RELIABILITY OF TORQUE MEASUREMENTS DURING PASSIVE ISOKINETIC KNEE MOVEMENTS IN HEALTHY SUBJECTS

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In the literature, few data are available about the reliability of torque measured during passive isokinetic knee movements. This study investigated the consistency of torque measurements during passive knee movements at 60, 180 and 300°/second in 30 healthy subjects. Intraclass correlation values ranged between 0.78 and 0.92 when the results of two consecutive tests were compared. When retests were performed after repositioning the subjects, intraclass correlation values ranged between 0.43 and 0.87. These findings indicate the necessity for meticulous standardization of the test situation. Series of 10 consecutive movements, specifically repetitions of knee flexion at 180 and 300°/second, indicated that torque measurements during the first two movements were less stable than those following. A concurrent change in electromyographic activity in the rectus femoris muscle suggested that these torque variations resulted from habituation of the stretch reflex.

Key words: reliability, passive movements, torque, dynamometry, biomechanics.

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INTRODUCTION

Isokinetic measurements have been widely used for evaluation and treatment planning (1). During recent decades, passive isokinetic dynamometry has been applied more and more often to investigate conditions such as muscle hypertonia or joint stiffness (2–5). It has also been used to further our understanding of reactions to slow muscle stretching in healthy subjects (6). The use of a motor allows the examination of passive movements at identical speeds within a pre-set range. Nevertheless, measurements should still be examined for consistency. In isokinetic scores, two principal sources of variability may be identified: biological variation and measurement variability due to experimental error, including instrumentation and tester variation (7).

Few results are available about the reliability of isokinetic dynamometry during passive movements. Broberg & Grimby (8) compared torque curves during passive ankle dorsiflexion using a Cybex II dynamometer in healthy subjects and persons with neurological pathological conditions, and mentioned that the reproducibility of measurements was good when recorded at an interval of about 1 minute. Boiteau et al. (9) investigated the reliability of torque measured during passive isokinetic ankle dorsiflexion using a Kin-Com dynamometer in 10 children with cerebral palsy. The intraclass correlation coefficient (ICC) for movements at 10 and 190°/second was 0.84. Lamontagne et al. (10) determined the reliability of torque measured during five consecutive passive ankle dorsiflexion movements in eight adults with spinal cord injury. At velocities of 5 and 180°/second, ICC values of 0.83 and 0.75, respectively, were found. When the first torque measurement was omitted from the sequence, ICCs increased to 0.99 and 0.93, respectively.

Underlying mechanisms of torque alterations during movement repetitions have been investigated by concurrent registration of EMG activity in the stretched muscle groups. Magnusson et al. (6) determined the reliability of force measurements using a Kin-Com device in nine healthy men. Passive knee extension movements at 5°/second were performed twice with a 60-min interval. Pearson's product-moment correlation coefficients between test-retest results were 0.94, 0.97 and 0.98 for the first, second and third parts of the movements, respectively. To our knowledge, this is the only study where the reliability of torque measurements during passive isokinetic movements of the knee in healthy subjects has been reported.

In the Department of Rehabilitation Sciences of the Faculty of Physical Education and Physiotherapy (University of Leuven, Belgium), an isokinetic apparatus has been developed to quantify muscle hypertonia in neurologically impaired subjects. The purpose of the present study was to investigate the test-retest reliability of torque measurements as a response to repeated passive isokinetic knee movements in healthy subjects to be used as a reference for interpreting results in persons with pathological conditions.

Several aspects of measurement repeatability were investigated and will be discussed further: (i) the consistency of two consecutive torque measurements within one series of movements; (ii) the consistency of two measurements when the subject is repositioned between test movements; (iii) the consistency of two consecutive measurements during move-

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Fig. 1. Experimental set-up.

ments with the lever arm of the dynamometer unloaded; and (iv) the consistency of 10 consecutive measurements within one series of movements.

METHODS

Subjects

The study was performed on 30 healthy subjects (15 males, 15 females) who were not acquainted with isokinetic dynamometry. The age of the subjects was 54.8 $\pm$ 11.7 years (mean $\pm$ SD) and ranged between 32 and 85 years. The choice of this heterogeneous group was determined by an age-matching procedure with a view to future data comparison with persons with multiple sclerosis, stroke and Parkinson's disease. Eight subjects were retired, six were administrative professionals, nine were healthcare professionals and seven were housewives. Persons with any known orthopaedic or neurological disorders were excluded. All subjects gave written informed consent prior to inclusion in the study, which was approved by the local ethics committee.

Test procedure

Experimental set-up and positioning of the subjects. The device used for this study consisted of a custom-made isokinetic apparatus incorporating a computer-controlled, direct-drive electric servomotor (Dynaserv, DR 1100/E) and a strain gauge bridge torquemeter (Lebow 2101). Motor and torquemeter were mounted on a tube frame to allow adaptation of the torquemeter position in the vertical plane. The torquemeter shaft was connected to a rotating lever where the tested limb was to be attached. Subjects were seated on a bench positioned just beside the device, with the back supported and the thigh fixed with an elastic Velcro strap (Fig. 1). Ankle and foot of the tested leg were fixed within an orthosis. The lower leg was attached on the lever just above the malleoli. The rotation axis of the lever was visually aligned with the rotation axis of the knee joint. All tests were performed on one side, the left in 15 subjects and the right in the 15 other subjects.

Test-retest with the subjects. The maximal movement amplitude of the knee was first determined manually and registered within the controlling software programme. Ranges of movement were 160–180° in full extension and 45–80° in maximal flexion. The assessor positioned the subject's leg in full extension and then started the electromotor connected with the lever of the dynamometer. The leg was moved through a flexion arc and back into extension in the individually registered range of movement at an angular velocity of 60°/second. Flexion and extension movements were repeated 10 times consecutively at 5-second intervals between each movement. Then, the series of 10 movements was repeated at velocities of 180 and 300°/second. These velocities were chosen with a view to future comparisons of stretch reflexes in persons with pathological conditions. In all subjects, the lowest velocity was applied first to avoid tissue strain. Accelerations and decelerations at the onset and end of each movement were set at 3000°/second. This allowed us to obtain torque values at constant speeds for a maximal range of movement. Subjects were instructed to relax the leg throughout the stretch movements and not to intervene.

After the series of 10 movements at the 3 velocities, a pause of 20 minutes was introduced, during which the subjects were asked to step off the bench and walk around. Then, the subjects were repositioned on the bench and a retest was performed, including 3 series of 10 movement repetitions at 60, 180 and 300°/second. Movement characteristics, such as range, velocity, acceleration and deceleration, were standardized.

The whole test procedure, including subject positioning, test and retest, lasted 2 hours at the most. The same person performed all assessments.

Test-retest with the lever unloaded. At the end of the test and retest sessions, an additional movement was always performed with the device unloaded to investigate the repeatability of the measurement system itself for the same range of movement as for the 30 subjects participating in this study.

Outcome parameters. Torque, angular velocity and electromyographic (EMG) activity of rectus femoris, biceps femoris and gastrocnemius medialis muscles were recorded at 1000 samples per second. Torque measurements were corrected for gravity by subtracting their values with the torque registered during the tenth movement (T1 $-$ 10, T2 $-$ T10 etc.). EMG activity was registered with bipolar silver-silver chloride surface electrodes (Nikomed), and pre-amplified with active electrodes (A = 54dB, CMRR 100 dB). Electrode placement was standardized (11). An isolated biomedical EMG amplifier with a band-pass filter (5–450 Hz) was used. Data were processed with a Microstar 12-bit resolution data acquisition card (DAP1200e/6) and an on-board co-processor. Muscle activity was calculated using a differentiation technique (12). Reliability was determined for average torque values measured in the mid-phase of test movements. This phase, the mid-third of the isokinetic part of the movement, was determined automatically by means of the Labview software programme on the basis of the velocity measurements.

Statistical analysis

The consistency of measurements was determined with ICC (1.1) according to Shrout & Fleiss (13). ICC were calculated using the SAS programme on the basis of a linear mixed model (14). In a second linear mixed model, EMG was added as a covariate to determine the effect of EMG activity of the stretched muscle groups on torque variations during movement repetitions.

Furthermore, consistency of torque measurements was determined in absolute terms by means of the standard error of measurement, $SEM = SD\sqrt{1-ICC}$, where SD = the standard deviation of the measurement (15). The method error, representing the systematic difference between two measurements, was calculated with the formula ME = SD

Table I. *Consistency of torque measurements during two passive knee movements in 30 healthy subjects and during movements with the lever of the dynamometer unloaded*

Test movement		Torque test (Nm)		Torque retest (Nm)			95% CI			
		Mean	SD	Mean	SD	ICC	Lower	Upper	SEM (Nm)	ME (Nm)
Test-retest without repositioning										
60°/second	Extension	0.21	1.13	0.09	0.86	0.91	0.85	0.97	0.34	0.53
	Flexion	0.30	1.76	−0.08	0.96	0.92	0.86	0.98	0.50	0.76
180°/second	Extension	0.59	1.53	0.24	0.72	0.79	0.65	0.93	0.70	0.77
	Flexion	1.00	3.29	0.26	1.07	0.85	0.74	0.96	1.27	1.83
300°/second	Extension	−0.07	0.32	−0.22	0.75	0.88	0.79	0.96	0.11	0.76
	Flexion	1.86	4.82	1.01	2.12	0.78	0.63	0.93	2.26	2.75
Test-retest with repositioning										
60°/second	Extension	0.21	1.13	0.07	0.73	0.87	0.78	0.96	0.41	0.65
	Flexion	0.30	1.76	−0.01	1.09	0.69	0.49	0.89	0.98	0.99
180°/second	Extension	0.59	1.53	−0.01	0.57	0.59	0.36	0.83	0.98	1.03
	Flexion	1.00	3.29	−0.01	1.13	0.83	0.70	0.95	1.36	1.93
300°/second	Extension	−0.07	0.32	−0.03	1.80	0.43	0.12	0.73	0.24	1.30
	Flexion	1.86	4.82	1.03	3.22	0.44	0.14	0.74	3.61	3.50
Test-retest with the lever unloaded										
60°/second	Extension	−0.002	0.026	0.002	0.026	0.99	0.98	0.996	0.003	0.036
	Flexion	0.001	0.026	−0.001	0.026	0.98	0.97	0.996	0.004	0.036
180°/second	Extension	−0.004	0.028	0.004	0.028	0.98	0.97	0.995	0.004	0.040
	Flexion	0.001	0.027	−0.001	0.027	0.98	0.97	0.995	0.004	0.039
300°/second	Extension	−0.007	0.038	0.007	0.038	0.98	0.95	0.99	0.005	0.053
	Flexion	0.006	0.038	−0.006	0.038	0.98	0.97	0.995	0.005	0.053

ICC = intraclass correlation coefficient; SEM = standard error of the measurement; ME = method error.

(torque test−torque retest)/ $\sqrt{2}$ (7). The consistency of measurements was also verified graphically using the method of Bland & Altman (16).

To compare the results of this study with those mentioned in the literature, the consistency of torque measurements was furthermore analysed using Pearson's product-moment correlation coefficients.

RESULTS

Consistency of torque measured during two test movements

Table I shows the mean and standard deviation of torque measured during tests and retests with 30 subjects and with the lever of the dynamometer unloaded. Mean torque values ranged between −0.22 and 1.86 Nm. The highest torque values were registered during flexion movements at 300°/second in tests with the subjects. During tests with the lever of the dynamometer unloaded, mean torque values ranged between −0.007 and 0.006 Nm.

ICC values for two consecutive torque measurements without repositioning the subjects ranged between 0.78 and 0.92. The maximum SEM was 2.26 Nm. The method error ranged between 0.53 and 2.75 Nm for the different test movements. Pearson's product-moment correlation coefficients varied between 0.84 and 0.99.

Comparison of measurements with repositioning of subjects resulted in ICCs ranging between 0.43 and 0.87. The lowest ICC values were found for tests at 300°/second. Pearson's product-moment correlation coefficients ranged between 0.61 and 0.98.

For repeated movements with the lever of the dynamometer unloaded, ICC values were 0.98 or higher (Table I). Maximal values for SEM and method error were 0.005 Nm and 0.05 Nm, respectively.

The graphical presentation of differences in torque measured during test and retest according to the method of Bland & Altman (16) revealed no systematic changes between the two tests. Since these results confirmed the information provided by the other statistics, the graphs were not included in the article.

Consistency of torque measurements during 10 consecutive test movements with subjects

Fig. 2 represents the evolution of mean torque and EMG activity of the stretched muscle groups during a sequence of 10 movement repetitions of the knee. A decreasing trend was found in the torque curves, particularly between the first and second flexion movements at 180 and 300°/second. ICCs over 10 consecutive movements ranged between 0.69 and 0.92, with the lowest values, 0.69 and 0.73, noted for repeated flexion at 180 and 300°/second, respectively. After omission of the torque measured during the first movement of the sequence, ICC values exceeded 0.75 for all test movements, representing excellent reliability according to Fleiss (17). The EMG activity in the stretched muscle groups presented a slight downward trend, particularly during the initial flexion movements at 180 and 300°/second. EMG activity in the rectus femoris muscle was found to have a significant effect on the torque variations during repeated knee flexion ($p = 0.0001$).

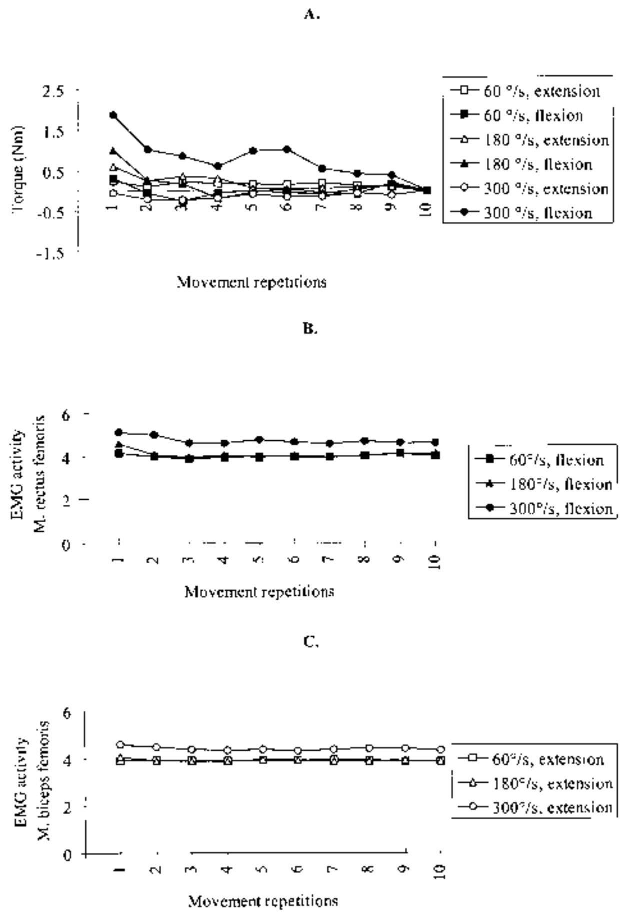

Fig. 2. Response to 10 consecutive passive isokinetic movements of the knee in 30 healthy subjects. (A) Torque. (B) EMG activity of the rectus femoris muscle during flexion movements. (C) EMG activity of the biceps femoris muscle during extension movements.

DISCUSSION

Standardization of the test position

The test-retest reliability of torque measurements was excellent in all test conditions except after repositioning of subjects. To avoid discrepancies between measurements, several aspects of the test situation, such as movement characteristics and body position, were standardized. Angles in hip and knee of the limb were checked and standardized with a goniometer. The ankle was kept in a 90° position with an orthosis throughout the test movements. Prior to each test, the knee joint of the subject was visually aligned with the axis of the dynamometer by adjustment of the height of the dynamometer and the horizontal position of the bench. The very high ICC values for repeated tests with the lever of the dynamometer unloaded indicated that differences in torque measurements between the two tests with the subjects were not due to the measurement tool. Some of the differences between the results of the two tests could be due to the repositioning of the subject on the bench. There may have been slight differences in the position of the knee axis, for example, as a consequence of minor internal or external rotation in the hip. Less variability in the test situation could possibly be obtained by using a contoured anatomical seat instead of a flat bench. Furthermore, the exact position of the seat and the dynamometer could be measured on the first test occasion and standardized during following tests.

Habituation of reflexes

During sequences of 10 movements, torque values decreased slightly, particularly during the initial repetitions. The concurrent registration of EMG activity in the stretched muscle groups revealed a similar downward trend, particularly during flexion movements at 180 and 300°/second. During the first movements, a reflex reaction may have occurred as a consequence of the fast drop of the lower leg. Repetition of the same movements may have resulted in habituation of this reflex response (18).

In a recent publication (10), the decrease in torque during repeated passive movements was attributed to thixotropic characteristics of the stretched tissues. The term “thixotropy” refers to the property of certain systems that become less viscous when shaken and return to their original viscosity after a period of not being disturbed (19). In the present study, the initial stretch movements may have produced a loosening of the muscles by disconnecting cross-bridges between actin and myosin filaments. However, the fact that EMG activity had a statistically significant effect on the resistive torque against the movements indicates that the torque variations were more related to reflex activity.

Reliability of torque measurements in view of other studies

Very few data seem to be available in the literature concerning the reliability of torque measurements during passive movements in healthy subjects. Magnusson et al. (6) reported the reliability of slopes in the forces measured during passive knee extension movements at 5°/second using a Kin-Com device. Pearson’s product-moment correlation coefficients ranged between 0.94 and 0.98 for different parts of the movement. In our study, comparable results were found for torque measured during repeated passive knee extension at 60°/second, with a Pearson’s product-moment correlation coefficient of 0.99.

CONCLUSIONS

Passive isokinetic dynamometry has been used to investigate normal and pathological reactions to joint mobilization. The tests in this study were performed on healthy persons. Within the limits of this study, such as the fact that the same person performed all assessments, the results demonstrated that torque can be reliably measured during consecutive passive movements. However, better standardization of subject positioning is necessary to improve the repeatability of measurements on different test occasions. Habituation of stretch reflexes may have occurred during repeated flexion at 180 and 300°/second. In persons with muscular hypertonia, the reaction to repeated mobilization may be different than in healthy subjects. It is generally accepted among clinicians that muscle hypertonia decreases by repeated stretching of spastic muscle groups. The measurements in healthy subjects presented in this study provide important information to be used as a reference for interpreting results in persons with pathological conditions.

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