Original Article

The importance of posture on the isokinetic assessment of spasticity

TH Kakebeeke^{*1}, H Lechner¹, M Baumberger¹, J Denoth², D Michel¹ and H Knecht¹

¹Swiss Paraplegic Center, 6207 Nottwil, Switzerland; ²Laboratory for Biomechanics, ETH-Zürich, Wägistrasse 4, 8952 Schlieren, Switzerland

Objective: To measure spasticity of the knee flexors and extensor muscles in two different hip positions.

Setting: Swiss Paraplegic Center Nottwil, Switzerland.

Methods: Twenty spinal cord injured (SCI) patients with complete lesions were tested with a torque-velocity dynamometer in the following positions: (1) supine with a hip angle of 0°; (2) sitting with a hip angle of 90°. The excursion of the knee was measured for both positions using a goniometer. Two flexion/extension movements of the knee were performed at a speed of 10° per sec. A further four flexion/extension movements over the same trajectory were made at a speed of 120° per sec. Eccentric peak torques were measured continuously during movement of both legs for both speeds.

Results: At a speed of 120° per second, there was a significant difference in stretch reflex of the hamstrings and quadriceps femoris muscles for the two positions (Wilcoxon's paired *t*-test, *P* < 0.05). Excitability was higher for the quadriceps femoris muscles in supine than in sitting position. For the hamstrings, the effect was reversed. Significant differences between sitting and supine position were not found for the speed of 10° per sec. Test–retest reliability was high for the movements of 120° per sec but low for 10° per sec.

Conclusions: Our findings indicate that for a reliable and comparable measurement of spasticity, an exact description of test position and procedure is essential.

Spinal Cord (2002) 40, 236–243. DOI: 10.1038/sj/sc/3101282

Keywords: spasticity; isokinetic; hip position; speed; spinal cord injury

Introduction

It is very difficult to objectively quantify spasticity.¹ However, it might be necessary to assess the efficacy of therapeutic interventions.^{2–5} Many scales (in particular the Ashworth spasticity scale,⁶ the modified Ashworth scale,⁷ Penn's scale on spasms⁸ and the pendulum test⁹) as well as other techniques^{3,5,10–12} are currently used in an attempt to measure objectively all aspects of spasticity. From a study by Priebe *et al.*² we learn that several clinical scales for the measurement of spasticity correlate only poorly with each other, suggesting that these scales might assess different aspects of spasticity. It is for this reason that Priebe *et al.*² and Pirotte *et al.*¹³ proposed to use different scales, including spasm severity and frequency scales, clonus and Ashworth scores, on one subject in order to describe all aspects of spasticity for one patient.

Recently, the assessment of spasticity was performed by using isokinetic dynamometry in patients with spinal cord injury (SCI)^{3,5,12} and other neurological disorders.^{7,14,15} With this technique it is possible to test the resistance to passive movement in the joints with preset speeds at different lengths of the same muscle. As spasticity is defined as a velocity-dependent response of muscle to passive stretching,¹⁶ isokinetic dynamometry seems to be a technique suited for this purpose.

Increased passive movement restraint may have many causes. The resistance can be attributed to the properties of the collagen tissue (eg tendons, joints and muscles) and to the intrinsic properties of the stretched muscles. These are called the non-reflex properties.^{17–19} This article will focus on the increase in resistance mediated by the stretch reflex. Changes in the mechanics of muscle (eg contractures) cannot automatically be attributed to increased reflex activity. However, the increased passive resistance due to muscle contractures is not velocity dependent. This implies that before spasticity measurements are

*Correspondence: TH Kakebeeke, Institute for Clinical Research, Swiss Paraplegic Center, 6207 Nottwil, Switzerland

performed, the excursion of the joints that are involved should be checked first at a low speed. Only then changes in passive restraint with increased speed can be attributed to increased reflex activity.

From the study of Perell *et al.*³ we learn that a speed of 120° per sec was sufficient to demonstrate differences in the sum of four consecutive peak torques in the knee between three groups of (1) a normal able-bodied, (2) a spastic and (3) a flaccid SCI group. Speeds of 30°, 60° and 120° per sec were also used by others to investigate spasticity in the knee.²⁰ With these tests it was possible to differentiate the normal motor control subjects from the spastic subjects at a testing speed of more than 60° per sec.

Nevertheless, all objective measurements are limited by the variability of the phenomenon 'spasticity' *per se*, which is highly changeable not only over the duration of 1 day, but also from day-to-day in dependence of many uncontrollable factors.²¹ For instance room temperature, time of the day, bladder and bowel distention, previous activities, exhaustion, stress, position in which the spastic limb is tested, contribute to a high variability in the spasticity measurements.²²

It is the aim of this study to investigate the influence of the position of the hip (and therefore indirectly of the length of the different muscles) on the stretch reflex activity of the hamstrings and quadriceps femoris muscles. For this purpose we tested a flexion/extension movement of the knee in the supine and sitting position. The range of motion (ROM) was equally defined for both positions enabling us to test extensors and flexors of the knee at different lengths. Test–retest reliability measurements were performed for movements at the low and at the high speed.

Methods

Subjects and material

Twenty patients who have had a motor complete spinal cord lesion (ASIA A/B) for a minimum of 4 months were studied. Patients were included who were known to have spasticity in the lower limbs, who did not suffer from any joint problems or severe osteoporosis and had a hip extension of 0°. Mean age of the patients was 33.4 years (SD 10.3; range 20–60), mean time post injury 7.1 year (SD 8.6; 0.3–22.6). The level of injury ranged from C5–T6. Before testing, patients were informed about the purpose of this study and they were free to withdraw from the experiment at any time. A complete experimental set-up was located in the Swiss Paraplegic Center (Nottwil), where all the testing took place. Room temperature was set at 21° Celsius and testing took place with an empty bladder.

A commercially available computerized isokinetic dynamometer (Cybex Norm II, Lumex Inc. Ronkoma, NY, USA) was used to measure the eccentric torque (in Nm).

Measuring set-up

Before real testing, individual knee extension and flexion limits were set by goniometric measurements and manual testing of the ROM for each patient separately. We tested how much extension in the knee was possible with a hip in 90° flexion. The maximal possible extension was taken as the endpoint of the flexion/extension movement in the sitting position. The maximal possible flexion in the knee was defined when the patient was in the supine position. For the two measuring positions the tested range was the same. The tested range varied from 90° to 120° amongst patients. In this way the ROM was adapted to the flexibility of every patient and muscles were tested in two defined, stretched positions.

Patients were seated with the pelvis fixed in an upright position, the hips in 90° flexion and the lower legs hanging over the edge of the seat. The rotational axis of the dynamometer was placed in line with the axis of flexion/extension movement of the knee. Proximal attachment of the lower limb was made just above the knee with straps (width 10 cm), the distal attachment 4 cm above the lateral malleolus. Gravity correction was performed to account for the weight of the limb. After that the leg was moved two times from flexion to extension and vice versa, with a low speed of 10° per sec. Then, the same ROM was performed on the leg but with a higher speed. This procedure consisted of four times flexion/extension movements of the knee with a speed of 120° per sec, maximal eccentric torque limit (100 Nm) and a pause after four repetitions (5 min). After one side was tested, exactly the same procedure (first the slow and then the fast movements) was performed on the other leg also in the sitting position.

In the supine position, patients were positioned with the lower leg hanging over the edge of the seat; the pelvis was fixated with a strap (width 10 cm) over the spinae iliacae anteriores superiores to prevent hyperlordosis; attachment of the thigh was done with straps to the table, as in the seated position; the lower leg was fixed with straps 4 cm above the lateral malleolus. The other leg was placed with flexed knee and hip with the foot on the table. This leg was held in position by one of the experimenters. Schematic drawings of the two positions are given in Figure 1.

Figure 1 Schematic drawings of the supine and sitting position during spasticity testing

Measuring protocol

In order to prevent inter-operator variability two experimenters performed the same tasks throughout all measuring sessions. One measuring session consisted of two slow movements of the lower leg, a pause of 15 s and then four quick movements. Measurements of the

two legs and the two positions, were interspersed by rests of 5 min. Movements were performed on both legs, in both positions. Measuring was always started with the right leg. Half of the patients had both legs tested first in sitting and then in supine position; the other half of the patients completed the inverse protocol.

Table 1 Σ torques of all subjects at two speeds, positions and legs

Subject number	10° per sec in sitting				10° per sec in lying			
	right leg sitting EXT	right leg sitting FLE	left leg sitting EXT	left leg sitting FLE	right leg lying EXT	right leg lying FLE	left leg lying EXT	left leg lying FLE
1	18	16	19	12	22	10	30	6
2	12	12	14	8	16	14	16	8
3	16	16	18	12	37	8	49	2
4	10	5	16	8	18	6	22	6
5	10	18	14	14	27	10	18	6
6	6	6	8	4	15	6	18	8
7	6	4	10	5	10	8	12	6
8	8	13	10	8	16	4	27	2
9	10	8	12	4	26	8	32	6
10	8	8	10	10	24	13	36	17
11	6	4	8	4	14	10	13	4
12	8	10	14	6	14	4	22	4
13	8	10	8	4	22	8	20	6
14	14	8	12	4	26	10	27	8
15	14	12	12	6	19	10	20	4
16	16	6	10	4	28	8	24	4
17	12	8	6	4	25	8	22	4
18	14	15	12	13	20	10	16	4
19	6	12	8	6	10	8	10	7
20	8	10	12	10	24	11	30	6
mean (SD)	10.5±3.8	10.1±4.1	11.7±3.5	7.3±3.4	20.6±6.7	8.7±2.6	23.2±9.2	5.9±3.2

Subject number	120° per sec in sitting				120° per sec in lying			
	right leg sitting EXT	right leg sitting FLE	left leg sitting EXT	left leg sitting FLE	right leg lying EXT	right leg lying FLE	left leg lying EXT	left leg lying FLE
1	32	47	34	37	84	12	96	12
2	16	20	24	12	56	20	33	12
3	94	147	44	201	146	24	283	21
4	24	42	15	15	52	40	34	15
5	19	142	21	125	33	35	41	18
6	46	42	40	34	83	8	73	8
7	12	4	19	0	37	10	39	3
8	12	20	21	25	95	14	95	8
9	16	33	21	42	106	21	81	16
10	38	29	20	26	136	48	110	47
11	10	8	12	7	45	12	33	7
12	12	12	20	8	110	12	36	2
13	13	20	16	8	139	11	79	8
14	20	17	20	19	32	17	47	14
15	16	16	16	6	m	m	24	4
16	26	12	23	20	43	13	31	6
17	20	12	12	4	50	12	50	8
18	20	58	20	50	112	21	119	4
19	29	65	16	8	66	18	30	8
20	16	27	20	25	50	13	89	13
mean (SD)	24.6±18.8	38.7±39.8	21.7±8.4	33.6±47.9	77.6±38.0	19.0±10.9	71.2±58.2	11.7±9.8

EXT = extensors; FLE = flexors; m = missing data

Statistics

In order to determine the reliability of our measurements, all patients were tested twice, with exactly 1 week between the first and second measurement. This allowed us, at least for the inpatients, to rule out the

influence of weekly therapeutic applications like sauna, hydrotherapy and hippotherapy. For the outpatients we used the same procedure, as their sporting and therapeutic activities were also organized on a weekly basis.

Table 2 Peak torques of all subjects at two speeds, positions and tests

Subject number	10° per sec in sitting				10° per sec in lying			
	right leg sitting EXT	right leg sitting FLE	left leg sitting EXT	left leg sitting FLE	right leg lying EXT	right leg lying FLE	left leg lying EXT	left leg lying FLE
1	9	6	8	8	11	7	5	4
2	6	6	6	8	8	9	7	6
3	8	7	8	7	26	10	4	6
4	5	5	3	3	9	9	3	3
5	5	5	9	9	14	12	5	3
6	3	3	3	5	8	6	3	4
7	3	3	2	1	5	5	4	3
8	4	3	7	6	8	10	2	1
9	5	4	4	4	13	12	4	4
10	4	4	4	6	12	11	7	4
11	3	3	2	4	7	9	5	4
12	4	6	5	5	7	10	2	4
13	4	4	5	6	11	15	4	6
14	7	8	4	4	13	18	5	5
15	7	6	6	3	10	13	5	4
16	8	5	3	3	14	13	4	3
17	6	5	4	2	13	11	4	3
18	7	6	8	9	10	11	5	5
19	3	3	6	7	5	4	4	5
20	4	4	5	6	12	12	6	3
mean (SD)	5.3±1.9	4.8±1.5	5.1±2.1	5.3±2.3	10.8±4.5	10.4±3.3	4.4±1.4	4.0±1.3

Subject number	120° per sec in sitting				120° per sec in lying			
	right leg sitting EXT	right leg sitting FLE	left leg sitting EXT	left leg sitting FLE	right leg lying EXT	right leg lying FLE	left leg lying EXT	left leg lying FLE
1	8	5	16	19	23	16	3	5
2	4	4	5	5	16	28	4	4
3	27	10	57	50	57	87	7	9
4	8	5	19	8	21	27	16	8
5	5	5	41	50	9	21	19	20
6	13	11	13	12	24	22	2	3
7	3	3	1	1	14	16	3	3
8	3	14	5	12	28	32	4	3
9	4	4	15	3	29	31	7	3
10	14	18	11	17	38	40	14	10
11	3	3	2	3	15	7	3	3
12	3	4	3	4	30	32	3	3
13	4	6	5	10	46	45	3	5
14	5	6	5	5	8	14	5	4
15	4	4	4	2	m	m	m	m
16	7	5	3	1	11	9	4	2
17	5	4	3	2	14	7	3	2
18	5	5	20	19	30	37	6	6
19	17	5	20	15	27	28	5	4
20	4	4	10	2	15	17	4	3
mean (SD)	7.3±6.1	6.3±3.9	12.9±14.1	12.0±14.3	23.9±12.9	27.2±18.2	6.1±4.8	5.3±4.2

EXT = extensors; FLE = flexors; m = missing data

Tests on the reliability of our measurements were performed with a Spearman's correlation coefficient on the peak torque of the two slow and the four quick repetitions, and the sum of the two slow and the four quick consecutive torques (Σ torque). After that, a comparison was made between the peak torque and Σ torque of the extensor and flexor muscles of the knee in the sitting and supine position (non-parametric Wilcoxon's signed rank test). We chose P -values <0.05 as level of significance.

Results

There was a statistical difference between the right and left leg on peak torques and Σ torques, so that statistical procedures were performed for both legs separately. The Σ torques of all the subjects at the two speeds and positions are presented in Table 1. The peak torques of the right leg of all subjects at the two speeds, positions and tests are shown in Table 2.

The correlation coefficients between the first and second protocol for the low speed were only moderate and not always significant (Table 3). Also, the difference in peak torque and Σ torque for both legs in the two positions and at the low speed, did not reach a level of significance (Wilcoxon's signed rank test). The correlation coefficients of the movements at the higher speed were more stable and high, with the exception of the correlation of the extensors in sitting and the flexors in supine position (Table 3).

For the movements of 120° per sec there was a significant difference for the two positions (Wilcoxon's

Table 3 Spearman's correlation coefficients of hamstrings and quadriceps muscles for two positions and legs for 10° per sec

	<i>Right leg, sitting</i>	<i>Left leg, sitting</i>	<i>Right leg, supine</i>	<i>Left leg, supine</i>
<i>Peak torque</i>				
extensors	0.84**	0.72**	0.73**	0.80**
flexors	0.88**	0.47*	0.28	0.28
Σ Torque				
extensors	0.83**	0.72**	0.74**	0.77**
flexors	0.89**	0.47*	0.37	0.22

* $P < 0.05$; ** $P < 0.01$

Spearman's correlation coefficient of hamstrings and quadriceps muscles for two positions and legs for 120° per sec

	<i>Right leg, sitting</i>	<i>Left leg, sitting</i>	<i>Right leg, supine</i>	<i>Left leg, supine</i>
<i>Peak torque</i>				
extensors	0.57*	0.65**	0.89**	0.76**
flexors	0.81**	0.87**	0.64**	0.77**
Σ Torque				
extensors	0.58	0.55*	0.82**	0.81**
flexors	0.81**	0.74**	0.68**	0.72**

* $P < 0.05$; ** $P < 0.01$

Table 4 Peak torque and Σ torques of all subjects at 120° per sec

	<i>Right leg, sitting (SD)</i>	<i>Left leg, sitting (SD)</i>	<i>Right leg, supine (SD)</i>	<i>Left leg, supine (SD)</i>
<i>Peak torque</i>				
extensors	7.3 (6.1)	6.0 (2.7)	23.9 (12.9)	20.9 (16.0)
flexors	12.9 (14.1)	10.5 (13.4)	6.1 (4.8)	3.6 (3.0)
Σ Torque				
extensors	24.6 (18.8)	21.7 (8.4)	77.6 (38.0)	71.2 (58.2)
flexors	38.7 (39.8)	33.6 (47.9)	19.0 (10.9)	11.7 (9.8)

signed rank test, Table 4). The excitability of the extensors of the knee was higher in the supine than in the sitting position, for the flexors it was reverse. In the sitting position it was easier to elicit spasms in the hamstring muscles. An example of the dependence of hip position and reflex reaction of the hamstrings and quadriceps femoris muscle is given in Figure 2.

Discussion

In this study we were able to demonstrate that the length of a muscle plays an important role when testing spasticity. For both muscle groups (knee flexors and extensors) the elicited torques were significantly higher in the lengthened than in the more shortened position.

Statistical procedures were performed for both legs separately, as there was a statistical difference in peak torque and Σ torque between the legs. This study was designed to investigate the influence of position on reflex excitability, so we counterbalanced the subjects for position order and not for dexterity. The degree of spasticity is rarely equal in the right and left leg in SCI subjects, but there is no indication in literature that dexterity has an influence on spasticity. For protocol reasons we always started with the right leg in both positions. This might explain why the measured torques in the right leg were mostly higher than in the left leg. The excitability of the muscles probably declined during testing.

At a speed of 10° per sec, there was no significant difference in neither peak torque nor Σ torque between the sitting and supine position. The reason for this was that the variability of the torques was larger than the differences in torque between the two positions. Probably this was caused by the experimental procedure as the ROM was checked manually and therefore was biased by the subjective determination. There was no reason to believe that the experimenter would judge this resistance in one direction or the other differently. It is, therefore, obvious that the movements with the low speed – based on mobility tested by the experimenter beforehand – only elicited small torques and that they did not differ significantly from each other.

Despite its widespread use, the Ashworth scale of 1964⁶ does not prescribe the speed with which the movements are to be made. Nielsen and Sinkjaer²³ tested the stretch reflex amplitude of the soleus muscle against stretch velocities between 16 and 120° per sec on multiple sclerosis patients. From a speed of 20° per sec and more, the stretch reflex amplitude started to increase clearly, indicating a dependence of stretch reflex activity and velocity. An increase in reflex activity was also found in relation to increased velocity imposed on the limb in spinal cord injured patients.^{3,5,20} We therefore used a speed of 120° per sec which has been

proven to be a useful speed to quantify spasticity.³ Our investigations show that spasticity measurements performed without mentioning the speed with which the limb is moved, are not very useful.

At the speed of 120° per sec, there was a significant difference concerning peak torque and Σ torque of the flexors and extensors for the two positions. Concerning the position of the limb, the effect of increasing muscle length on reflex activity of the quadriceps and hamstrings stretch reflex was investigated in another study.¹⁰ The response to sinusoidal oscillations was investigated for both muscles in a position of different

Figure 2 Example of 4 × 4 eccentric torques at 120° per sec in dependence of position

magnitude of stretch for the muscle. The effect of increasing muscle stretch on the quadriceps stretch reflex was inhibitory, whereas this effect was opposite on that of the hamstrings. In the latter, the strongest reflex responses were with the longer muscle length. The explanation for this phenomenon lies in the 'flexor reflex afferent' which produces an autogenic inhibition of extensor reflexes and facilitation of flexor reflexes in response to changes in muscle length.¹⁰ As we did not measure EMG we were not able to determine where exactly in time and angle the reflex was strongest. In our experiment we measured different responses in torque for the two positions and muscles with the greatest response in torque appearing at a later stage in the movement for the hamstrings compared to the quadriceps muscles.

We found a difference in torque and Σ torque for the flexors and extensors dependent of hip positions. As the greatest difference between the sitting and supine position concerning the lower limb is accounted for by the difference in stretch of the knee flexors and extensors, there are very good reasons to assume this difference to be attributed to these differences in length. This implies that for the sitting position the flexors of the knee are more lengthened during extension of the knee than in supine position. For the supine position the opposite is true: in this position the extensors of the knee are more lengthened during flexion of the knee compared with the sitting position.

Also in the experiments of Burke *et al*, there was a linear relationship between the velocity of stretch and the integrated EMG response underlining the dynamic nature of the stretch reflex in both muscles.¹⁰ The difference in eccentric torque between the low and the high speed in our experiment is in line with these data. Actually, during the movements at the low speed we were not able to elicit spasticity and hence we could not find any statistical differences between the two hip positions concerning torque and Σ torque.

The position of the subject and the limbs involved in the movement have to be defined before the testing can start. As the reflex activity of both the flexors and extensors was position dependent in our study, a standardized performance of spasticity testing concerning position of limbs and trunk seems to be very important.

Also, we were able to repeat our measurements reliably from 1 week to another. Correlation coefficients were even higher, when we were able to elicit spasticity. The highest correlation coefficients were gathered for the knee extensors in the supine position and for the knee flexors in the sitting position. In these positions it was most easy to elicit spasticity as the muscles were more stretched during testing.

Conclusions

Our data demonstrate that it is possible to quantify spasticity reliably on condition that the patient is positioned in such a way that spasticity can be

provoked. The most reliable measurements of spasticity can be drawn when the spasticity producing muscle is in a lengthened position. The two muscle groups that were investigated in this study produced definitely more torque and Σ torque, ie it was easier to elicit spasticity when the tested muscles were exposed to more stretch prior testing.

The following conclusions with regard to the practical implication for the measurement of spasticity with an isokinetic dynamometer can be made: the hamstrings are best tested with hips flexed in 90° while for the quadriceps muscle extended hips are preferable. If an isokinetic dynamometer is not available, the results found in this study are also applicable for other measurements of spasticity, eg Ashworth scale or EMG recordings. Precise documentation of standardized measuring protocols is most important when high reproducibility is required.

References

- 1 Sehgal N, McGuire JR. Beyond Ashworth: Electrophysiologic Quantification of Spasticity. *Phys Med Rehabil Clin N Am* 1998; **9**: 949–979.
- 2 Priebe MM, *et al*. Clinical assessment of spasticity in spinal cord injury: a multidimensional problem. *Arch Phys Med Rehabil* 1996; **77**: 713–716.
- 3 Perell K, Scremin A, Scremin O, Kunkel C. Quantifying muscle tone in spinal cord injury patients using isokinetic dynamometric techniques. *Paraplegia* 1996; **34**: 46–53.
- 4 Wang R, Tsai M, Chan R. Effects of surface spinal cord stimulation of spasticity and quantitative assessment of muscle tone in hemiplegic patients. *Am J Phys Med Rehabil* 1998; **77**: 282–287.
- 5 Franzoi AC, Castro C, Cardone C. Isokinetic assessment of spasticity in subjects with traumatic spinal cord injury (ASIA A). *Spinal Cord* 1999; **37**: 416–420.
- 6 Ashworth B. Preliminary trial of carisoprodol in multiple sclerosis. *Practitioner* 1964; **192**: 540–542.
- 7 Bohannon RW, Smith MB. Interrater Reliability of a Modified Ashworth Scale of Muscle Spasticity. *Phys Ther* 1987; **67**: 206–207.
- 8 Penn RD *et al*. Intrathecal baclofen for severe spinal spasticity. *Lancet* 1989; **320**: 1517–1521.
- 9 Wartenburg R. Pendulousness of the legs as a diagnostic test. *Neurology* 1951; **77**: 282–287.
- 10 Burke D, Lance JW. Studies of the reflex effects of primary and secondary spindle endings in spasticity. In: Desmedt J (ed). *New Developments in Electromyography and Clinical Neurophysiology*. Basel: Karger. 1973, pp. 475–495.
- 11 Sköld C *et al*. Simultaneous Ashworth Measurements and Electromyographic Recordings in Tetraplegic Patients. *Arch Phys Med Rehabil* 1998; **79**: 959–965.
- 12 Akman MN *et al*. Assessment of spasticity using isokinetic dynamometry in patients with spinal cord injury. *Spinal Cord* 1999; **37**: 638–643.
- 13 Piroette B *et al*. Chronic intrathecal baclofen in several disabling spasticity: Selection clinical assessment and long-term benefit. *Acta Neurol Belg* 1996; **4**: 267–269.
- 14 Brar SP *et al*. Evaluation of Treatment Protocols on Minimal to Moderate Spasticity in Multiple Sclerosis. *Arch Phys Med Rehabil* 1991; **72**: 186–189.

- 15 Smith MB *et al.* Baclofen Effect on Quadriceps Strength in Multiple Sclerosis. *Arch Phys Med Rehabil* 1992; **73**: 237–240.
- 16 Lance JW. Symposium synopsis. In: Feldman RG, Young RR, Koella WP (eds). *Spasticity: Disordered motor control*. Chicago:Yearbook Medical Publishers 1980, pp 485–494.
- 17 Katz RT, Rymer WZ. Spastic hypertonia: mechanisms and measurement. *Arch Phys Med Rehabil* 1989; **70**: 144–155.
- 18 O'Dwyer NJ, Ada L. Reflex hyperexcitability and muscle contracture in relation to spastic hypertonia. *Curr Opin Neurol* 1996; **9**: 451–455.
- 19 Sinkjaer T. Muscle stiffness in spastic patients. In: Miscio G, Pisano F (eds). *Spasticity: mechanisms, treatment and rehabilitation*. Pavia: Maugeri Foundation Books 1999, pp. 23–35.
- 20 Firoozbakhsh KK, Kunkel CF, Scremin AME, Moneim MS. Isokinetic dynamometric technique for spasticity assessment. *Am J Phys Med Rehabil* 1993; **72**: 379–385.
- 21 Little JW, Micklesen P, Umlauf R, Britell C. Lower Extremity Manifestations of Spasticity in Chronic Spinal Cord Injury. *Am J Phys Med Rehabil* 1989; **68**: 32–36.
- 22 Tripp EJ, Harris SR. Test-Retest Reliability of Isokinetic Knee Extension and Flexion Torque Measurements in Persons with Spastic Hemiparesis. *Phys Ther* 1991; **71**: 390–396.
- 23 Nielsen JF, Sinkjaer T. A comparison of clinical and laboratory measures of spasticity. *Mult Scler* 1996; **1**: 296–301.