1.44	.16	−6.2 to 1.1
No. of oscillations	−0.06	−0.40	.69	−0.4 to 0.2
Duration of oscillations (s)	−0.16	−1.10	.28	−0.4 to 0.1
Nonexercised (left) limb				
First swing excursion (°)	−1.75	−1.05	.30	−5.1 to 1.6
No. of oscillations	−0.01	−0.05	.96	−0.4 to 0.4
Duration of oscillations (s)	−0.03	−0.07	.95	−0.4 to 0.4

[a] CI=confidence interval.

regression analysis indicated that the degree of quadriceps femoris muscle spasticity in subjects with CP, as assessed using a modified Ashworth scale, was not related to changes in any of the measures following exercise (*P*>.05).

Because the subjects were asked to perform exercises with maximum efforts, we believed that it was important to examine the joint moments and forces used during each exercise. The control subjects were able to generate greater joint moments as compared with subjects with CP for all 3 types of exercise. The control subjects generated an average of 89.4 N·m (SD=42, range=24.0–162.2) during isometric exercise and 82.9 N·m (SD=38, range=30.6–161.4) during isokinetic exercise. The subjects with CP generated 37.2 N·m (SD=21, range=10.2–89.2) and 29.8 N·m (SD=21, range=3.6–84.1), respectively, for these exercises. Isotonic exercises were done with ankle weights that were 11.2 kg (SD=4, range=5.5–15.9) for the control subjects and 6.4 kg (SD=4, range=1.4–14.3) for the subjects with CP.

Discussion

Children with CP did not demonstrate a difference in quadriceps femoris muscle spasticity immediately following strengthening exercises as compared with the children without CP. We believe that our finding refutes the premise that the performance of exercises with maximum efforts will result in a large, or detrimental, increase in spasticity. Confidence intervals are a means of providing insight into the maximum difference that would be likely if there were a large subject population (Tab. 3). Using this analysis, outcome measure differences between the subjects with CP and the subjects without CP for the exercised limb would be expected to be similar to the differences for the limb that simply rested during the experiment. The maximum possible change in spasticity in either direction was substantially less than the change that we believe is required to create a clinically perceptible change. Fowler et al,[18] for example, reported mean values for first joint excursion of 44.1 degrees for subjects with CP with severe quadriceps femoris muscle spasticity, 77.2 degrees for subjects with CP with mild to moderate spasticity, 101.4 degrees for subjects with CP without measurable spasticity, and 136.2 degrees for subjects without CP. The changes that we observed in the present study could be in the direction of increased or decreased spasticity, and the maximum change we observed for any exercise for children with CP was 5 degrees.

The considerable variation in spasticity within the group of subjects with CP was a potential confounding variable that could have been masked in the ANOVA. We recruited a greater number of subjects with CP and created subgroups based on severity of spasticity, and the statistical tests performed did not result in significant findings. These groups, however, were not equal and contained a small number of subjects. Despite these limitations, we believe that the severity of spasticity was not an important factor. The change in mean first joint excursion following exercise—our most sensitive measure—was greater for subjects with CP and no detectable quadriceps femoris muscle spasticity (grade 1) than for those with severe spasticity (grade 4). In addition, the 3 subjects with CP who consistently exhibited decreased first joint excursion for the exercised limb did not exhibit severe quadriceps femoris muscle spasticity.

We contend that a fundamental problem in the interpretation and application of Bobath concepts is that their clinical view of "spasticity" differs substantially from the definition that is widely adopted and supported today. The Bobaths described spasticity as a phenomenon that could be assessed by observing a patient move.[2,22] They stated that hypertonus is caused by tonic reflexes (tonic labyrinthine, asymmetrical tonic neck reflexes; symmetrical tonic neck reflexes; associated reactions; and positive and negative supporting reactions),[2] and they included co-contraction[2] and "abnormal coordination"[22] in their description of spasticity. They were critical of clinicians who measured spasticity at the "local muscular" level.[22,23] Clearly, their descriptions differed from the definition accepted by neuroscientists in 1980[11] and used for the present study. In this definition, spasticity is a velocity-dependent increase in muscle stretch reflexes resulting from hyperexcitability of the stretch reflex, as one component of the upper motor neuron syndrome.

The children with CP who performed exercises in this study appeared to change posture, and this might fit the Bobath description of increased spasticity. Many children with CP moved their left lower extremity and tensed muscles in their upper extremities, trunk, and face when asked to perform isolated right knee extension exercise. Although extraneous, or nonagonist, movement was also observed in the subjects without CP, especially younger children, it was most pronounced in the children with CP.

Once a theory becomes shaped and championed, the clinical practice model is not always adjusted as new knowledge is gained.[24] The view that muscular effort will increase spasticity continues to be taught in some physical therapy curriculums. Despite evidence that strengthening exercise programs can improve function in children with CP,[4,5,7–9] the use of weight training equipment is not common. We have seen reluctance to use resistive exercise following surgical or pharmacological treatments that have reduced or eliminated spasticity.

In our study, we assessed spasticity before and after a single bout of exercise training. Although long-term exercise programs have not demonstrated detrimental effects on related outcomes such as range of motion, spasticity, in our view, was not critically examined, and this is a direction for future research.

Conclusion

The results of this study showed no increase in quadriceps femoris muscle spasticity after subjects with CP completed quadriceps femoris muscle strengthening exercises with maximum efforts. These results, considered along with the results of other studies that have demonstrated improvements in force production in individuals with CP, suggest that there are no detrimental effects associated with muscle strengthening programs. We believe that our results should promote the use of strengthening exercises in individuals with CP where muscle weakness may contribute to functional problems.

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