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Pelvic Floor Muscle Function in Continent and Stress Urinary Incontinent Women Using Dynamometric Measurements

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Aims: To compare the pelvic floor muscle (PFM) function in continent and stress urinary incontinent women using dynamometric measurements. **Methods:** Thirty continent women and 59 women suffering from stress urinary incontinence (SUI), aged between 21 and 44 and parous, participated in the study. An instrumented speculum was used to assess the static parameters of the PFM: (1) passive force at 19 and 24 mm of vaginal aperture (antero-posterior diameter), (2) maximal strength in a self-paced effort at both apertures, (3) rate of force development and number of contractions during a protocol of rapidly repeated 15-sec contractions, and lastly (4) absolute endurance recorded over a 90-sec period during a sustained maximal contraction. The parameters described in the two latter conditions were assessed at the aperture of 19 mm. Analyses of covariance were used to control the confounding variables of age and parity when comparing the PFM function in the continent and incontinent women. **Results:** The continent women demonstrated higher passive force at both openings and a higher absolute endurance as compared to the incontinent women ($P \leq 0.01$). In the protocol of rapidly repeated contractions, the rate of force development and number of contractions were both lower in the incontinent subjects ($P \leq 0.01$). The differences between the two groups for maximal strength at the 19- and 24-mm apertures did not reach the statistically significant level. **Conclusions:** The PFM function is impaired in incontinent women. The assessment of PFM should not be restricted to maximal strength. Other parameters that discriminate between continent and incontinent women need to be added to the PFM assessment in both clinical and research settings. *Neurourol. Urodynam. 23:668–674, 2004.* © 2004 Wiley-Liss, Inc.

Key words: **dynamometry; endurance; muscle strength; passive force; pelvic floor musculature; speed of contraction**

INTRODUCTION

Several theories have been put forward to explain female urinary continence mechanisms [DeLancey, 1988; Petros and Ulmsten, 1997]. Although the theories differ in some points, the importance of the pelvic floor muscles (PFM) in urethral closure for maintaining continence is recognized by most if not all authors [DeLancey, 1988; Petros and Ulmsten, 1997]. The pathophysiology of stress urinary incontinence (SUI) remains unclear but PFM dysfunction is suspected. However, discrepancies have been found when comparing PFM maximal strength in continent and stress urinary incontinent women. Some studies have demonstrated that incontinent women have lower PFM strengths than continent women [Sampselle, 1989; Laycock, 1992; Gunnarsson and Mattiasson, 1994, 1999; Hahn et al., 1996; Samuelsson et al., 2000; Gunnarsson et al., 2002; Janssens et al., 2002] while others have reported non-significant differences [Bo et al., 1994; Morkved and Bo, 1999; Boyington and Dougherty, 2000; Gunnarsson et al., 2002; Sartore et al., 2003]. However, these studies differ in terms of methodological approach used, such as the technique chosen to measure the PFM strength and the characteristics of the samples studied.

Considering the muscle composition of the pelvic floor, parameters other than strength may be involved in the main-

Abbreviations: PFM, pelvic floor muscles; SD, standard deviation; SUI, stress urinary incontinence.

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tenance of continence. The pelvic floor musculature is composed predominantly of type I fibers (slow twitch), accounting for 63–67% of its anterior component (pubococcygeus) [Gilpin et al., 1989; Heit et al., 1996], which indicates that these muscles are suited to maintain tone or contraction over a long period. According to DeLancey and Starr [1990], the resting activity of the PFM is important for sustaining the pelvic organs in the optimal position for continence. Furthermore, when repeated or prolonged solicitations of the continence mechanisms such as jogging or even daily living activities occur, PFM endurance may contribute to continence. Type II fibers (fast twitch) are also present [Gilpin et al., 1989; Heit et al., 1996] and may be involved in rapid PFM contractions preceding an abrupt rise of the intra-abdominal pressure associated with coughing or sneezing [Bo, 1995]. Overall, these parameters remain sparsely studied and their inclusion in the PFM assessment could well enhance our understanding of SUI pathophysiology.

The aim of this study was to investigate and compare the PFM function in continent and stress urinary incontinent women. Various static parameters including passive force at rest, maximal strength, speed of contraction, and endurance were recorded in a dynamometric assessment of PFM.

MATERIALS AND METHODS

Subjects

Women attending the obstetrics and gynecology clinic of Sainte-Justine Hospital were invited to participate in the study through an information sheet. Thirty continent and 59 stress incontinent women, aged between 21 and 44, were recruited. In order to have a homogenous sample and considering that the onset of SUI is strongly related to parity [Rortveit et al., 2001], the target population of this study was women who had delivered vaginally once or more and were still in the reproductive stage of their lives (neither perimenopausal nor postmenopausal women). The exclusion criteria were pregnancy, other types of incontinence (demonstrated by the urodynamic examination, reported spontaneously by the subjects or mentioned in the Urogenital Distress Inventory questionnaire), past urogynecologic surgery, previous physiotherapy treatment for incontinence, major organ prolapse (PopQ > Stage 2) [Bump et al., 1996], active urine or vaginal infection, excessive vaginal scarring, or any other disease that may interfere with pelvic floor function measurements. All women gave written consent to participate in the study, which was approved by the Ethics Committee of Sainte-Justine Hospital.

The continence status of each participant was ascertained by different assessments, which allowed the subjects to be assigned to either the continent or the stress incontinent group. Subjects were included in the stress incontinent group when they fulfilled the following criteria. First, the women had to report SUI symptoms that matched the International Continence Society definition (complaint of involuntary leakage on effort or exertion, or on sneezing or coughing) [Abrams et al., 2002]. After that, the symptomatic subjects underwent a urodynamic evaluation including cystometry in order to confirm the absence of detrusor overactivity. The Urogenital Distress Inventory questionnaire was also used to document various incontinence-related symptoms as it has already demonstrated good psychometric properties such as reliability, validity, and responsiveness [Shumaker et al., 1994; Hagen et al., 2002]. Finally, a modified 20-min pad test with standardized bladder volume was also performed to verify and quantify the symptoms [Abrams et al., 1988; Sand, 1992]. To do so, the bladder was filled with a 250-ml solution using a transurethral catheter. A pre-weighed pad was then put on and the subject had to perform standardized exercises: walking for 10 min, stair climbing (equivalent to one flight up and down), standing from sitting 10 times, coughing vigorously 10 times, running on the spot for 1 min, bending to pick up a small object from the floor 5 times, jumping-jack 10 times, and washing hands in running water for 1 min. Finally, the presence and severity of incontinence were appreciated by weighing the pad at the end of the test.

Women were diagnosed as continent if they did not report any type of urinary incontinence, urgency, or other urogynecologic symptoms either spontaneously or in the Urogenital Distress Inventory questionnaire. They were also assessed by the 20-min pad test. However, to eliminate the invasiveness of the catheterization associated with artificial bladder filling, the bladder volume was measured by ultrasound (Bladder Scan 3000, Diagnostic Ultrasound). Thus, women had to drink 1 L of water 1 hr before the test. The pad test was performed when the bladder contained more than 250 ml, which corresponded to the bladder volume of the incontinent subjects. In interpreting the results, subjects with a pad weight gain up to 1 g, which may be due to weighing errors, sweating or vaginal discharge, were considered continent [Abrams et al., 1988; Artibani et al., 2002].

Instrumentation

A new dynamometer specifically designed to evaluate the PFM function was used for the static measurements. As extensively described by Dumoulin et al. [2003], this equipment comprises an instrumented speculum connected to a computerized central unit. The instrumented speculum is composed of two aluminum branches. The upper branch is fixed while the other, equipped with strain gauges, can be moved by an adjustable screw allowing measurements to be taken for different vaginal apertures. Thus, different muscle lengths of the PFM could be evaluated. The voltage outputs of the dynamometer were calibrated using known forces applied to the lower branch. In addition, the differential recordings of the two pairs of the strain gauges ensure that application of the same resultant force at any location on the lower branch of the speculum produces the same voltage output. This theoretically improves the accuracy of the speculum since the site of the force applied to the lower branch can vary between measurements as well as between subjects. Furthermore, the dynamometer has demonstrated good test-retest reliability in incontinent women for parameters such as maximal strength and rate of force development [Dumoulin et al., 2004].

Pelvic Floor Muscle Function Assessment

The PFM function assessment was entirely conducted by a skilled physiotherapist properly trained in dynamometric measurements. After receiving detailed information about contracting her PFM, each subject adopted a supine lying position with hips and knees flexed, feet flat on a conventional gynecologist's table. Considering that a high percentage of women have difficulties contracting their pelvic floor properly at their first attempt [Benvenuti et al., 1987; Dietz et al., 2003], vaginal palpation was used to teach them how to perform a PFM contraction correctly without compensation (e.g., rectus abdominus, adductors, and gluteal muscles). When their ability to contract had been confirmed, the intra-vaginal dynamometric assessment was carried out. Before the device was inserted into the vaginal cavity, each branch of the speculum was covered with a condom and appropriately lubricated with a water-soluble jelly. The two closed branches were then inserted to a depth of 5 cm, allowing assessment of the pelvic floor musculature, which is located approximately 3.5 cm from the opening of the vaginal cavity [Bo, 1992]. Three unrecorded practice contractions were performed to ensure that the subjects were comfortable with the device inserted. During the whole examination, the performance (force curves) of the subjects was observed by the evaluator on the computer screen and stored on hard disk when acceptable. This visual feedback was not accessible to the subjects. The PFM parameters evaluated were:

Passive force. The passive force was measured at two different speculum openings, which correspond to vaginal apertures of 19 and 24 mm. These antero-posterior diameters comprise the thickness of the speculum branches, 6 mm for the upper branch and 8 mm for the lower one, as well as the distance between the two branches (5 mm for the aperture of 19 and 10 mm for that of 24 mm). The women were instructed to relax their PFM in order to record the passive force over a period of 15 sec. The mean value was considered as an index of PFM tonicity (Fig. 1).

Maximal strength in self-paced effort. The subjects were asked to squeeze and lift their PFM as if preventing the escape of flatus and urine while breathing out [Laycock, 1994]. The speed of contraction was not prescribed by the evaluator. The maximum strength values were obtained by subtracting the baseline value recorded before the effort from the maximum peak value (Fig. 2). The measurements were taken at vaginal apertures of 19 and 24 mm. Three 10-sec contractions separated by a 2-min rest

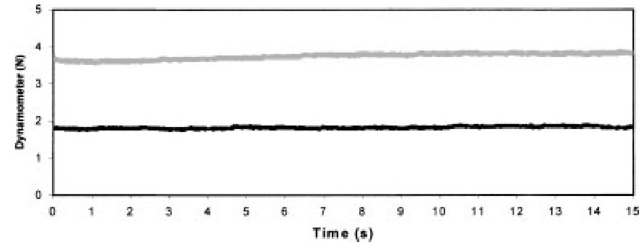

Fig. 1. Passive forces recorded by the instrumented speculum at 19-mm aperture (black line) and 24-mm aperture (gray line) when subjects were instructed to relax their PFM.

period were recorded for each aperture. The mean of the three trials was used in the statistical analyses.

Rate of force development and number of contractions. The women were instructed to contract maximally and relax as fast as possible during a protocol of rapidly repeated 15-sec contractions (Fig. 3). Two parameters allowed the speed of contraction to assessed at the 19-mm opening: the maximal rate of force development of the first contraction (slope of the force curve) and the number of contractions performed.

Absolute endurance. Still at the 19-mm opening, the subjects were required to rapidly contract and maintain a maximal contraction for 90 sec (Fig. 4). The area under the force curve taken between 10 and 60 sec after the beginning of the effort was used for estimating the endurance.

Statistical Analysis

The baseline characteristics of the continent and stress urinary incontinent women were compared using Student's *t*-test for the ratio variables and the Chi-square for nominal data. Considering the significant differences in age and parity between the two groups, analyses of covariance were used to

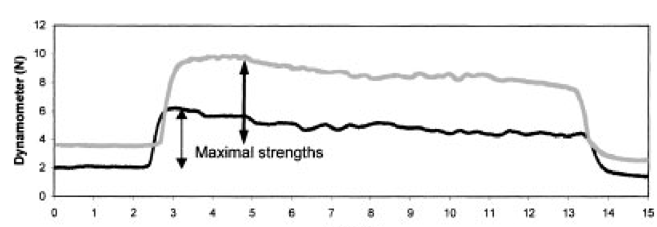

Fig. 2. Maximal strength recorded during a self-paced maximal contraction of the PFM in a single subject at 19-mm aperture (black line) and 24-mm aperture (gray line). Maximal strength was defined as the force changes from baseline occurring during the voluntarily contraction.

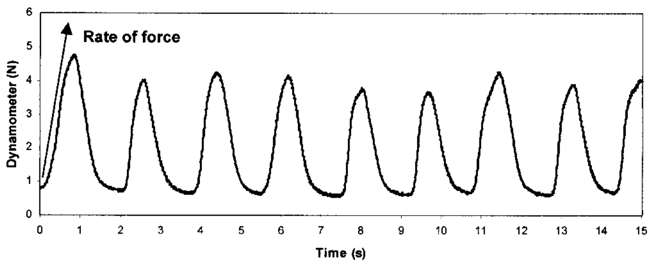

Fig. 3. Rate of force development and number of contractions recorded during a protocol of rapidly repeated contractions in a single subject. The subject was instructed to repeatedly contract and relaxed the PFM as fast as possible within a 15 s duration.

control for these confounding variables when comparing the PFM function in the continent and incontinent women. As a prerequisite to the analyses of covariance, the absence of interaction between groups and covariates was verified.

RESULTS

A comparison of the baseline characteristics of the stress incontinent and continent women is presented in Table I. The two groups were similar in body mass index and percentage of physically active women, which is defined by women participating in physical activity as a leisure for at least once a week. However, significant differences in age and parity were observed in that the incontinent women were older and had experienced more parity. These two potentially confounding variables, age and parity, were therefore controlled in the PFM function analyses. In the pad test, the continent women demonstrated non-significant leakage (<1 g) [Abrams et al., 1988; Artibani et al., 2002] while the stress incontinent women lost a mean of 35.2 g (SD = 55.4 and range = 5−309).

As shown in Table II, the stress incontinent women demonstrated lower values in passive force, absolute endurance, maximal rate of force development and number of contractions performed than the continent women ($P < 0.05$). No statistically significant differences regarding mean maximal strengths were observed although the mean maximal strength was lower at the 19-mm aperture.

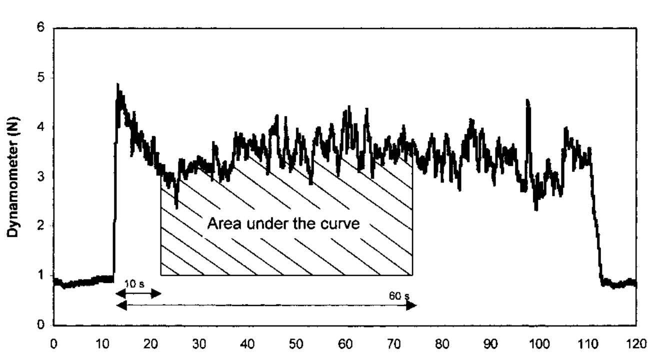

Fig. 4. Example of a sustained maximal voluntarily contraction of the PFM. The area under the force trace for 50 s was calculated as an index of endurance.

DISCUSSION

Even if the recruitment procedures were identical for the continent and incontinent groups, significant differences in age and parity were found concerning age and parity. These findings are not surprising since incontinence has been associated with age [Hannestad et al., 2000] and parity [Rortveit et al., 2001] in the Norwegian EPINCONT study, an epidemiological study composed of 27,900 women. Differences in age and parity when comparing PFM function have often not been considered in the statistical analyses of previous studies comparing PFM in continent and incontinent women [Laycock, 1992; Gunnarsson and Mattiasson, 1994; Gunnarsson et al., 2002]. However, these confounding variables were controlled in our study using analyses of covariance to establish confidence that differences in muscle function originate from their continence status, not their age or parity.

A recent magnetic resonance imaging study demonstrated that stress incontinent women presented pelvic floor laxity, lower PFM volume, and bladder neck descent in comparison with asymptomatic subjects [Hoyte et al., 2001]. This would corroborate the role of PFM for supporting organs and, therefore, maintaining continence. In the present study, a lower passive force was found in the stress incontinent group. However, it should be emphasized that the intra-vaginal passive measurements inevitably include not only PFM activity but also the passive resistance of the surrounding non-muscular tissues. Nonetheless, our findings concur with studies that assessed PFM electromyographic activity at rest in continent and stress incontinent women [Janssens et al., 2002]. A lower electromyographic activity was found in incontinent women [Janssens et al., 2002]. Furthermore, a higher passive force at the 24-mm vaginal aperture as compared to the minimal opening was expected in both groups because a resistance from the passive properties of muscles and surrounding tissues is produced when resting muscles are passively stretched [Gajdosik, 2001].

With regard to maximal strength, this parameter was assessed at vaginal apertures of 19 and 24 mm. The difference in maximal force between the continent and incontinent groups was not statistically significant at these two apertures. Several factors are, therefore, suspected to influence maximal force. First, as found in a previous study [Dumoulin et al., 2004], PFM produces higher forces at a larger aperture and, consequently, at a longer muscle length. Thus, the maximal strength differs, depending on the aperture. In the present study, the difference between continent and incontinent seems to be more marked at the lower aperture. In any case, greater attention needs to be paid to the vaginal aperture when comparing strength in continent and stress incontinent subjects. Second, the controversies about strength differences in continent and stress incontinent subjects in the literature

TABLE I. Characteristics of Women (Mean ± 1 Standard Deviation (SD); Range or Percentage in Parentheses)

	Continent women n = 30	SUI women n = 59	*P*-values
Age (years)	31.9 ± 5.5 (21–44)	36.1 ± 3.6 (24–43)	<0.0001
Parity	1.7 ± 0.8 (1–4)	2.1 ± 0.8 (1–4)	0.035
Body mass index (kg/m^2)	23.3 ± 2.5 (18.8–28.8)	24.1 ± 4.3 (18.7–34.5)	0.348
Number of women physically active (%)	17 (57%)	35 (59%)	0.810

mentioned earlier could be related to the instrument or technique used. Digital evaluation [Sampselle, 1989; Laycock, 1992; Gunnarsson and Mattiasson, 1994, 1999; Hahn et al., 1996; Samuelsson et al., 2000; Gunnarsson et al., 2002; Sartore et al., 2003], surface electromyography [Gunnarsson et al., 2002; Janssens et al., 2002], cones [Hahn et al., 1996], and pressure measurements [Laycock, 1992; Bo et al., 1994; Hahn et al., 1996; Morkved and Bo, 1999; Boyington and Dougherty, 2000; Gunnarsson et al., 2002; Sartore et al., 2003] have been used to appreciate maximal force but all of these instruments or techniques have been criticized for their psychometric properties. Digital muscle evaluation has shown a low intra-rater reliability [Bo and Finckenhagen, 2001] and sensitivity [Morin et al., 2004] while intra-vaginal pressure and pelvic floor electromyography have been criticized for their lack of validity. It has been suggested that the pelvic floor surrounding muscles (cross-talk) and intra-abdominal pressure interfere significantly with electromyography recordings and intra-vaginal pressure, respectively [Hahn et al., 1996; Peschers et al., 2004]. Furthermore, vaginal cones have been found unsuitable for PFM assessment because a heavy cone can be retained in spite of a weak PFM because of its transverse position in the vagina [Hahn et al., 1996]. Since the instrumented speculum has proven to be a direct and reliable tool for evaluating the PFM function [Dumoulin et al., 2004], we chose this instrument to avoid the disadvantages of other currently used techniques or instruments. Third, the definition of continence status may also be responsible for the inconsistency of the results in the literature. Some studies included several types of incontinence such as stress, urge, and continuous incontinence in their symptomatic group [Bernstein, 1997; Morkved and Bo, 1999; Gunnarsson et al., 2002] whereas Sartore et al. [2003] compared maximal strength in women suffering from SUI to a mixed group including continent and women with other urologic symptoms. The results from these studies yielded non-significant differences when comparing maximal strength in continent and incontinent women. Since the pathophysiology of these types of incontinence is different, we focused our study on SUI. Fourth, when using pressure measurements, calculations of the maximal strength may also explain discrepancies in the literature. Some authors include passive forces in the maximal pressures [Dougherthy et al. 1986; Boyington and Dougherty, 2000] while others exclude the passive force of the calculations by subtracting the passive force from the maximum peak value or by resetting the apparatus when the probe was inserted in the vaginal cavity [Laycock, 1992; Bo et al., 1994; Morkved and Bo, 1999]. In the present study, exclusion of the passive forces was preferred in order to be sure that any differences in maximal strength originate from the active forces of the subjects, not their passive forces. As anticipated, inclusion of the passive forces would have yielded significant differences between continent and incontinent women ($P < 0.05$): 6.9 ± 2.7 N for continent women versus 4.8 ± 1.9 N for incontinent women at the 19-mm aperture and 9.7 ± 3.3 N for continent women versus 7.6 ± 3.3 N for incontinent women at the 24-mm aperture. Although these important factors (vaginal aperture, instrument reliability and validity, homogeneity of the population,

TABLE II. Pelvic Floor Muscle Function

	Mean ± 1 SD		
Parameters	Continent	SUI	*P*-values
Passive force at 19-mm vaginal aperture (N)	2.3 ± 1.0	1.6 ± 0.7	0.011
Passive force at 24-mm vaginal aperture (N)	3.7 ± 1.4	2.8 ± 0.8	0.005
Maximal strength in self-paced effort at 19-mm vaginal aperture (N)	4.5 ± 2.3	3.7 ± 1.8	0.229
Maximal strength in self-paced effort at 24-mm vaginal aperture (N)	5.9 ± 2.8	5.6 ± 3.2	0.671
Rate of force development (N/s)	8.7 ± 4.5	5.6 ± 3.9	0.012
Number of contractions (count)	10.3 ± 3.9	8.5 ± 3.0	0.011
Absolute endurance, area under the force curve (N*s)	129.1 ± 75.3	81.3 ± 52.8	0.001

continence status definition, and inclusion or not of passive measurements in maximal strength calculations) were controlled in our study, we found no statistically significant difference in maximal strength between continent and stress incontinent women but observed significant differences for other PFM parameters.

The small sample size could also be a factor to consider for the discrepancies in previous studies. Hence, the inability to find statistically significant differences in PFM strength between continent and stress incontinent women in our study may have been a type II error. Even if the mean value of maximal strength was not statistically different between groups, this does not exclude the fact that some women have a real weakness of the PFM. This view is supported by the lower mean values found in incontinent women, particularly at the aperture of 19 mm.

In the protocol of rapidly repeated contractions, the rate of force development suggests that the incontinent women have an impaired ability to recruit PFM fast fibers. Accordingly to Janssens et al. [2002] and Laycock [1992], the continent women were able to produce a faster contraction than stress incontinent subjects. These findings support the study of Miller et al. [1998] in which stress incontinent women learned to perform a quick PFM contraction to successfully prevent anticipated urine leakages. Furthermore, continent women achieved a greater number of contractions within 15 sec, which may be related to a higher speed of contraction as well as better muscle control.

The sustained maximal contraction was included in the PFM function assessment to target muscle endurance. Since the continent women showed a higher area under the force curve, it can be hypothesized that the PFM endurance may contribute to continence by occluding the urethra during repeated or prolonged activities such as jogging, bouts of coughing, or even daily living activities. To exclude the initial contraction slope, the area under the curve force was calculated between 10 and 60 sec after the beginning of the contraction. After the first 10 sec, subjects had reached a more stable value, which is probably more a reflection of the slow twitch fiber endurance. Similar curve patterns were observed in both continent and stress incontinent groups. The predominant curve pattern was as follows: higher force values were produced when the subject started contracting but, subsequently, the forces began to decrease with large fluctuations. Nevertheless, the decrease in force over time was impossible to evaluate because some women returned to their maximal force during these oscillations. It has been hypothesized that this pattern is due to the constant contraction of the slow-twitch fibers while the fast-twitch fibers are repeatedly recruited and fatigue [Laycock, 1992]. Furthermore, we recognize that the area under the curve is mathematically influenced by the maximal strength of the subjects, which is why the term “absolute endurance” was used in the present study. Deindl et al. [1994] assessed endurance in a different way: their subjects had to contract maximally as long as possible. Continent women were able to hold the contraction longer than incontinent women. A holding time of up to 647 sec has been reported, which is much longer than our endurance trial. In contrast, Laycock [1992] and Boyington and Dougherty [2000] reported fatigue indices and an endurance index, which corresponded to the percentage of force at the end of the contraction(s) compared to the initial strength. However, no significant result discriminating between continent and incontinent women arises from these techniques. Thus, the difference in endurance across studies appears to depend on the measurement technique. One possible approach to resolve this issue is to use EMG spectral analysis to infer on the recruitment and frequency discharge of motor units [Lariviere et al., 2002].

Different aspects of the PFM function seem to be affected in stress incontinent women. Further research would increase our understanding of this function across age, parity, deliveries, menopause, etc. and this better understanding of the SUI pathophysiology could enable a rehabilitation program to be adapted to specific PFM impairments. Finally, optimal PFM training targeting these PFM parameters needs to be investigated. Current studies reveal meager knowledge about the effect of different treatment regimens (types of exercise, vaginal cones, electrical stimulation, etc.) on the PFM parameters.

CONCLUSION

The PFM function is deficient in stress urinary incontinent women. Our results suggest that PFM assessment should not be restricted to maximal strength. Other parameters such as passive force, speed of contraction, and endurance significantly discriminate between continent and stress incontinent women. A complete PFM function analysis is mandatory to evaluate changes over time or following treatment.

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