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Isokinetic muscle testing for weak patients suffering from neuromuscular disorders: A reliability study

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Abstract

Precise, sensitive muscle strength testing methods are needed to investigate muscle function in patients with neuromuscular disorders (NMD). Here, we describe an isokinetic knee flexor and extensor testing procedure using the Biodex 3®'s continuous passive motion (CPM) mode. The torque values recorded during passive isokinetic motion were subtracted from the torque values obtained for the same movement with maximal, concentric effort. The aims of the present study were to (i) evaluate the method's reliability in NMD patients presenting mild to severe muscle weakness and (ii) study the relationship between manual muscle testing (MMT) and isokinetic dynamometry. The fifteen participating patients were tested twice; the respective intraclass correlation coefficients (ICCs) for the two sessions ranged from 0.91 to 0.99 for the peak torque, work and power and from 0.50 to 0.90 for the angle at peak torque. The Spearman rho correlation coefficients comparing isokinetic values and MMT values ranged from 0.67 to 0.74 ($p < 0.01$). This reliable, dynamic method appears to be of great value in NMD evaluation when sensitive strength measurement at the knee is required.

Keywords: Neuromuscular; Isokinetic; Reliability

1. Introduction

Muscle weakness is the major clinical manifestation in hereditary neuromuscular disorders. Precise, sensitive strength testing methods are needed to investigate muscle function in very weak patients. The quantitative measurement of muscle strength can be performed with an isokinetic dynamometer: these machines enable the quantitative assessment of a dynamic muscle contraction in which the velocity, the resistance and the joint position are tightly controlled [1]. Indeed, isokinetic evaluation methods have displayed good reliability and sensitivity for knee and ankle function assessment in people suffering from orthopaedic disorders. To date, isokinetic dynamometers have mostly been used as a reinforcement technique or as a muscle strength assessment method in people with mild or moderate strength impairments. However, the use of isokinetic evaluation has rarely been described in neurological defects in general and in neuromuscular disorders (NMDs) in particular.

A few studies have described the use of isokinetic testing in NMD patients with mild or moderate weakness [2–13]. The first studies involving the use of isokinetic dynamometers to evaluate neurological disturbance were reported by Griffin et al. and by Wagner et al. [14,15]. Both featured the use of a Cybex

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II® active procedure to investigate muscular dystrophy patients. Wagner et al. studied the efficacy of a reinforcement program on a patient with scapuloperoneal muscular dystrophy. Griffin et al. studied the relation between MMT and isokinetic dynamometry and concluded that the latter method was not suited to subjects with severe muscle weakness. Using a similar approach (isokinetic dynamometry on the Cybex II® with an active procedure), Backman monitored children with Duchenne muscular dystrophy and noted the method's limitations for assessment of very weak patients [16]. In 1992, Merlini et al. first described the use of a continuous passive motion (CPM) procedure with the Lido-active® dynamometer [11] (it should be noted that the latter apparatus is no longer on the market). These authors reported the isokinetic evaluation (at 30°/s) of patients with Duchenne and Becker muscular dystrophy and spinal muscular atrophy at different disease stages. Comparison of the isokinetic torque with the MMT values for the knee flexors and extensors showed that isokinetic measurement was more sensitive than MMT, even in cases of severe weakness. To date, only one other article has reported the use of this method: Andersen et al. evaluated the strength of ankle flexors and extensors of patients with neuropathy using the Lido-active® dynamometer's CPM mode and reported that the reproducibility was low for very weak patients [4]. No other study has described the use of the CPM isokinetic method.

Isokinetic strength evaluation in facioscapulohumeral muscular dystrophy (FSHD) has been studied by Kilmer et al. by using the Lido-active® dynamometer [9,17] to test elbow and knee flexors and extensors with an active procedure that had been described earlier by Lord et al. [9]. Kilmer et al. also evaluated simulated work performance tasks by mean of the Lido Work-SET, a microcomputer-controlled work simulation device which was developed to test functional tasks in patients with neuromuscular disorders [6].

Use of the CPM procedure enables very weak subjects to be tested, which is not possible with active procedures. The method is simple; the patient is instructed to actively accompany the movement (i.e. whilst pushing as hard as possible against the lever arm) and any exerted force is recorded – even if the patient is very weak.

The major criticism of isokinetic methods is that they only allow evaluation at a few joints and, above all, that they lack sensitivity in cases of severe weakness. The standard isokinetic testing method requires the subject to have enough strength to "actively" move the limb and the lever arm. During "active" isokinetic testing, the patient is instructed to push "as hard as possible" on the lever arm in order to move it and reach the predetermined velocity; this is not possible in cases of severe weakness, when patient is not even strong enough to move his limb and the lever arm against gravity.

This disadvantage is circumvented if a continuous passive motion (CPM) programme is chosen; here, the robot moves the limb and the dynamometer lever arm at a preset velocity whilst recording all forces applied to the lever arm. After calculating and compensating for the combined weight of the limb and the lever arm, even slight forces produced by the subject can be detected. Merlini et al. [11] have described this type of procedure for neuromuscular disorders and showed that at low velocity (30°/s), it was possible to test patients scoring less than grade 3 in manual muscle testing (MMT).

Here, we describe an isokinetic testing procedure using the Biodex 3®'s CPM mode. The method includes passive, isokinetic limb mobilisation, which allows one to measure gravity and passive resistance. This measurement is then subtracted from the value recorded during the same mobilisation in which the patient has to actively accompany the motion, i.e. whilst pushing against the lever arm as hard as possible. The torque curve resulting from this subtraction represents the force actually exerted by the patient.

The aim of the present study was to (i) evaluate the reliability of this isokinetic method for knee flexor and extensor testing in NMD sufferers presenting mild to severe muscle weakness and (ii) study the relationship between MMT and isokinetic dynamometry.

2. Subjects and methods

2.1. Subjects

Fifteen subjects with hereditary neuromuscular disorders (12 women, 3 men) aged from 16 to 67 years (mean age: 40.4) participated in the study. All subjects had a confirmed diagnosis (via molecular biology or muscle biopsy methods) but were exempt from consistent leg muscle or joint pain. All subjects had a knee range of motion (ROM) of about 90°, except for one individual (suffering from limb girdle muscular dystrophy 2A, LGMD2A) with a lower value (50°) for both knees. The population is described in Table 1. All subjects received comprehensive information about the study's goals and procedures and gave their informed consent to participation.

2.2. Measurements

A Biodex 3® isokinetic dynamometer (Biodex Medical Systems Inc., Shirley, NY, USA) was used for all measurements. Subjects were seated in all tests, with a hip flexion of 85°. Stabilization straps were placed across the trunk, around the waist and around the mid-thigh of the leg to be tested. The dynamometer's lever arm was positioned 2 cm proximal to the lateral malleolus. The lever's axis was aligned visually with

Table 1
Description of the population

Subjects	Diagnosis	Age (y)	BMI (kg m^{-2})	Gender	MMT			
					Right knee		Left knee	
					Extensors	Flexors	Extensors	Flexors
1	Distal myopathy (Miyochi)	34	22.1	F	3	3	3	3
2	Facioscapulohumeral dystrophy	64	23.8	F	4	3+	4	4
3	Congenital muscular dystrophy	16	22.7	F	3+	3+	3+	3+
4	Steinert muscular dystrophy	40	21.2	F	4+	5	4+	4
5	Limb girdle muscular dystrophy 2A	23	28.4	F	3−	2	3−	2
6	Type 2 Glycogenosis	39	17.3	F	4+	4−	4+	4
7	Type 2 Glycogenosis	20	18.8	F	3−	2−	3−	2−
8	Limb girdle muscular dystrophy 2A	67	19.6	M	4−	2	4	2
9	Steinert muscular dystrophy	50	27.5	M	3−	4	3−	4
10	Central core congenital myopathy	40	30.4	F	4	3+	4	3+
11	Facioscapulohumeral dystrophy	55	23.1	M	5	3+	5	4
12	Limb girdle muscular dystrophy	55	28.8	F	4+	5	4−	4−
13	Limb girdle muscular dystrophy 2A	19	22.8	F	4	4	4	4
14	Facioscapulohumeral dystrophy	40	29.6	F	5	5	5	5
15	Distal myopathy	50	33.3	F	4	4	4	4

the knee's anatomical rotational axis. The position of the seat and dynamometer and the length of the lever arm were noted, in order to reproduce the set-up in the patient's subsequent test session. Each subject's weight and body height were noted. Manual muscle testing was performed using the modified MRC scale [10].

The reference position (90° flexion) was recorded. The amplitude of the range of motion (ROM) varied from 80 to 100° (except for patient 8, who had a ROM of 50°). All subjects performed two sessions, separated by at least 2 h. Right and left knees were tested during each session.

The sessions were performed according to the following procedure:

1. Mode 1: passive mobilization of the knee, with 5 consecutive flexion/extension cycles at 10°/s. The patient was instructed to relax as full as possible.
2. Mode 2: the patient was instructed to accompany the same movement whilst trying to push as hard as possible against the lever arm, for 3 consecutive flexion/extension cycles. The patient received strong verbal encouragement during the procedure.

Same procedure was repeated at a velocity of 30°/s. The contralateral limb was then tested with the same position and recording procedures.

Analog signals (position, velocity and torque) were directly recorded from the dynamometer, sampled at 1000 Hz and recorded on a computer for further analysis.

2.3. Signal processing

Raw signals were smoothed using moving average filtering (window length: 100 ms). The strength produced by the patient was computed by subtracting the force curve measured when he was relaxed from that measured when he attempted to actively assist the lever arm movement (Fig. 1). The Biodex technology relies on constant measurement of the torque produced by the patient and then modifies the resistance or the torque produced by the dynamometer in order to control the velocity. Depending on the intensity of the applied torque, this regulation can take a few milliseconds and so a time delay between the mode 1 and mode 2 curves is progressively induced. Hence, the signals are first re-sampled in order to align the curves in both modes and thus compensate for this time shift.

Parameter computation was performed for 80% of the ROM in each direction of movement (10% at the beginning and 10% at the end of the movement were deleted for computation), in order to avoid errors due to (i) delays in muscle activation at the start of the movement and (ii) early termination of muscle contraction before the change in movement direction (see Fig. 1). For each of the three efforts, peak torque, angle at peak torque, total work and mean power were computed for 80% of the ROM.

2.4. Statistical analysis

For the within-session repeatability study, a coefficient of variation (standard deviation/mean) was calculated for each variable in each of the three efforts. We then computed an intraclass correlation coefficient (ICC) for the three efforts. $ICC_{2,1}$ was computed according to Shrout and Fleiss formulas ($ICC_{2,1}$ = patient variance/total variance) on the whole patient population ($n = 15$) assuming a repeated measurements design with three MVC trials ($k = 3$) for the within session reliability evaluation. ICC was calculated using a two-way mixed effects

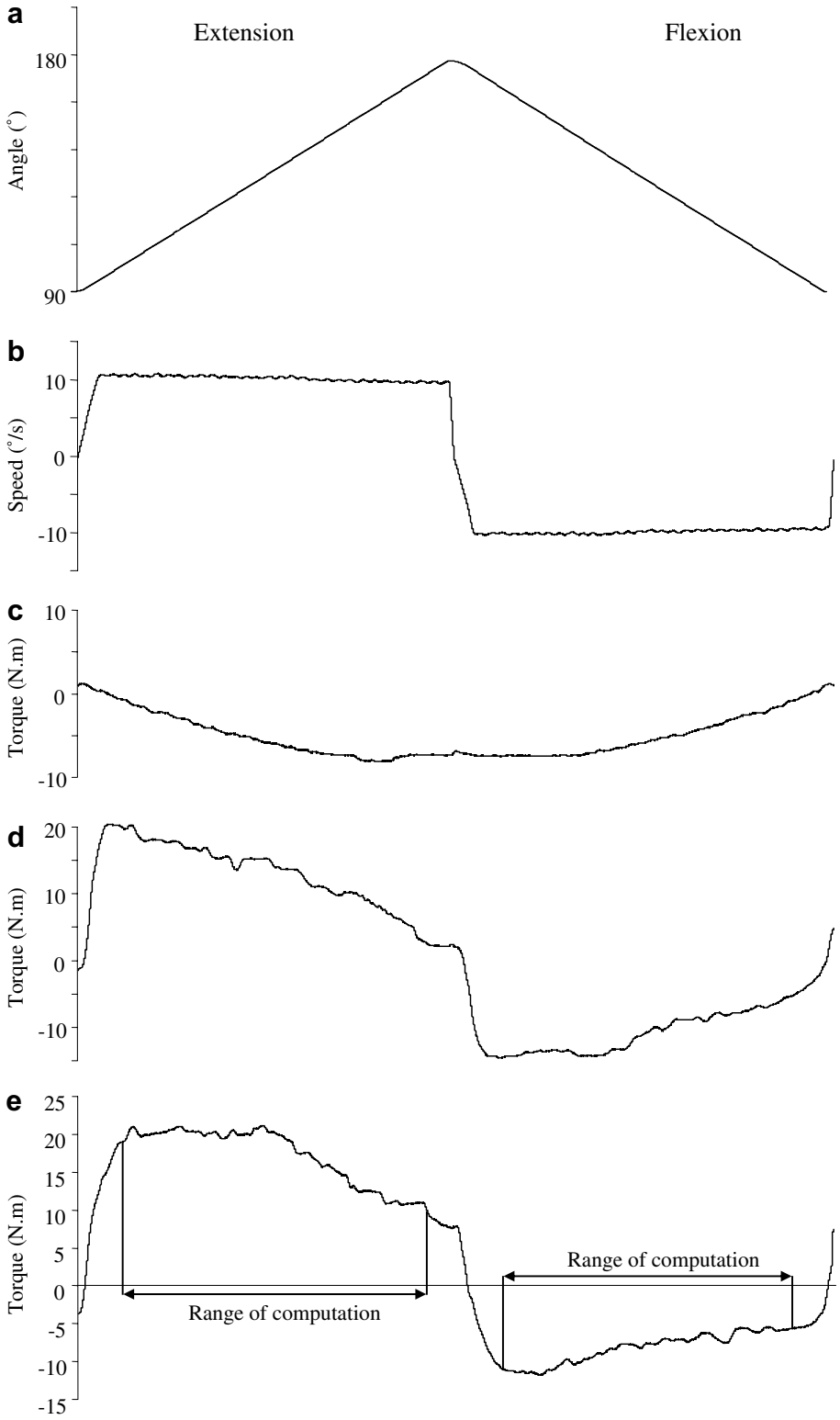

Fig. 1. Angle, movement speed and force curves for one extension/flexion cycle. (a) Knee angle curve. (b) Movement speed curve. (c) Force curve recorded in mode 1, with the subject as relaxed as possible. (d) Force curve recorded in mode 2, with the subject actively accompanying the movement (i.e. pushing as hard as possible). (e) The resulting force curve for the subject, following subtraction of the mode 1 curve from the mode 2 curve; the graph represents the subtracted force after resampling, hence the actual force generated by the patient. The subject was a 16-year-old female patient suffering from a congenital muscular dystrophy (without merosin deficiencies). Manual muscle testing (MMT) scores were 3+ for flexion and extension, on both sides.

model in SPSS for each session, each speed of movement and each leg. $ICC_{2,1}$ was derived from an analysis of variance (ANOVA) and was generally considered as poor when below 0.6, as good when comprised between 0.6 and 0.8 and as excellent when above 0.8 [12].

For between-session repeatability, we first identified which of the three efforts in each of the two sessions displayed the highest work value. The method's reliability was then assessed by calculating an $ICC_{2,1}$ for these two maximal efforts.

Manual muscle testing and isokinetic data were compared via calculation of a Spearman rho correlation coefficient. The modified MMT uses a non-linear scale where numerical main scores (graded from 0 (no muscle activation) to 5 (normal strength)) may be combined with non-numerical subscores (giving a score of 3− or 4+, for example). Hence, we converted the non-numerical subscores into numerical scores (i.e. 1+ = 1.33, 2− = 1.66, and so on) in order to calculate correlation coefficients.

All statistical analyses were performed with SPSS v11.5 software (SPSS, Chicago, IL, USA).

3. Results

All subjects performed the procedure twice for each knee (with the exception of subject 13, who was tested for the left knee only, due to right knee pain on the day of examination).

Pulling the data of both sessions, peak torque values for the knee extensors ranged from 5.6 to 163.8 Nm at 10°/s (see Fig. 2 lower graph) and from 4.6 to 174.4 Nm at 30°/s. Peak torque values for the knee flexors ranged from 1.7 to 67.8 Nm at 10°/s (see Fig. 2 upper graph) and from 2.2 to 72.7 Nm at 30°/s.

3.1. Within-session repeatability

The coefficients of variation for the three efforts in each session ranged from 5% to 13% for the peak torque, from 7% to 32% for the angle at peak, from 8% to 17% for the work and from 8% to 17% for the power.

Within-session ICCs were systematically higher than 0.91 for the peak torque, work and power and ranged from 0.50 to 0.90 for the angle at peak torque (Table 2). Mean within-session ICCs were calculated for both sessions (including right and left sides) for flexion and extension. Apart for the angle at peak torque, within-session ICCs tended to be higher in the second session than in the first one. However, individual maximal performances were similar in both sessions.

3.2. Between-session repeatability

Between-session ICCs ranged from 0.92 to 0.99 for the peak torque, work and power and from 0.56 to 0.90 for the angle at peak (Table 3).

3.3. Correlations between MMT scores and isokinetic measurements

Correlation coefficients comparing MMT scores and isokinetic parameters ranged from 0.67 to 0.74 (Table 4). Fig. 2 shows the relationships between MMT scores and the isokinetic peak torque measured at 10°/s. It should be noted that a given MMT grade can correspond to a broad range of dynamic strengths as measured by the isokinetic dynamometer. The correlation coefficients were slightly better for the work than for the other parameters.

4. Discussion

This study aimed at assessing the reliability of isokinetic measurements of muscle strength in a population of weak NMD patients.

Previous studies about isokinetic dynamometry reliability with normal adult subjects have been conducted with higher velocities (60 to 300°/s) and with different devices: it is admitted that isokinetic dynamometry shows good intrarater and interrater reliability. Nevertheless, reliability of a specific procedure adapted to weak patients with neuromuscular disorders has not previously been studied. Since the procedure was described specifically for these patients, we decided to study the reproducibility with an affected population and not to compare the affected population to a normal one. The results showed excellent repeatability for the peak torque, work and power values in consecutive efforts within a single session and when comparing maximal efforts in two successive, repeated sessions. However, we observed greater mean within-session ICCs for the second session than for the first one: this may be due to habituation or a learning effect for the patient vis-à-vis the dynamometer and implies that short-term follow-up studies should include at least one "training" visit. This will be of particular importance in therapeutic trials.

We observed that reliability for the angle at peak torque was always lower than other parameters except for within session 1 reliability at 10°/s for the right knee (see Table 2). Although this parameter is frequently reported in isokinetic studies, it does not seem to be reliable and is almost certainly related to the features of the torque curve. Here, weak patients (tested at low velocities) had to maintain a maximal effort for between 3 and 10 s, and the resulting torque curve frequently displayed a stabilisation phase. The absence of a bell-shaped curve meant that the peak torque could occur at a range of angles (see Fig. 1).

The correlations between isokinetic data and MMT values are worthy of comment. Firstly, we had to convert non-numerical MMT values into numerical values. On the MRC clinical rating scale, the score

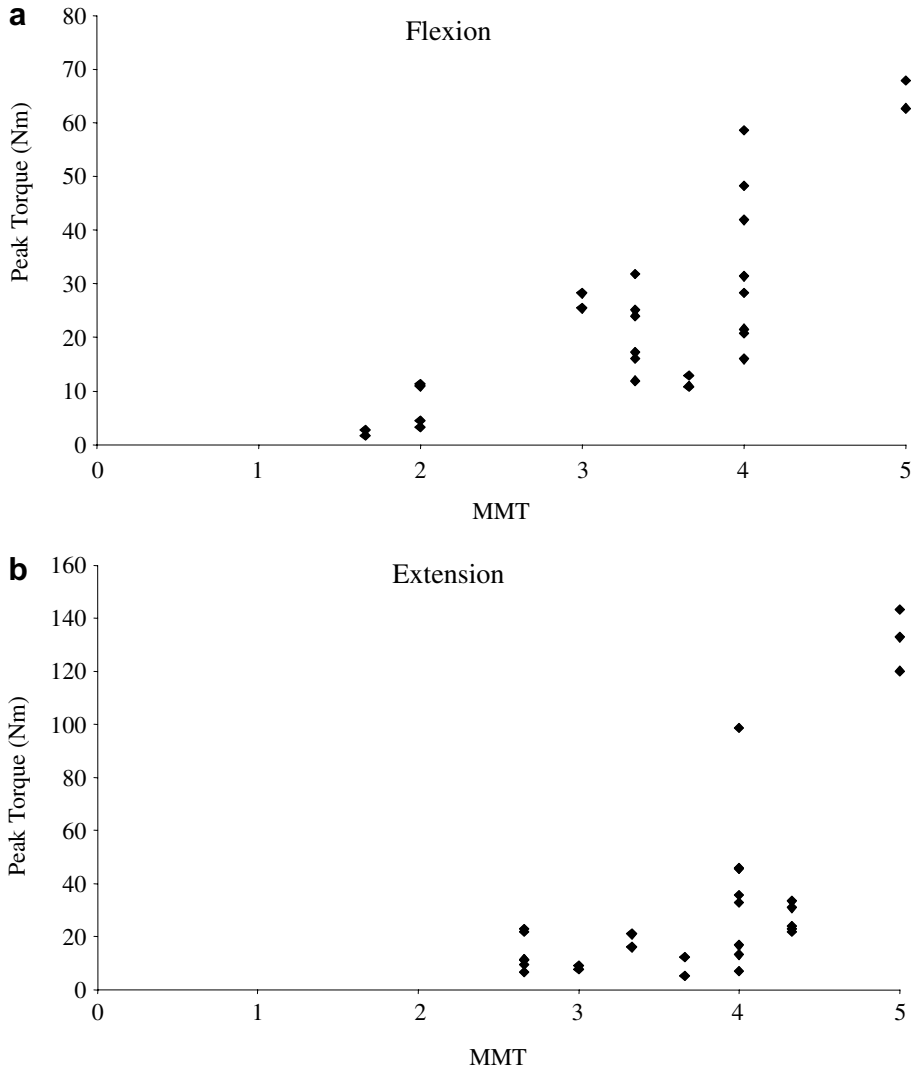

Fig. 2. Relationship between manual muscle testing (MMT) scores and isokinetic peak torque (i.e. the highest value of three efforts, see statistical analysis) measured at 10°/s during session 1. (a) Flexion. (b) Extension.

depends on the movement produced in a standardized position and so is not a linear measurement of muscle strength. Since the MMT score is related to the subject's ability to move the limb against gravity, we must bear in mind that MMT depends on the limb's weight. Merlini et al. observed the change in strength over time for a young patient with spinal muscular atrophy: even though the strength measured with an isokinetic dynamometer remained constant or increased slightly during the growth period, the imposition of greater resistance (as the limb increased in length and weight with age) was interpreted by MMT as a loss of strength [10]. This observation means that unlike isokinetic measurement, the MMT score is not a guide to absolute strength. By way of an illustration, a given MMT grade can correspond to a large range of absolute strength values, as shown in Fig. 2.

Although the correlation coefficients for the flexors and extensors appeared to be good, we observed a non-linear relationship between isokinetic data and MMT values (seen in Fig. 2) which could be described as "exponential" (meaning that the difference between score 3 and score 4 is greater than the difference between score 2 and score 3).

Previous isokinetic testing studies have used low velocities but which always exceeded 30°/s. We decided to test patients at 10°/s because our past experience had suggested that very weak patients had trouble accompanying the movement at 30°/s. One could argue that fatigue would prevent the maintenance of maximal effort throughout the entire duration of movement at low speeds; we can nevertheless report that tests at 10°/s show good reproducibility.

The reliability of isokinetic measurements can decrease for several reasons. Firstly, this method

Table 2
Within-session intraclass correlation coefficients (ICCs)

	Right knee		Left knee	
	Extension	Flexion	Extension	Flexion
Within-session 1 intraclass correlation coefficients (ICCs)				
	10°/s			
Peak torque	0.95	0.99	0.95	0.98
Angle at peak	0.90	0.86	0.50	0.58
Work	0.99	0.98	0.97	0.98
Power	0.99	0.94	0.96	0.98
	30°/s			
Peak torque	0.97	0.98	0.97	0.94
Angle at peak	0.90	0.86	0.88	0.56
Work	0.91	0.96	0.98	0.93
Power	0.91	0.96	0.97	0.93
Within-session 2 intraclass correlation coefficients (ICCs)				
	10°/s			
Peak torque	0.99	0.96	0.99	0.98
Angle at peak	0.81	0.75	0.91	0.91
Work	0.99	0.98	0.98	0.98
Power	0.99	0.98	0.99	0.98
	30°/s			
Peak torque	0.96	0.97	0.99	0.98
Angle at peak	0.76	0.76	0.73	0.68
Work	0.97	0.99	0.99	0.99
Power	0.97	0.99	0.99	0.99

evaluates voluntary, maximal strength during a controlled-velocity movement. Variations in voluntary strength are notably related changes in the patient's degree of motivation. Verbal encouragement can minimize this effect but it is difficult to affirm that the strength produced is maximal throughout the full ROM. This explains the inter-effort difference seen for a given session. However, we believe that these variations are acceptable. Moreover, movement duration is longer at lower velocities. At 10°/s, it takes 9 s to cover the entire ROM and it is difficult to maintain a maximal effort during this time. Nevertheless, we found that the reliability was higher at 10°/s than at 30°/s. Thus, we conclude that it is easier for very weak people to accompany the movement at a very low velocity.

Another factor relates to potential variations in positioning, which can be avoided if the latter is standardized. The alignment of the dynamometer's axis with that of the knee is particularly important; in a reliability study involving isokinetic measurements at the ankle, Andersen showed that a slight (1.5 cm) displacement of the axis resulted in an 8.3% change in the peak torque, which exceeds the usual within-subject variability [4].

In our study, patients were tested twice on the same day; it is therefore possible that the test and retest sessions differed in terms of the physiological conditions. From a strictly scientific viewpoint, it would perhaps have been more logical to retest the patients under the same conditions on another day (i.e. at the same time of the day and, if possible, at the same atmospheric pressure and ambient temperature). However, the reality of clinical follow-up meant that many of our neuromuscular clinic outpatients were unable to stay for more than one day at the clinic or to return more regularly.

5. Conclusions

Our study showed that isokinetic dynamometry is a reliable strength assessment tool, even in weak patients. Isokinetic testing is a possible outcome measure for the follow-up of neuromuscular disorders and could be of value in therapeutic trials. We are now investigating the possibility of applying this CPM methodology to other joints, such as the elbow.

Table 3
Between-session intraclass correlation coefficients

	10°/s				30°/s			
	Right knee		Left knee		Right knee		Left knee	
	Extension	Flexion	Extension	Flexion	Extension	Flexion	Extension	Flexion
Peak torque	0.92	0.95	0.98	0.97	0.99	0.97	0.97	0.98
Angle at peak	0.90	0.79	0.77	0.85	0.90	0.90	0.76	0.56
Work	0.96	0.95	0.97	0.98	0.99	0.96	0.95	0.99
Power	0.96	0.94	0.97	0.98	0.99	0.96	0.95	0.99

Table 4
Rho Spearman correlation coefficients for MMT scores and isokinetic data (Peak torque)

	10°/s			30°/s		
	Peak torque	Work	Power	Peak torque	Work	Power
Extension	0.70**	0.67**	0.71**	0.70**	0.67**	0.69**
Flexion	0.74**	0.71**	0.70**	0.71**	0.71**	0.67**

** $p < 0.01$ for all correlation coefficients in the table.

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