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Assessment of spasticity using isokinetic dynamometry in patients with spinal cord injury

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Objectives: To determine the value of isokinetic dynamometric measurement of passive resistance in quantifying spasticity.
Setting: Turkey.
Methods: Thirty-three spastic spinal cord-injured patients and 14 age-matched normal individuals were studied. Five consecutive flexion-extensions of the knee, abduction-adductions of the hip, and dorsal-plantar flexions of the ankle were performed at specific velocities (15, 30, 60, 90 and 120°/s) using a computerized isokinetic dynamometer set at the continuous passive motion mode. We recorded maximum torque and the sum of torque amplitudes for five repetitions of each type of joint motion at all velocities.
Results: Maximum torque values and the sum of torque amplitudes were both significantly higher in spastic patients than in controls, and there was a positive correlation between torque values and Ashworth scores. There was no significant linear increase in torque values associated with increasing velocity for any of the motions in either controls or patients.
Conclusion: Isokinetic dynamometric measurement of passive resistance appeared to be a valuable tool for assessing and quantifying spasticity, as well as other types of hypertonus.

Keywords: spinal cord injury; spasticity; isokinetic dynamometer

Introduction

Spasticity is defined as a type of hypertonus that increases with the velocity of joint movement.[1] Spasticity and other types of hypertonus (ie, flexor withdrawal reflex, extensor spasms) often compromise function and activities of daily living for spinal cord-injured (SCI) patients. One important goal for these patients is to minimize spasticity and, thus, improve quality of life. Measuring the magnitude of hypertonus is essential in determining the effectiveness of therapeutic intervention. Unfortunately, all the evaluation techniques that are currently in use have disadvantages, and all fail to reflect the clinical status of a patient's muscle tone.[2–4] The aim of this study was to determine the value of isokinetic dynamometric measurement of passive resistance in quantifying spasticity.

Methods

The patient group consisted of 33 SCI patients, 27 male and six female, all of whom had varying degrees of hypertonus on clinical examination (Ashworth scale = 1–4). The control group included 14 able-bodied subjects with normal muscle tone (Ashworth scale = 0). The mean age of the patients was 29.2 ± 5.0 years, and of controls was 31.6 ± 13.2 years. This difference was not statistically significant. Twenty-eight of the SCI patients had paraplegia (18 complete and ten incomplete) and five had tetraplegia (three complete and two incomplete). The mean time post-injury for the patient group was 13.5 ± 7.6 months.

For all patients, the same physician recorded Ashworth grades for hip abduction-adduction, knee flexion-extension, and ankle dorsal-plantar flexion. A commercially available computerized isokinetic dynamometer (Cybex 770 Norm, Lumex Inc., Ronkomkoma, NY, USA) was used to quantify passive resistance. We created a new protocol and added it to the continuous passive motion mode menu of the machine in order to standardize our method. Knee measurements were done in the sitting position, and hip and ankle measurements were taken in the supine position. All measurements were recorded in the morning hours before patients had undergone physical therapy or any other therapeutic activity.

Five consecutive passive joint motions were performed at five pre-selected velocities (15, 30, 60, 90 and 120°/s) for each motion type. Correction for gravity was undertaken to account for the weight of the limb. According to the set-up of the machine, positive torque values represent the forces pushing

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against the lever, while the negatives represent pulling forces. For each joint, resistance to passive motion was determined by recording the five negative peak torque values in foot.pounds (ft.lb) at all velocities and joint motions. The maximum peak torque (mT) values of five repetitions, and the sum of five peak torques (ΣT) for each joint motion at each velocity were recorded. Average mTs and ΣTs were also calculated for each subject by summing the five mTs and ΣTs at five velocities and dividing by five. Statistical analysis was performed with the SPSS software package using the Student's *t*-test, Mann-Whitney U-test, Wilcoxon test, and Pearson and Friedmann analyses.

Results

Tables 1 – 3 list the means and standard deviations of mTs and ΣTs for each joint motion at specific velocities, as well as average values for the study and control groups. In the study group, there were significant differences between resisting torque values of hip abduction and adduction, and ankle dorsal flexion and plantar flexion ($P<0.01$), but there were no significant differences between the resistance values for these opposing movements in the control group. Consistent with our observations and Ashworth grade scores, spasticity was most pronounced in the adductors of the hip joint and the plantar flexors of the ankle joint. For this reason, we used the data for hip abduction, knee flexion and extension, and ankle dorsal flexion for further analyses in this study.

Our data indicated that mT and ΣT values were significantly higher in the patient group than in the control group for each joint motion at all velocities ($P<0.01$). The results also showed that the average mT and ΣT values were positively correlated with the Ashworth grades (Table 4). On the other hand, in knee flexion-extension and ankle dorsal flexion, patients with Ashworth grade one did not differ from control group in their torque values while they differ significantly in hip abduction ($P<0.05$), and in knee flexion-extension, the difference between torque values

Table 1 Resisting torque values for hip motion in the study and control groups (mean ± SD)

	Hip adductors (during abduction)				*Hip abductors (during adduction)*			
	mT		*ΣT*		*mT*		*ΣT*	
	study	*control*	*study*	*control*	*study*	*control*	*study*	*control*
15°/s	22.86 ± 12.67	6.07 ± 3.75	94.24 ± 51.87	22.86 ± 17.6	15.32 ± 9.7	3.79 ± 3.42	63.5 ± 43.74	15.14 ± 14.32
30°/s	22.39 ± 12.75	5.79 ± 3.68	92.07 ± 52.11	20.86 ± 15.48	14.14 ± 9.36	3.5 ± 3.25	60.14 ± 42.11	16.64 ± 13.59
60°/s	21.5 ± 11.82	5.07 ± 2.81	93.46 ± 47.28	20.81 ± 13.63	11.68 ± 8.4	4.93 ± 2.62	52.07 ± 37.77	15.07 ± 15.02
90°/s	23.93 ± 11.77	6.0 ± 2.84	99.11 ± 48.43	23.14 ± 12.65	11.79 ± 7.57	4.86 ± 2.66	50.89 ± 33.15	17.43 ± 14.49
120°/s	28.5 ± 14.91	6.86 ± 3.42	119.25 ± 57.73	25.21 ± 11.9	11.5 ± 8.99	4.5 ± 2.14	49.71 ± 36.91	18.21 ± 13.36
Average	23.84 ± 12.05	5.96 ± 2.65	99.64 ± 48.23	22.59 ± 12.91	12.89 ± 8.54	4.31 ± 2.88	55.28 ± 37.69	16.21 ± 13.84

Table 2 Resisting torque values for knee motion in the study and control groups (mean ± SD)

	Knee flexors (during extension)				*Knee extensors (during flexion)*			
	mT		*ΣT*		*mT*		*ΣT*	
	study	*control*	*study*	*control*	*study*	*control*	*study*	*control*
15°/s	11.14 ± 9.14	6.93 ± 2.46	48.0 ± 37.89	28.71 ± 12.3	8.79 ± 6.91	5.93 ± 2.3	37.66 ± 27.16	25.36 ± 11.38
30°/s	12.38 ± 10.11	6.29 ± 2.76	52.62 ± 42.79	27.07 ± 14.38	8.83 ± 6.66	4.86 ± 2.14	39.83 ± 31.02	20.57 ± 11.75
60°/s	14.24 ± 11.65	5.71 ± 2.16	62.0 ± 52.29	26.86 ± 11.76	8.97 ± 6.87	4.29 ± 1.86	42.03 ± 32.14	19.86 ± 10.11
90°/s	13.93 ± 12.35	6.29 ± 2.09	60.38 ± 52.83	28.0 ± 10.5	8.24 ± 7.01	4.0 ± 1.84	37.9 ± 32.47	17.86 ± 8.91
120°/s	13.2 ± 11.35	6.14 ± 2.25	59.79 ± 52.94	28.5 ± 10.2	8.21 ± 7.3	3.79 ± 1.97	37.31 ± 33.97	17.5 ± 9.04
Average	12.98 ± 10.6	6.27 ± 2.12	56.56 ± 46.63	27.83 ± 11.41	8.61 ± 6.78	4.57 ± 1.72	38.95 ± 30.56	20.23 ± 9.39

Table 3 Resisting torque values for ankle motion in the study and control groups (mean ± SD)

	Plantar flexors (during dorsal flexion)				*Dorsal flexors (during plantar flexion)*			
	mT		*ΣT*		*mT*		*ΣT*	
	study	*control*	*study*	*control*	*study*	*control*	*study*	*control*
15°/s	12.29 ± 9.17	5.57 ± 3.92	57.0 ± 43.56	26.79 ± 18.45	7.42 ± 4.99	4.64 ± 3.08	33.74 ± 22.18	21.86 ± 14.16
30°/s	12.55 ± 8.05	5.21 ± 3.56	58.32 ± 42.54	25.86 ± 17.63	7.13 ± 4.54	4.43 ± 2.79	32.42 ± 19.78	20.7 ± 12.54
60°/s	13.16 ± 8.52	4.93 ± 3.29	59.77 ± 44.67	23.5 ± 15.91	7.61 ± 4.85	4.14 ± 2.63	32.65 ± 19.86	19.07 ± 12.05
90°/s	11.9 ± 9.28	4.57 ± 3.03	55.71 ± 42.61	22.21 ± 16.66	7.26 ± 5.2	3.64 ± 2.24	31.97 ± 20.85	17.79 ± 10.88
120°/s	10.77 ± 7.7	4.5 ± 3.06	49.9 ± 35.02	22.14 ± 14.7	6.9 ± 4.65	3.89 ± 2.43	29.97 ± 20.55	17.5 ± 10.43
Average	12.14 ± 8.64	4.96 ± 3.36	56.14 ± 40.34	24.1 ± 16.22	7.27 ± 4.7	4.1 ± 2.57	32.19 ± 20.92	16.27 ± 10.13

of patients with Ashworth grade 2 and control group was insignificant. There was no significant linear correlation between torque values and velocity of joint motion in either the patient or the control group. The torque-velocity relationships are illustrated in Figures 1–4.

Discussion

Quantification of spasticity is a complex problem for clinicians and researchers. Current techniques used for assessment of spasticity can be classified as clinical, neurophysiological, and biomechanical.[5] Although the Ashworth scale, the most commonly used clinical technique, is simple and practical, it remains a highly subjective measure and is of questionable reliability.[2,6,7] Neurophysiological techniques, such as the H-reflex, the H/M ratio, and the dynamic EMG, are highly dependent on the recording technique used, and the correlation between clinical spasticity and test results is poor.[8,9] Biomechanical tests, such as the pendulum, ramp and hold tests, among others, are not used regularly in daily practice since they require special equipment and do not provide information that is easily interpreted by the clinician.[4,10] Clearly, there is a need for a more reliable and easily applicable method for quantifying spasticity.

Recently, isokinetic dynamometers have been used to assess spasticity. These computer-run machines enable the investigator to standardize both velocity and angle of motion, and objectively record the amount of force generated by the patient's muscles. The operation and interpretation of this method is simple, and it can be applied to a variety of joints and muscles. In a study of eight spastic and six normal individuals, Firoozbakhsh *et al* used an isokinetic dynamometer to record four consecutive resisting torque amplitudes during flexion and extension of the knee joint at 30, 60 and 120°/s velocities.[11] They reported that the sum of torque amplitudes and the slopes of the torque-velocity curves was higher in the spastic patients than controls. Perell *et al* used the same method to assess muscle tone in ten normal individuals, and 11 spastic and six flaccid SCI patients.[12] They pointed out that this technique correctly classified 100% of the spastic subjects and could be useful in assessing individual response to therapeutic interventions aimed at modifying spasticity. In their recent report, Engsberg *et al* suggested that a combination of the key elements of stretch, resistance, and velocity under the mechanical term 'work' be used as a measure of spasticity instead of torque.[13] This parameter was calculated using the formula Work = Torque × Angular displacement,

Table 4 Correlation between Ashworth grades and average torque values

Spasticity score (Ashworth)	*Knee flexors (during knee extension)* *mT* *Mean±SD*	*ΣT* *Mean±SD*	*Hip adductors (during hip abduction)* *mT* *Mean±SD*	*ΣT* *Mean±SD*	*Knee extensors (during knee flexion)* *mT* *Mean±SD*	*ΣT* *Mean±SD*	*Ankle plantar flexors (during ankle dorsal flexion)* *mT* *Mean±SD*	*ΣT* *Mean±SD*
1	5.9±1.5	27.9±6.7	14.1±6.8	65.2±34.6	4.0±1.1	19.3±5.3	4.7±3.6	23.0±17.7
2	6.8±2.8	29.1±10.7	21.8±5.3	91.8±25.5	4.3±2.8	18.5±9.0	8.6±3.1	37.3±14.3
3	14.4±6.9	64.1±30.1	26.0±12.9	104.8±44.1	10.5±5.7	46.4±21.8	14.4±7.8	66.5±33.0
4	29.1±10.2	122.6±55.0	31.8±14.6	131.1±64.1	18.2±5.1	83.7±27.3	21.2±8.2	99.2±40.6
Correlation	$r=0.76^*$	$r=0.72^*$	$r=0.48^*$	$r=0.39^{**}$	$r=0.69^*$	$r=0.68^*$	$r=0.82^*$	$r=0.82^*$

$^*P<0.01$; $^{**}P<0.05$

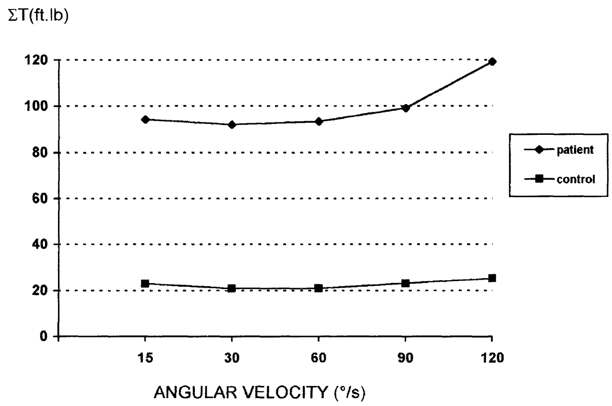

Figure 1 The relationship between angular velocity and ΣT for hip adductors during abduction

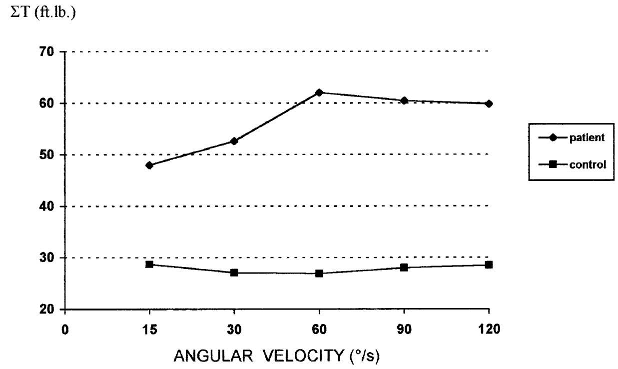

Figure 2 The relationship between angular velocity and ΣT for knee flexors during extension

which equaled the area between the torque-angle curve and zero line.

Our method was similar to Firoozbakhsh *et al* in that we measured spasticity on the bases of maximum torque and the sum of five consecutive torque amplitudes. This choice was made because the results of our preliminary study conducted on ten spastic SCI patients indicated that 'work' as a measurement of

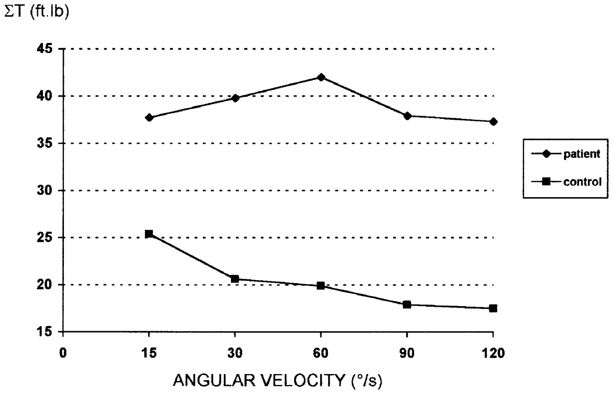

Figure 3 The relationship between angular velocity and ΣT for knee extensors during flexion

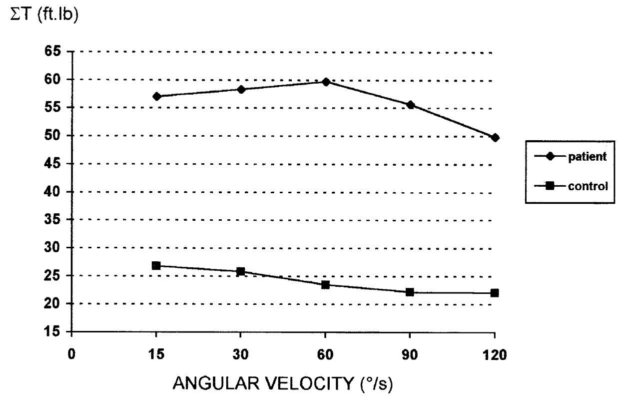

Figure 4 The relationship between angular velocity and ΣT for ankle plantar flexors during ankle dorsal flexion

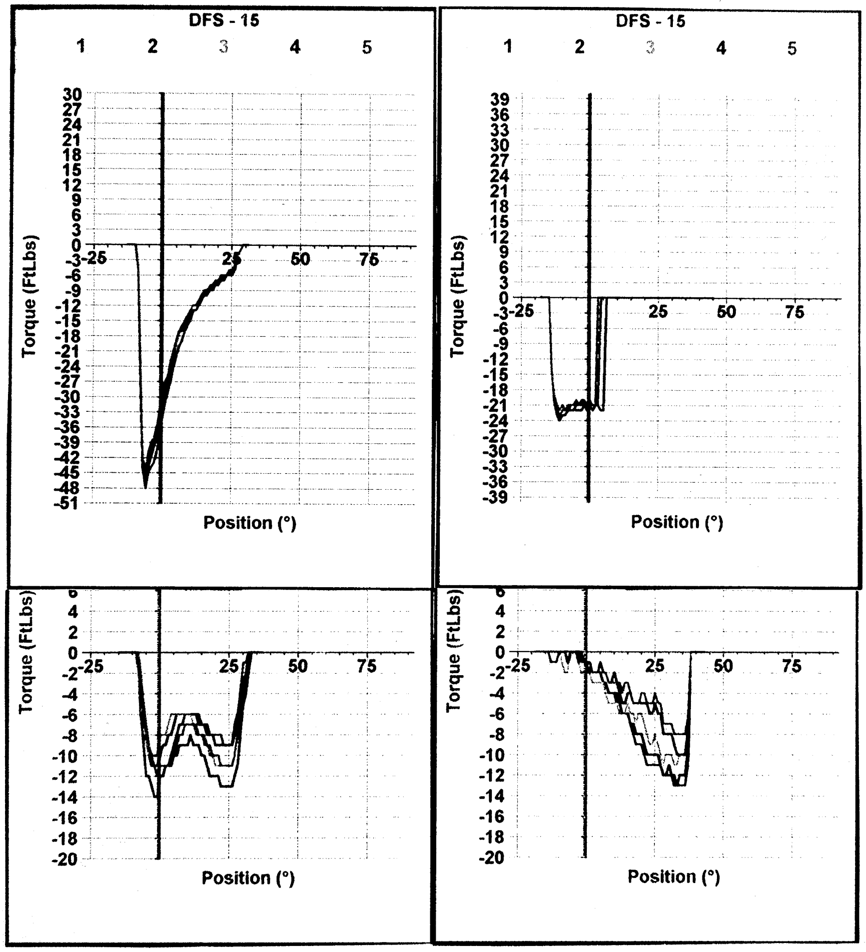

Figure 5 Torque-angle curves of four different patients obtained during ankle dorsal flexion studies at a velocity of 15°/s

spasticity is unreliable.[14] In that study, we obtained a variety of curve types, possibly representing different types of hypertonus, and not all could be classified as spasticity (Figure 5).

Spasticity can be distinguished from other types of hypertonus by its sensitivity to velocity of joint motion and reaching maximum early in the range of motion (Figure 6), manifesting a 'clasp-knife' quality.[5] We speculated that muscles exert almost equal resisting torque throughout the range of motion represent the effect of hyperactive, cutaneomuscular and/or tonic stretch reflexes, while a rapid increase and sudden giving way of resistance represent spasticity, a manifestation of hyperactive, phasic stretch reflex. In contrast, increasing resistance with greater joint angle, and hitting maximum at the end of the range of motion represent contracture. Although one muscle group may have a high peak torque and manifest a clasp-knife quality, representing severe spasticity, the work done by that muscle group can be minimal, and thus the area under the curve small. For this reason, we believe that torque amplitudes should be the measure of spasticity in the isokinetic dynamometric technique, but that 'work' can be used to quantify hypertonus of any type.

We studied not only the knee joint, but also the hip and ankle, to investigate the applicability of this method to other joints. All previous studies have been performed on knee flexors and extensors. We observed no significant linear increase in resisting torque values associated with increasing velocity in any of the motions we tested, a finding which concurs with the results of several previous studies.[11–13] This suggested to us that hypertonus may be due not only to hyperactive phasic stretch reflexes but also to other reflexes and to impairment of muscle viscoelasticity in the form of tightness or shortening/contracture. Katz and Rymer pointed out that intrinsic factors play an important role in resistance to joint motion.[3] Several investigators have stated that changes in the intrinsic mechanical properties of muscle are largely responsible for hypertonus, and that not all hypertonus is spastic.[5,15–18] We conducted our testing in the morning hours before patients underwent stretching and other exercises. It may be logical and more

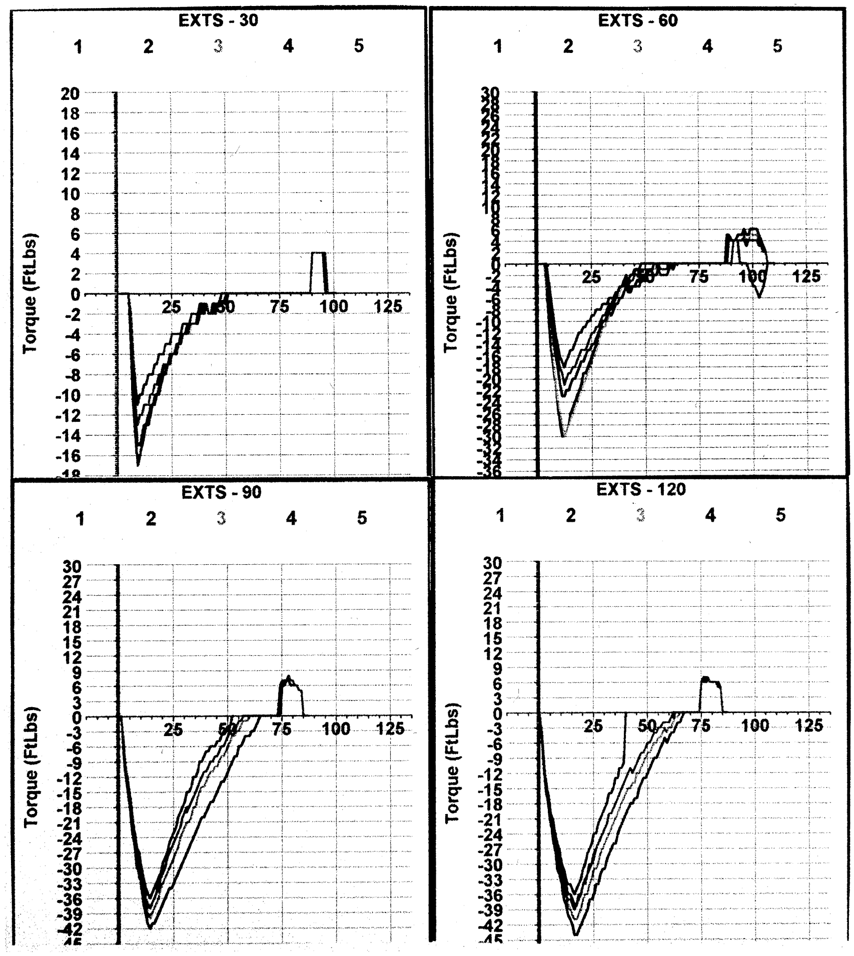

Figure 6 One patient's torque-angle curves obtained during knee extension studies at velocities of 30, 60, 90 and 120°/s

informative to re-measure after stretching and range of motion exercises.

We conclude that the isokinetic dynamometric technique is a valuable tool for assessing spasticity and all other hypertonic conditions. The resisting torque values correlate closely with Ashworth grades and perfectly reflect the clinical status of muscle tone. On the other hand, this method seemed to have its limitations where sensitivity is concerned, because patients with slightly increased muscle tone did not differ from normal individuals in torque values in most of the joint motions we tested. This method can be applied to all large joints of the lower limb, and data interpretation is simple. The torque-velocity curves may give information about the type of hypertonus involved, and may help to distinguish severe spasticity from contracture.

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