Scand J Rehab Med 27: 219–226, 1995

KNEE EXTENSOR AND FLEXOR STRENGTH IN ELDERLY WOMEN AFTER RECENT HIP FRACTURE: ASSESSMENT BY THE CYBEX 6000 DYNAMOMETER OF INTRA-RATER INTER-TEST RELIABILITY

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ABSTRACT. The reliability of knee extensor and flexor strength measurements was assessed in 20 women (age 68–88 years) who had experienced a hip fracture two to four weeks before but who were otherwise healthy. Using the Cybex 6000 isokinetic dynamometer, isokinetic knee extensor and flexor strength (peak torque, total work and power) at 30 and 120°/second and isometric knee extensor and flexor strength (peak torque) were measured by the same examiner in both legs, successively, on four separate days within one week. Compared with the non-involved leg, the median reduction in peak extensor and flexor torque of the involved leg was 50% ($p<0.001$). With the protocol used, no significant change in muscle strength occurred during the test period. Individual coefficients of variation (CVs) were calculated for each muscle strength variable. Depending on whether torque, work or power were measured, the median CVs of extensor and flexor strength measurements of the non-involved leg ranged from 5.6–14.6% and 10.8–28.6%, respectively. The corresponding CVs for the involved leg were 10.9–22.1% and 13.0–35.2%. Substantial variability between individual CVs were found for all strength variables. In conclusion, although muscle strength measurements may be applicable when comparing larger groups of hip fracture patients, the large CVs may be a limitation in monitoring individual patients. This finding should be taken into consideration when planning individual training programmes.

Key words: muscle strength, reliability, hip fracture.

Osteoporotic fractures are a major publich health problem. For example, in the United States osteoporosis predisposes to more than 1.3 million fractures annually, including more than 250,000 hip fractures and costs the nation in excess of US $ 10 billion (9). Women aged 65–84 years are estimated to experience the largest number of fractures/person/year and fracture care costs (8).

In the elderly, muscle strength relates to functional status (20), chair rising ability (7) walking and stair climbing speed (4, 6, 7), and a strong association between impaired muscle strength and the risk of recurrent falls (25, 41) and fractures has been found (24, 33). Furthermore, muscle strength and physical activity have been shown to correlate with bone mineral density (26, 37). Thus a reduction in muscle strength may also result in an accelerated bone loss increasing the risk of fractures. Therefore, to avoid functional disability, immobilisation and further loss of bone mass, muscle strengthening exercises in the rehabilitation of hip fracture patients seems to be vital. The positive effects of strength training programmes in the elderly further indicate that testing for changes in muscle strength will become more widespread in these patients (14).

In studies of groups of patients, the probability of detecting differences in muscle strength between the groups for a given sample size is calculated on the basis of the standard deviate of the variable in question (power calculation) (2). In clinical practice, however, changes in the individual patient must be evaluated on the basis of the reliability of the measurements (27), otherwise, the clinician cannot determine whether the patient has become "stronger" or "weaker". In both clinical practice and in research studies, the reliability of the measurements is of interest with regard to the number of test sessions required to reach peak torques.

For the past decades the majority of studies involving isokinetic muscle strength measurements have been performed using the Cybex II. This system has now been replaced by a new isokinetic device, the Cybex 6000 dynamometer, for which only one previous study of the reliability of leg strength measurements has been published (3). The study sample comprised young subjects. Studies of the reliability of other isokinetic dynamometers have been performed (13, 15, 16, 18, 30), but none of these have focused solely on old and disabled patients.

The aim of the present study was to examine the test-retest reliability of muscle strength measurements including several strength variables of the lower limbs assessed by the Cybex 6000 dynamometer in elderly women after recent hip fracture.

MATERIAL AND METHODS

Subjects

Twenty women hospitalized at the Copenhagen Municipal Hospital for rehabilitation following a recent fracture of their hip were studied. Age ranged from 68 to 88 years (median 78), weight from 40 to 80 kg (median 60) and height from 148 to 170 cm (median 160). Time since the hip operation ranged from 14 to 30 days (median 18 days). At discharge the length of the hospital stay ranged from 21 to 42 days (median 30 days). All patients were discharged to their previous home.

Only women who had not experienced any complications following the operation were included. Furthermore, only women with previous normal walking ability, who had no complaints of knee joint or muscle pain, who were able to stretch out both knees from 90° to 0° of flexion and who were able to follow instructions were included in the study. No changes in medications were allowed during the test period. At the time of the examination, 15 women were mobilized with sticks and five with rollators. The subjects had no experience with muscle strength testing.

Informed consent according to the Helsinki II Declaration was obtained from all subjects. The protocol was approved by the local ethics committee.

Muscle strength measurements

Muscle strength expressed as peak torque in Newton meters (Nm), total work in Joule (J) and power in Watts was assessed by the isokinetic dynamometer Cybex 6000 (10).

Isokinetic knee extensor and flexor strength (peak torque, total work and power) were recorded at velocities of 30° and 120°/second. Isometric knee extensor and flexor peak torque was measured with the knee flexed 75°.

Strength measurements were done four times on separate days, at the same time of day, within one week by the same experienced examiner (OR Madsen). Positioning of the subjects were standardized. Hip position was maintained at 90° of flexion, and a shoulder and lap stabilization belt was applied for each subject. A thigh strap stabilized the test leg. The mechanical axis of rotation of the dynamometer lever arm was aligned to the axis of rotation of the knee. The resistance pad at the end of the lever arm was strapped to the most distal point of the anterior tibia that would still allow full dorsi-flexion of the ankle. The contralateral limb was tucked behind a stabiliser to prevent unwanted movements. The subject held on to the handles on either side of the chair. Correction for the effect of gravity was performed. On the first test day the exact positions of the adjustable seat back tilt, the seat back, the seat, the dynamometer height and the resistance pad were noted for each patient. On the following test days exactly the same positions were used. To obtain comparable data on peak torque, work and power range of motion was assessed using a window of 0° to 90°.

Strength was measured in both legs, separately. The non-involved leg was measured first. Each subject was tested in the same order, beginning with isokinetic strength measurements followed by measurements of isometric strength. The subjects were verbally encouraged during the tests. For each velocity and for isometric strength, the subject was given one submaximal trial to acquaint her with the test conditions. The subject was then allowed to rest for 30 seconds. The test consisted of three maximal repetitions recorded as data with rest intervals of 10 seconds. The highest values of peak torque, work and power were selected for analysis. Sixty seconds of rest between testing at each angular velocity was allowed.

The isokinetic dynamometer was calibrated once a month according to the manufacturer's manual (10).

Statistics

For each strength variable in each patient, the reliability between repeated measurements was expressed as the coefficient of variation in % (CV% = 100 × standard deviation/mean). Comparisons of several items were performed by the Friedman's two way analysis of variance. Pairs of items were compared by the Wilcoxon signed rank test. Correlations between variables were assessed by Spearman's rank correlation test.

When correlating strength with age, height and weight, torque was expressed as the mean value of isometric torque and isokinetic torque at 30 and 120° per second. Total work and power were expressed as the mean value of total work and power, respectively, at the two velocities. This procedure was chosen to reduce the number of correlation analyses.

Multiple stepwise regression analyses were used to examine the influence of age and body weight on the correlations between paired observations of torque, total work and power. Before running these analyses all variables were normalized by a logarithmic transformation (2). Unless a p-value of 0.05 or less is stated, two tailed p-values of 0.01 or less were considered statistically significant. The software package SPSS Statistics V. 4.01 (SPSS International BV, Chicago, USA) was used for the statistical analyses (35).

RESULTS

The dynamometer calibration measurements remained stable during the study. All values recorded during the calibration procedures were within the manufacturer's specified ranges for strength measurements (10).

Table I shows the number of women who were able to perform the different tests. One patient was not able to stretch out her knee with the lever arm attached to the involved leg from which no data were collected. Another patient completed the first three test days but due to acute pain in the groin of the involved leg, only muscle strength of the non-involved leg was measured on the last day. Clinical examination and radiology

Table I. *Number of hip fracture patients who were able to produce measurable torque on the first test day and on all four test days, respectively*

	Non-ivolved leg Knee extension n_1*/n_{1-4}**	Involved leg Knee extension n_1*/n_{1-4}**	Non-involved leg Knee flexion n_1*/n_{1-4}**	Involved leg Knee flexion n_1*/n_{1-4}**
Torque				
isometric	20/20	19/18	20/20	19/18
30°/sec.	20/20	19/18	20/20	19/18
120°/sec.	20/20	19/18	20/19	11/9

* n_1 = number of patients who were able to produce torque on the first test day.
** n_{1-4} = number of patients who were able to produce torque on all four test days.

did not explain the pain which decreased during the following days. The strength measurements of the involved leg for this patient were not included in the calculations of CVs. Only half of the women were able to produce flexor strength with the involved leg at a velocity of 120°/second.

The results of the knee strength measurements from the first day are presented in Tables II and III. However, results for the patient in whom strength of the involved leg was not determined are not shown in the tables. Including the results of this patient in the calculations of median and range values for the non-involved leg did not influence the median and range values shown.

In both legs, flexor strength was lower than extensor strength ($p < 0.001$). Both the median extensor and flexor strength of the involved leg were reduced by approximately 50% ($p < 0.01$) compared with the other leg. Peak torque, total work and power of the non-involved leg measured on the first test day were negatively correlated with age (R_s ranging from −0.52 to −0.63, $p < 0.05$–0.005) and positively correlated with body weight (R_s ranging from 0.49 to 0.68, $p < 0.05$–0.001). Similar correlations were found between flexor strength and age.

In multiple regression analyses, age and body weight did not significantly influence the correlations between paired variables of torque, total work and power. A correlation-matrix demonstrating the inter-correlations (R_s) between knee extensor muscle torque, total work and power measurements obtained from the non-involved leg on the first test day is presented in Table IV. Similar correlations were found between extensor strength measurements of the involved leg and between isokinetic flexor strength measurements of both the non-involved and the involved leg. Isometric and isokinetic flexor strength measurements correlated with R_s values ranging from 0.41 (not significant) to 0.61 ($p < 0.005$).

When studying the patients as a whole, no significant change in any strength variable occurred during the test period (Friedman's two way analysis of variance). The Wilcoxon signed rank test revealed

Table II. *Knee extensor strength of the non-involved and involved leg in 19 women two to four weeks after hip fracture operation*

	Non-involved leg Median (range)	Involved leg Median (range)	*p**
Torque (Nm)			
isometric	64 (34–94)	27 (20–65)	<0.001
30°/sec	61 (26–99)	30 (19–54)	<0.001
120°/sec	34 (12–68)	19 (7–36)	<0.001
Total work (J)			
30°/sec	58 (24–102)	30 (15–49)	<0.001
120°/sec	35 (11–71)	15 (3–34)	<0.001
Power (watts)			
30°/sec	20 (7–52)	10 (4–17)	<0.001
120°/sec	40 (14–88)	16 (4–47)	<0.001

* The Wilcoxon signed rank test.

Table III. *Knee flexor strength of the non-involved and involved leg in 19 women two to four weeks after hip fracture operation*

	Non-involved leg Median (range)	Involved leg Median (range)	p*
Torque (N-m)			
isometric	23 (8–37)	14 (7–22)	<0.001
30°/sec	20 (9–45)	11 (7–28)	<0.001
120°/sec	12 (4–37)	4 (0–24)**	<0.005
Total work (J)			
30°/sec	18 (8–52)	8 (1–28)	<0.001
120°/sec	8 (1–35)	1 (0–20)**	<0.001
Power (watts)			
30°/sec	6 (3–16)	3 (1–9)**	<0.01
120°/sec	10 (1–40)	2 (0–29)**	<0.005

* The Wilcoxon signed rank test.
** 0 indicates that seven of 19 patients were unable to flex the leg with the velocity in question and that the measured strength for that reason was 0.

no significant differences in any strength variable between day 1 and any of the following days.

Precision errors, expressed as CVs, for those women who were able to produce measurable torque on all four test days are presented in Table V. All measurements were characterized by large median CVs and by substantial variability between individual CVs, e.g. the range and 80% central range of CVs for extensor strength of the non-involved leg measured at 30°/second was 1.14–18.32% and 2.50–10.15%, respectively. Only extensor peak torque and total work at 30°/second of the non-involved were characterized by median CVs lower than 7%.

When comparing CVs of power, total work and peak torque measurements, power measurements had significantly higher CVs for both the non-involved and the involved leg. Flexor strength measurements had significantly higher CVs than extensor strength measurements. CVs of strength measurements of the involved leg were general significantly higher than those of the non-involved leg. A tendency toward a negative relationship between magnitude of strength and CVs was also found, although this relationship was not statistically significant.

DISCUSSION

A high incidence of falls after hospital discharge has been reported for patients who are functionally dependent (28) and fall characteristics have been shown to be important risk factors of hip fracture

Table IV. *Correlations (R_s)* between isokinetic torque, total work and power at the velocities 30° and 120°/second of the knee extensors of the non-involved leg in 20 women two to four weeks after hip fracture operation*

	Isokinetic					
	Torque		Total work		Power	
	30	120	30	120	30	120
Torque (N-m)						
isometric	0.79	0.76	0.78	0.77	0.80	0.77
30°/sec	—	0.81	0.97	0.81	0.82	0.69
120°/sec	—	—	0.80	0.99	0.76	0.92
Total work (J)						
30°/sec	—	—	—	0.81	0.85	0.72
120°/sec	—	—	—	—	0.75	0.92
Power (watts)						
30°/sec	—	—	—	—	—	0.67

* Using Spearman's correlation test, all correlations were significant with p-values less than 0.0001.

Table V. *Reliability of knee extensor and flexor strength in women with a recent hip fracture*

Only CVs for those patients who were able to produce measurable torque at the velocity in question on all four test days are presented (Table I). Pairs of items are compared by the Wilcoxon signed rank test

	CV(%)			
	Non-involved leg Knee extension Median (range)	Involved leg Knee extension Median (range)	Non-involved leg Knee flexion Median (range)	Involved leg* Knee flexion Median (range)
Torque				
Isometric	7.6 (2.6–16.9)	10.9 (2.2–29.1)#	10.8 (3.0–46.7)#	13.0 (4.3–45.9)
30°/sec	5.6 (1.1–18.3)	11.0 (1.2–26.5)#	12.6 (0–36.3)#	17.9 (3.5–45.5)
120°/sec	10.1 (1.6–52.1)	14.6 (3.5–25.2)#	11.7 (3.0–32.3)	31.0 (4.6–200.0)
Total work				
30°/sec	6.7 (1.6–16.8)	14.0 (3.3–32.3)**#	13.5 (5.2–54.7)**#	23.3 (7.2–56.6)
120°/sec	8.9 (1.8–71.0)**	22.1 (4.3–47.9)**	28.3 (1.9–69.4)**#	31.9 (7.7–61.7)
Power				
30°/sec	9.5 (3.5–72.1)***	18.3 (5.1–74.2)***#	16.6 (0–44.5)#	22.2 (7.4–76.6)
120°/sec	14.6 (1.5–73.5)***	21.9 (7.2–69.7)***	28.6 (3.4–75.6)**#	35.2 (7.9–59.5)

* CVs in this column were not statistically compared with other CVs.
** Higher than torque at the same velocity, $p < 0.01–0.05$.
*** Higher than total work and torque at the same velocity, $p < 0.01–0.05$.
# Higher than extension of the non-involved leg at the same velocity in subjects measured in both legs, $p < 0.01–0.05$.

(17). Although a combination of factors such as body sway, coordination, vision, orthostatic hypotension and pain may be important predictors of falls in elderly people, quadriceps strength has been documented to be strongly associated with walking speed (6) and risk of falling (23, 38) and to be an independent and powerful predictor of fracture incidence (24, 33). Moreover, as the risk of a second hip fracture is increased six times compared to the risk of the first one (36), it seems resonable to assume that muscle strengthening exercises in the rehabilitation of these patients is of major importance.

With the exception of a single study (41), previous studies of the relationship between muscle strength and falls or walking ability have, to our knowledge, focused solely on isometric extensor strength (4, 6, 7). From a theoretical point of view, adequate knee extensor and flexor strength at higher speeds may be an important factor in protecting against falls. This is in agreement with the findings of Whipple et al. (41), who found that the ability to develop knee and ankle extensor and flexor torque at higher limb velocities (120°/second) compared with low velocities (60°/second) were significantly more affected in fallers than in non-fallers. Accordingly, we found the measurements of knee and flexor strength at both low and high velocities to be of relevance.

No previous studies on muscle strength in subjects with a recent hip fracture exist. We found a 50% reduction in muscle strength of the involved leg two to four weeks after hip surgery. This weakness may be caused by several factors including pain, reflex inhibition, central factors and/or muscle atrophy (11, 38). Pain and reflex inhibition prevent full voluntary activation of muscles and may directly contribute to atrophy and weakness of affected muscle groups, thereby undermining effective rehabilitation.

During flexion, half of the women were not able to accelerate the involved leg to 120° per second making measurements of strength impossible. Although the clinical significance of this finding is unclear it does suggest that a high testing velocity reveals flexor strength deficits better than slower velocities.

Most of the previous studies on the reliability of muscle strength measurements have expressed reliability as coefficients of correlation. However, as shown by Altman & Bland (1, 2) the correlation coefficient between repeated measurements reflects the strength between the measures and not the agreement between them. They concluded that the correlation coefficient is inappropiate and misleading in studies of reliability. Furthermore, in the present study muscle strength correlated to age and body weight, making the use of correlations in the assessment of reliability even more problematic. Consequently, we chose to express reliability as CVs.

The reproducibility of isokinetic strength measurements has previously been studied in young women (3, 18, 22, 30, 39), but has received only minor attention in older women (15, 19, 31, 32) and not at all in elderly and disabled persons. In the present study, the reliability of the strength measurements of the non-involved leg was superior to that of the involved one and measurements of extensor strength was more reliable than flexor strength measurements. Peak extensor and total work strength measurements of the non-involved leg at 30°/second were reproduced best with median CVs of 5.6 and 6.7%, respectively. CVs can be interpreted by calculating critical differences (1, 27, 40). The critical difference is the difference between two measurement results which would be statistically significant when applied to a reference group (27). The critical difference (CD) at a 0.05 level of significance is defined in percentage terms as $CD_{0.05} = z_{0.05} \times \sqrt{2} \times CV$ where $z_{0.05} = 1.96$ is the standard deviate for $p = 0.05$ (27). The concept of critical differences is well-known in the field of clinical chemistry (27, 40). A clinical example: Extensor strength at 30°/second of the non-involved leg in a hip fracture patient measured 1 and 2 weeks after surgery is 80 and 70 Nm, respectively. The observed difference is 10 Nm or 12.5% of the first measurement, i.e. smaller than the critical value of 15.6% calculated on the basis of the median CV (5.6%). The probability of finding a change of the observed magnitude in a reference hip fracture patient is >0.05. Therefore, the 12.5% reduction in strength may be due solely to expected within-subject variation. Consequently, a median CV of 5.6% may not be acceptable for monitoring individual patients. The large variability in individual CVs further complicates the use of strength measurements in the individual patient, e.g. for extensor torque of the non-involved leg measured at 30°, half the patients had CVs higher than 5.6% increasing to a maximum of 18.3%. The variability between individual variances can be taken into account by calculating a pooled CV $[(\sqrt{\Sigma s_i^2/n})/\text{mean}$, where $\Sigma s_i^2/n$ is the pooled variance$]$ instead of a median CV (2). The pooled CV for extensor torque at 30°/second (non-involved leg) was 7.9% corresponding to a critical difference of 21.9%.

Numerous factors including subject motivation, learning, medication, pain, subject positioning and stabilization may explain the fluctuations in strength performance over the test period. However, the repeated tests in the present study were performed as constant as possible.

Only previously freely mobilized women without complications following the operation were included in the study. Consequently, both the muscle strength and the ability to produce reliable results in this age-group of hip fracture patients may have been overestimated. Patients who were disabled before the fracture, patients with complications or patients with signs of intellectual reduction might have been even weaker and might have produced even more unreliable results. This selection of patients should be taken into consideration when interpreting the results of the study. It should also be noted that patients who were unable to produce torque were not excluded from the study. CVs for these patients could not be calculated at all.

Learning may be a factor associated with increased muscle strength measured in an isokinetic dynamometer over short periods of time (15, 21, 29). As recommended by others (29) we let the subjects perform more than one maximal trial in each session and found no increase in muscle strength in either the involved or the non-involved leg over the four test days. Apparently, in the subjects examined and with the protocol used, learning did not significantly contribute to the variability in strength between the test days. This finding also indicate that one test session may be sufficient to reach peak torques when studying groups of patients.

Age and body weight did not influence the correlations between the paired muscle strength variables. Consequently, it was acceptable to set up a correlation-matrix without adjusting for differences in age and body weight. Moderate correlations were found between isometric and isokinetic peak torque, total work and power. As discussed above, previous studies of ability and muscle strength have focused on isometric strength. We found only moderate correlations between isometric and isokinetic torque, e.g. for the non-involved leg, the correlations between isometric torque and isokinetic torque at 30° or total work at 30°/second were 0.79 and 0.78, respectively, which implies that only 60% of the variability of isokinetic strength was explained by the association with isometric strength (2). Therefore, additional studies of the relationship between isokinetic strength and functional performance must be performed before it can be established whether isometric strength measurements can substitute isokinetic strength measurements in elderly people.

Several studies have evaluated reliability of muscle strength testing, but little research has been performed to investigate the technical reliability and validity of the isokinetic devices (5, 12, 34). The Kincom, the Lido and the Cybex II system have been shown to be technically reliable and valid for some measurements (5, 12, 34), but the Cybex 6000 dynamometer has not yet been evaluated. Although the results of the calibration procedures in this study indicate that the Cybex 6000 system is valid for measuring outputs by known calibration weights, methodological studies of the technical reliability and validity of this new isokinetic device should be performed.

In conclusion, muscle strength of the involved leg in women with a fracture of the hip was substantially reduced two to four weeks after surgery. Pain and/or reflex inhibition may be the main reason for this finding, although the possibility of subsequent muscle atrophy can not be excluded. Therefore, in these patients, studies of changes in strength over longer periods of time may be of interest, especially with respect to falling and thereby the risk of rehospitalization with or without new fractures.

Although muscle strength measurement may be applicable when comparing groups of hip fracture patients, the large CVs may limit the use of muscle strength measurements in the individual patient.

ACKNOWLEDGEMENT

This work was supported by the 100 Years Anniversary Fund of the Copenhagen Municipal Hospital.

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