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Reliability of Dynamometric Measurements of the Pelvic Floor Musculature

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Aims: The objective of this study was to evaluate the reliability of strength and endurance dynamometric measurements of the pelvic floor musculature (PFM). **Materials and Methods:** Twenty-nine female participants, primipara and multipara, aged between 27 and 42 and presenting different severity levels of stress urinary incontinence (SUI), participated in the study. They were evaluated using a new pelvic floor dynamometer, an instrumented speculum based on strain-gauged technology. Strength and endurance evaluations were repeated in three successive sessions, each followed by a 4-week period. Maximal strength values were recorded at three dynamometer openings (5 mm, 1 cm, and 1.5 cm between the two dynamometer branches). The maximal rate of force development (MRFD) and percentage of strength lost after 10 and 60 sec were computed from the endurance trial. The generalizability theory was applied to estimate the reliability of the PFM measurements. The reliability was quantified by the index of dependability and the corresponding standard error of measurement (SEM) for one and the mean of three trials performed in one session for the strength measurements and one trial completed in one session for the MRFD and endurance measurements. **Results:** For the maximal strength measurements, the largest coefficient of dependability was obtained at the 1 cm opening, with a value of 0.88. The corresponding SEM reached 1.49 N. The reliability of the MRFD was also very good with a coefficient of 0.86 and an SEM of 0.056 N/sec. The reliability was minimally affected by the number of trials. The strength loss measurements at 10 and 60 sec were unreliable, with coefficient values of 0.38 and 0.10, respectively. **Conclusions:** The results of the present study indicate that the reliability of the strength parameters (maximal strength and MRTD measurements) was high enough for future investigations on pelvic floor rehabilitation programs. *Neurourol. Urodynam. 23:134–142, 2004.*
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Key words: **dynamometer; female urinary incontinence; pelvic floor musculature; reliability; strength**

INTRODUCTION

Maintenance of urinary continence is multifactorial but depends mainly on detrusor control and the urethral closing function [Delancey, 1988]. The integrity of the pelvic floor musculature (PFM) is of paramount importance in urethral closing [Delancey, 1988]. PFM exercises are thought to facilitate and strengthen the PFM, thereby improving urethral pelvic force and preventing urinary leakage during any abrupt increase in abdominal pressure [Delancey, 1988]. The involvement of PFM in urinary continence emphasizes the need for scientific information on its contractile properties.

Abbreviations: MRTD, maximal rate of force development; PFM, pelvic floor musculature; SUI, stress urinary incontinence; SEM, standard error of the measurement.

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A literature review identified many methods to assess the PFM function. Digital muscle evaluation using various scoring systems [Worth, 1986; Laycock, 1992; Brink et al., 1994] has been criticized for its lack of reliability and sensitivity in the measurement of PFM strength for scientific purposes [Bo, 2001]. Intra-vaginal pressure as well as perineal electromyography measurements during pelvic floor muscle contraction have shown limitations because they do not selectively record the pelvic floor muscle strength [Hanh et al., 1996; Peschers et al., 2001].

Recognizing the importance of direct measurements of the pelvic floor strength for evaluating the effects of stress urinary incontinence (SUI) treatment aimed at strengthening the PFM, we recently developed a pelvic floor muscle dynamometer. In an earlier study, this dynamometer demonstrated excellent transducer properties during in vitro calibration and was deemed acceptable by continent and incontinent women [Dumoulin, 2001, 2003].

Whatever type of methods used to obtain the measurements, the reliability of the information collected is a key component of the assessment process. Portney and Watkins [1993] have stated that reliability is fundamental to all aspects of clinical research because, without it, it is impossible to have confidence in the data collected or draw rational conclusions from it. Reliability refers to the extent to which there is consistency in the responses upon repeated applications of the measurement protocol. Repeated applications may be obtained by multiple trials in the same session (intra-session reliability), by measurements over time (test–retest reliability or inter-occasion reliability) or by different raters (inter-rater reliability) [Dittmar and Gresham, 1997].

The objective of the present study was to evaluate (a) the intra-session reliability, the inter-session (test–retest) reliability of strength measurements and (b) the inter-session (test–retest) reliability of endurance measurements of the PFM taken with a new dynamometer in young parous women suffering from SUI.

MATERIALS AND METHODS

Patients

A total of 29 female participants, 9 primipara and 20 multipara, between 27 and 42 years old, were recruited during their annual visit to the Maisonneuve-Rosemont Obstetrics-Gynecology Clinic. After completing a questionnaire on SUI, patients reporting symptoms of SUI as defined by the Standardization of Terminology of Lower Urinary Tract Function Report (complaints of involuntary leakage on effort, on exertion, or on sneezing or coughing) [Abrams et al., 2002] for more than 6 months after delivery, were evaluated by the urogynecologist.

The exclusion criteria were pregnancy, important organ prolapse (PopQ > stage II) [Bump et al., 1996], active urine or vaginal infection, excessive vaginal scarring preventing dynamometer insertion, degenerative neurological disorder, or any other disease that may interfere with force measurement of the pelvic floor. Of the 29 participants in the study, 17 reported episodes of involuntary leakage from the urethra when coughing or sneezing or during physical exertion or effort but did not demonstrate any involuntary leakage in the provocative stress test [Schull et al. in Abrams et al., 1999]. The other women (n = 12) reported the same symptoms as previously but had involuntary leakage from the urethra in the provocative stress test in the standing position. All gave written consent to participate in the study and the Ethics Committee of the Maisonneuve-Rosemont Hospital approved the study.

It should be pointed out that the planned study population (young parous women suffering from SUI) was chosen in terms of the future application of the dynamometric method, since the reliability of a measuring device is intimately linked to the population to which it will be applied [Streiner and Norman, 1995].

Instrumentation

A new dynamometer designed to measure the static force of the PFM was used in the present study. Details of this dynamometer were presented in an earlier article [Dumoulin, 2003] and the description here will be limited to characteristics relevant to the study.

The dynamometer is composed of a dynamometric speculum and a computerized central unit. The speculum comprises two aluminum branches. One branch is fixed while the other, equipped with strain gauges, can be moved by an adjustable screw allowing static forces to be measured at different vaginal apertures (Fig. 1). Thus, the dynamometer design allows the PFM strength to be measured at different muscle lengths. The central unit consists of customized strain gauge amplifiers (Analog Devices, model 2B31), a laptop computer (Toshiba Satellite Celeron 400 MHz) and a PCMCIA analog-to-digital acquisition card (DAQCard-700 by National Instruments Corporation). The voltage values from the strain gauge amplifier are digitized at a frequency of 50 Hz and converted into units of force (N) using the factor obtained during the calibration procedure [Dumoulin et al., 2003]. During the experimental session, it is possible to display the strength recording. If acceptable, the data are stored on hard disk for further processing.

Experimental Protocol

Design of the study. To evaluate the test–retest reliability, the participants were evaluated for their PFM strength on three different days, each separated by a 4-week period. According to Mawdsley [1982], when dynamometric tests are separated by 2 weeks or more, the strength values are not influenced by the potential training effect associated with the measurement itself. Moreover, the choice of a 4-week period between measurements

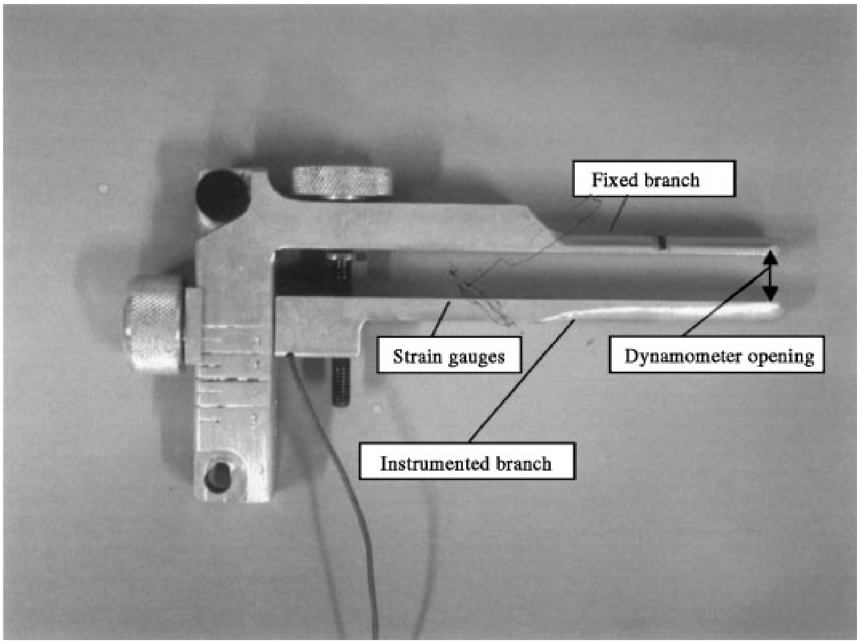

Fig. 1. Dynamometric speculum.

was preferred because it corresponds to a complete menstrual cycle. Although it has not been documented for the pelvic floor muscles, the influence of the hormonal cycle has been shown to affect the strength in women's forearm musculature [Petrofsky and Phillips, 1980]. Therefore, to eliminate possible fluctuation in the strength value related to the menstrual cycle and further eliminate the reduction in the strength value related to abdominal and pelvic pre-menstrual pain, the measurements were repeated at the same time during the menstrual cycle, excluding the pre-menstrual and actual menstrual period.

During each evaluation session, three trials of PFM strength were taken at each of three different openings of the pelvic floor dynamometer (5 mm, 1.0 cm, and 1.5 cm between the dynamometer branches). These speculum opening, correspond to vaginal apertures of 19, 24, and 29 mm, respectively if the thickness of the speculum branches, 6 mm for the upper branch and 8 mm for the lower one, is added to the distance between the two branches. The women were instructed to relax their PFM to allow the passive force to be recorded over a period of 15 sec. The mean value was considered as an index of PFM tonicity. The trials were separated by a 2-min rest period to avoid fatigue, as suggested for dynamometric testing of the limb muscles [Caldwell et al., 1974]. Six different opening sequences (O1 = 5 mm, O2 = 1.0 cm, and O3 = 1.5 cm) were used (O1,O2,O3; O1,O3,O2; O2,O3,O1; O2,O1,O3; O3,O1,O2; O3,O2,O1). These sequences were randomly assigned across participants to balance the potentially confounding effect of the previous openings. Nevertheless, for a specific subject, the same sequence was used in all three sessions. Beside the strength measurements, one measurement of the endurance was taken at the 1 cm opening of the dynamometer at the end of each session.

Pre-measurement methodology. The participants adopted a supine lying position, hips and knees flexed and supported, feet flat, on a conventional gynecologist's table. Prior to insertion of the dynamometer, the evaluator, an experienced physical therapist, gave detailed instructions about contracting the PFM. The participants were asked to squeeze and lift the PFM as if preventing the escape of flatus and urine while breathing out [Laycock in Schussler et al., 1994]. Then, using vaginal palpation, the evaluator verified the patient's understanding of how to contract the PFM. Pre-evaluation instruction was mandatory since many studies have shown that PFM contraction may be difficult to perform and that more than 30% of women fail to do it correctly at their first attempt [Benvenuti et al., 1987].

Subsequently, the evaluator prepared the instrument by covering each branch of the speculum with a condom and lubricating it with a hypo-allergen gel. The two branches of the measuring device were brought to minimum opening and the dynamometer was inserted into the vaginal cavity in an antero-posterior axis to a depth of 5 cm (upper branch calibrated at 5 cm). According to Bo [1992], the muscular mass of the pelvic floor is located some 3.5 cm from the opening of the vaginal cavity. The 5-cm depth therefore allows the peri-vaginal portion of the pelvic floor to squeeze the lower branch of the dynamometer while the upper branch presses underneath the pubic bone to provide stability.

PFM measurement methodology. In the position described earlier and with 5 mm between the branches of the dynamometer, a practice trial was carried out. The evaluator then separated the two branches with the screw to obtain the appropriate opening. Before the effort, a passive recording was

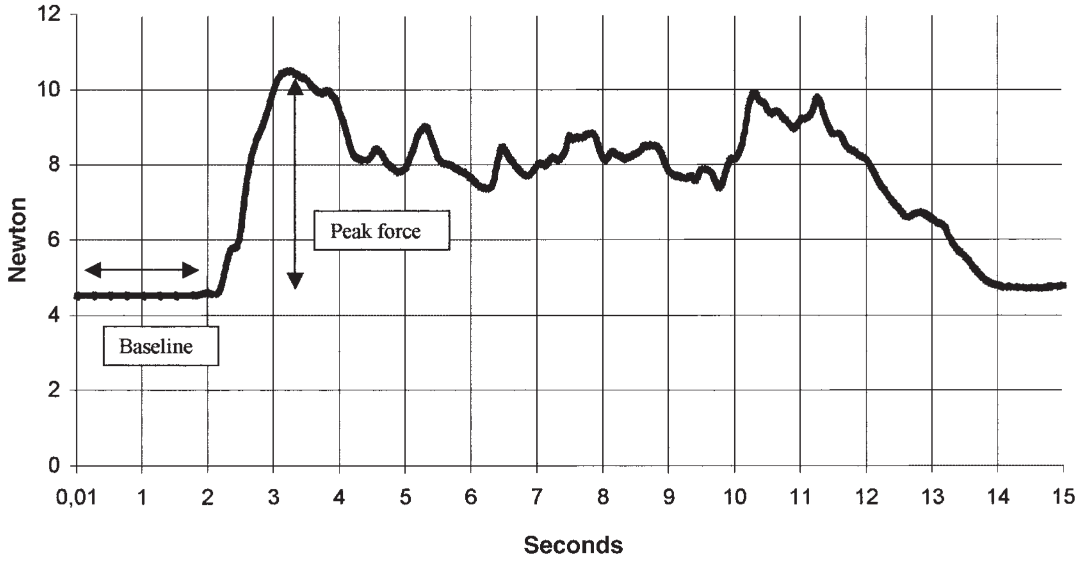

Fig. 2. Recording of a maximal pelvic floor musculature (PFM) strength measurement.

made in order to have a baseline value. Participants were instructed to contract their PFM as hard as they could over a 10-sec period. The rapidity of the PFM contractions were not prescribed by the evaluator. Hood has shown that, when the experimenter asks for a rapid contraction, the maximum strength in the skeletal muscle is less than when the subject increases her muscle tension at her own pace [Hood and Forward, 1965]. Standard verbal encouragement was given throughout the effort. Figure 2 presents a sample recording of a maximal PFM strength measurement.

The endurance measurement consisted of a 1-min maximum contraction with standardized verbal encouragement. The participants were instructed to contract as hard and fast as possible while breathing in and out for 1 min. Figure 3 presents a recording of a PFM endurance measurement. After the evaluation session, the condoms were discarded and the dynamometer was disinfected.

Strength and endurance parameters. The maximum PFM strength value was calculated for each strength trial as the peak force value obtained during the effort minus the baseline value recorded just before the beginning of the PFM contraction (Fig. 2). The speed of contraction was quantified by the maximal rate of force development (MRFD). This parameter was the maximal slope (N/sec) computed from the endurance curve in the region between the baseline value and the maximum strength value (seen in Fig. 3). The reason for using the endurance curve to measure the MRFD is because the instruction given in the strength trials did not encourage a rapid contraction as opposed to the instruction given in the endurance trials. The results of the MRFD will be reported with the strength data because this muscle parameter is known to be associated with the peak value [Stothart, 1973; Nadeau et al., 1997]. After correction for the baseline value, the endurance parameters are the percentage loss in strength after 10 and 60 sec relative to the maximal force recorded during the trial (Fig. 3).

Statistical Analysis

Reliability was estimated separately for the peak forces recorded at each opening, for MRFD and for each endurance parameter. The reliability was evaluated using the generalizability theory [Shavelson, 1991], a statistical approach based on analysis of variance. The first step of this theory, known as the G-study, computes all possible sources of variance components associated with the participants, trials, days, and their interactions using the data collected in the study. The next step, the D-study, calculates the expected reliability for a particular combination of days and trials. In the present study, the reliability is reported for a D-study involving (a) one and the mean of three trials obtained in 1 day for the strength measurements and (b) one trial obtained in 1 day for the parameter obtained from the endurance tests. The reliability is quantified by two reliability indices, namely the index of dependability (Φ), a statistic similar to the classical intra-class correlation coefficient of type 2 for absolute agreement [McGraw and Wong, 1996], and the standard error of measurement (SEM). The former is computed as the ratio of the subject variance to the total variance, i.e., the sum of the subject variance and the absolute error variance. The latter includes systematic errors associated with trials and days as well as random errors due to interactions between participants, trials, and days. It is computed as the square root of the absolute error variance. The maximum value of (Φ) is 1 when no error is present. The SEM gives the error of measurement in force units. It will also be reported as a percentage of the mean value. The formulas used to calculate (Φ) and SEM are presented in Appendix A.

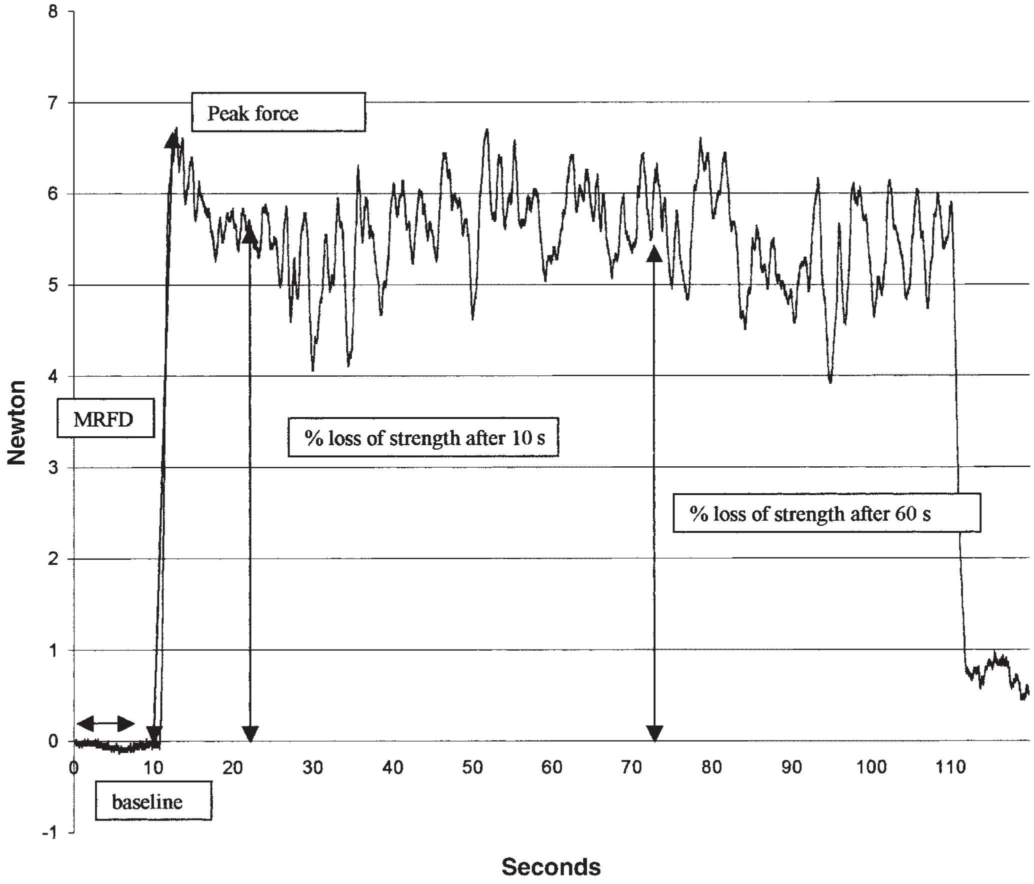

Fig. 3. Recording of a PFM endurance measurement.

As a complementary analysis to the reliability study, statistical comparisons between the three openings were performed using a repeated analysis of variance. For this analysis, the overall mean value across trials and days for each opening represents the score for each subject. Post-hoc contrasts were used to find the exact source of difference between openings.

RESULTS

Maximal Strength Data

The overall average across trials and days for each dynamometer opening are presented in Figure 4. The analysis of variance ($F = 63.944$, $P < 0.000$) and post-hoc contrasts confirm that the PFM strength varies with the dynamometer opening, increasing significantly from the 5-mm opening to the 1.5-cm.

As expected, the results of the G-study reported in Table I show that the largest source of variance for all openings is related to the subject component (S). The percentage of the total variance attributable to the systematic effect of days (D) and trials (T) was small, with values less than 0.89%. The interaction between subjects and days ($S \times D$) was the main source of error variance, with percentages ranging between 10 and 25%. Finally, the residuals ($S \times D \times T$) reach percentage values of less than 6%. In Table II, the dependability indices found in the D-study indicate good to very good reliability. The highest coefficient (0.88) is obtained for the 1-cm opening and the SEM at this position (1.49) is not very different from the lowest SEM calculated at the 5-mm opening (1.22). When

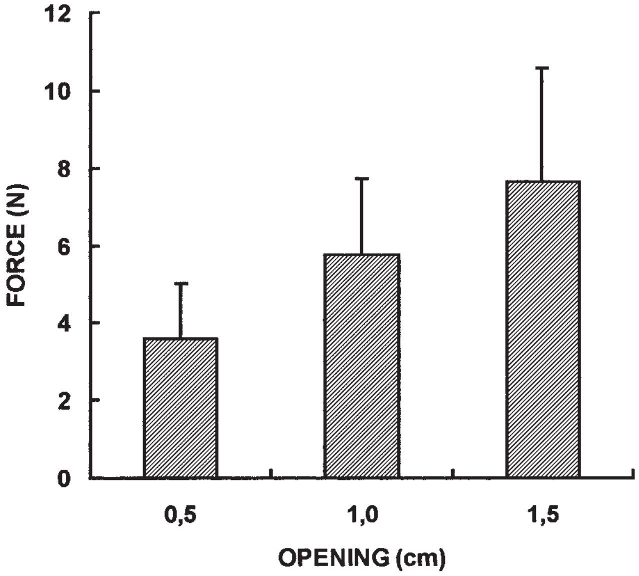

Fig. 4. PFM maximal strength at three dynamometer openings.

TABLE I. Result of the G-Study for Strength Measurement at the Different Dynamometer Openings

	Dynamometer opening (in cm)		
	0	1.0	1.5
Subject (S)	68.40	86.29	74.39
Day (D)	0.89	0.00	0.00
Trials (T)	0.03	0.07	0.08
S × D	25.10	10.59	22.68
S × T	0.47	0.15	0.75
D × T	0.00	0.00	0.02
S × D × T	5.12	2.90	2.08

Percentage of the total variance calculated for each variance components.

TABLE II. Dependability Indexes (Φ), Standard Error of Measurements (SEMs), and SEM in Percentage of Mean Force for the Strength Measurements at Different Dynamometer Openings for a D-Study Design Involving One and the Mean of Three Trials in 1 Day

	Dynamometer opening (in cm)		
	0	1.0	1.5
One trial, 1 day			
Φ	0.69	0.86	0.74
SEM (N)	1.30	1.62	2.78
SEM (% of mean force)	33	23	33
Mean of three trials, 1 day			
Φ	0.71	0.88	0.76
SEM (N)	1.22	1.49	2.11
SEM (% of mean force)	30	21	24

expressed as a percentage of the mean strength, the SEM is smallest at the 1-cm opening, with a value of 21%.

For the MRFD, the results of the reliability study (second column, Table IV) were very comparable to the results found for the peak strength value recorded at the 1-cm opening. More specifically, the subject's variance represented about the same percentage of the total variance, the day factor determined almost no variance and the percentage related to the interaction between participants and day (S × D) was of the same magnitude. In Table V, the dependability index found in the D-study indicates good to very good reliability. The coefficient (0.86) is similar to the one obtained for the peak strength value recorded at the 1-cm opening.

TABLE III. Maximal Rate of Force Development (MRFD) and Pelvic Endurance Measurements Descriptive Statistics (Mean ± 1 SD)

	Endurance measurements		
	MRFD	Lost of strength % after 10 sec	Lost of strength % after 60 sec
Day 1	0.216 ± 0.158	42 ± 15	42 ± 21
Day 2	0.214 ± 0.148	45 ± 24	43 ± 23

TABLE IV. Result of the G-Study for MRFD and Endurance Measurements

	Endurance measurements		
	MRFD	Lost of strength % after 10 sec	Lost of strength % after 60 sec
Subject (S)	86.36	38.85	10.36
Day (D)	0.00	0.00	0.00
S × D	13.64	61.15	89.73

Percentage of the total variance calculated for each variance component.

Endurance Data

The pelvic floor endurance measurements on days 1 and 2 are presented in Table III. A review of the mean endurance measurements in this table does not support the existence of an effect of days. Table IV gives the percentage of total variance for each component derived from the G-study. The results show that the subject variance represents 39 and 10% of the total variance for the 10 and 60-sec endurance tasks, respectively. The percentage attributable to days is small for all measurements while interaction between subject and days is the source of major error variance, with percentages between 61 and 90%. In Table V, the dependability indices found for a D-study for the 10 and 60-sec endurance tasks indicate low reliability, with values of 0.38 and 0.10, respectively.

DISCUSSION

Strength Measurements

The results indicate that the peak maximum strength (peak force value obtained during the effort minus the baseline value) increases with the dynamometer opening. This relationship was expected because the magnitude of tension increases with muscle length up to the optimal length [Lieber, 1992]. The low maximal strength value obtained at shorter lengths may make it difficult to demonstrate a difference in muscle strength before and after a PFM rehabilitation program, or even between continent and incontinent women. This could partially explain the disagreement in the literature regarding the difference in PFM strength between incontinent and continent women, with some authors arguing that there is a significant difference in PFM maximum strength in continent as opposed

TABLE V. Dependability Indexes (Φ) and SEM for the MRFD and Endurance Measurements for a D-Study Design Involving One Trial in 1 Day

	Endurance measurement		
	MRFD	Lost of strength % after 10 sec	Lost of strength % after 60 sec
Φ	0.86	0.38	0.10
SEM (N/sec or %)	0.056 (N/sec)	15.71 (%)	20.75 (%)

to incontinent women [Hanh et al., 1996; Samuelsson et al., 2000] and others saying there is no significant difference [Bo et al., 1994; Morkved and Bo, 1999; Boyington and Dougherty, 2000].

In the G-study of the reliability analysis, the largest percentage of variance for the peak strength values and MRFD variables was related to differences among participants. This explains the high computed dependability indices calculated in the D-studies because the variation between participants (subject variance: S) is much greater than other sources of variance. The small percentages of the total variance associated with the day factor mean that no systematic differences existed across days and supports our design premise that no systematic important change would take place in the subject over a 1-month period. Of additional interest is the finding that the patient–day interaction was the major error variance component. The interpretation of this finding is that some patients demonstrated higher PFM strengths on the first day, while others produced greater values on the second. This random error of the day factor across participants must be taken into consideration in clinical trials involving comparison of treatments.

Having found no systematic differences across trials (T), and low random variance (S × T) across trials in the strength evaluation, it can be concluded that no fatigue or learning occurs across trials. Moreover, a representative estimate of the patient strength may be the value of one trial. The gain of using the mean of three trials instead of one trial is a decrease of 2% or 0.13 N of the total variance.

The results of this study indicate that the dynamometer opening affects the reliability of pelvic floor measurements. In Table II, the dependability indices found in the D-study indicate lower reliabilities at the 5-mm and 1.5-cm openings than at 1 cm. The lower coefficient at 5 mm between dynamometer branches can be explained by the smaller subject variance, as the muscle strength is at its lowest at this dynamometer opening. At the same time, the absolute variance error also decreases albeit not proportionally to the decrease in subject variance. In fact, the SEM, which is the root square value of the absolute error variance, represents about 30% of the mean strength at this opening. The lower reliability at 1.5 cm may be associated with the patient's discomfort at large dynamometer openings, a variable that could have influenced their capacity to produce a stable maximum voluntary contraction across trials or days.

The highest reliability is found at the 1-cm dynamometer opening with a coefficient of 0.88 and a corresponding SEM of 1.49 N. Expressed as a percentage of the mean strength value at the 1-cm opening, this SEM is the lowest across all openings, with a value of 20%. Consequently, the pelvic floor strength measured before and after conservative treatments of SUI in young parous women should be taken at a dynamometer opening of 1 cm. In judging the effect of SUI treatment in a group of patients, taking into consideration the error of measurement, the average difference between the pre- and post-treatment, pelvic floor strength measurements must be higher than the SEM of 1.49 N found at this opening. To apply this last finding to the interpretation of individual scores, it is common to calculate confidence intervals around a subject's score from the SEM [Crocker and Algina, 1986]. Thus, if a subject's score (mean of three trials) is 7 N and the SEM is 1.49 N, we are 95% confident that the true score of the subject lies between 4.1 (7 − [1.96 × SEM]) and 9.9 (7 + [1.96 × SEM]).

The reliability of the MRFD measurements was very similar to that found for the peak strength values. This was expected because the MRFD is correlated positively with the peak value in limb strength testing [Stothart, 1973; Nadeau et al., 1997]. This parameter is probably very important because it indicates the patient's capacity to quickly recruit muscles when intra-abdominal pressure varies rapidly, as during coughing or laughing.

Endurance Measurements

The percentage of variance components computed in the G-study of endurance measurements (Table IV) demonstrated that the total error variance exceeds the subject variance. This condition necessarily determines low reliability, as in fact was found in the D-study. The error variance is more random than systematic because the variance attributable to the interaction between subject and day (S × D) is high while the variance of the day factor (D) is small. Observations of the participants' endurance profiles (Fig. 3) show strong fluctuations in pressure over the test period, which can, in part, explain the random error across days. It is hypothesized that these fluctuations are the manifestation of repeated recruitment and failure of muscle fibers to maintain a PFM contraction for long durations.

The endurance protocol used in the present study appears unable to characterize the endurance of pelvic floor muscles reliably. The protocol asks for the maximal tension to be held for over 60 sec but this type of endurance seems impossible to measure because of the force instabilities recorded over time. In limb muscles, endurance is also measured by the time that a subject is able to maintain a percentage of maximal tension [Petrofsky and Phillips, 1980]. This sub-maximal approach should be explored in future research because it corresponds more to the endurance needs on a day-to-day basis.

Limits of the Study

The present reliability study is closely linked to the population to which the measurement is to be applied, that is gravid young women aged between 27 and 42. Although this approach might be perceived as inefficient for assessing reliability in general, we believe that it is based on a realistic view of the measurement for the population concerned and is not a limitation of reliability. A similar reliability study should be undertaken before dynamometer measurements are taken in older women.

Inter-observer reliability has not been addressed in the present article because our current clinical trial involves just one evaluator. An inter-observer reliability study should therefore be undertaken for research protocols that involve more than one evaluator.

Lastly, the foregoing recommendation regarding the dynamometer opening to be used during pelvic floor strength measurements is based on the results of the present reliability study. Whether the strength measurement at the 1-cm dynamometer opening correlates best with urinary incontinence measurements remains to be answered. This question will be addressed in a subsequent correlation study between PFM strength measurements at different dynamometer openings and urinary incontinence measurements.

For more information on the pelvic floor dynamometer, interested researchers can contact the first author directly at dumoulin@sympatico.ca.

CONCLUSION

Measurements of maximum strength and speed of contraction (MRFD) showed very good test–retest reliability. It is proposed that measurements be done at a dynamometer opening of 1-cm because the highest reliability and low SEM (% of mean value) are found at this opening. For group comparison and individual evaluation, one and multiple trials are recommended, respectively. To appreciate the effect of conservative treatments of SUI in young gravid women, an increase of 1.49 N for the strength and 0.056 N/sec for the MRFD or more would demonstrate gain over the error of measurement.

A clinical trial with conservative treatment of SUI is currently under way to evaluate the impact on the PFM dynamometric parameters described earlier. Another research project is in progress to compare PFM dynamometric parameters in young parous females suffering or not from SUI. A better understanding of dynamometric parameters in continent and incontinent women may identify pertinent information on pelvic floor dysfunction related to the success and/or failure of conservative SUI treatments.

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APPENDIX A

Coefficient of Dependability

$$\phi = \frac{\sigma_S^2}{\sigma_S^2 + \underbrace{\frac{\sigma_D^2}{n_D} + \frac{\sigma_T^2}{n_T} + \frac{\sigma_{DT}^2}{n_D n_T} + \frac{\sigma_{SD}^2}{n_D} + \frac{\sigma_{ST}^2}{n_T} + \frac{\sigma_{SDT}^2}{n_D n_T}}_{\text{Absolute error variance}}}$$

Components of Variance

σ_S^2 = subject variance; σ_D^2 = day variance (systematic); σ_T^2 = trial variance (systematic); σ_{DT}^2 = day−trial interaction (random); σ_{SD}^2 = subject−day interaction (random); σ_{ST}^2 = subject−trial interaction (random); σ_{SDT}^2 = subject−day−trial interaction (residual variance); n_D = number of days in the D-study; n_T = number of trials in the D-study.

SEM

$$\text{SEM} = \sqrt{\frac{\sigma_D^2}{n_D} + \frac{\sigma_T^2}{n_T} + \frac{\sigma_{DT}^2}{n_D n_T} + \frac{\sigma_{SD}^2}{n_D} + \frac{\sigma_{ST}^2}{n_T} + \frac{\sigma_{SDT}^2}{n_D n_T}}$$