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ORIGINAL ARTICLE

Pelvic floor morphometry: a predictor of success of pelvic floor muscle training for women with stress and mixed urinary incontinence

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Abstract
Introduction and hypothesis The aim of this study was to determine if pelvic floor muscle (PFM) morphometry at baseline, as measured by MRI, can predict response to PFM training in women with stress or mixed urinary incontinence (UI).
Methods This study was a prospective quasi-experimental pre-test, post-test cohort study of women with UI, aged 60 years and older. All participants completed a baseline assessment of UI severity and impact, using the 72-h bladder diary and the Incontinence Impact Questionnaire. They underwent a pelvic MRI examination to assess the PFM anatomy. Women then participated in a 12-week PFM training program. Finally, they attended a post intervention assessment of UI severity and impact. The association between morphometry and PFM training response was assessed by univariate analysis, multivariate analysis, and receiver operating characteristic (ROC) curve analysis.
Results The urethro-vesical junction height at rest, as measured by MRI before treatment, was associated with response to PFM training both on univariate ($p \leq 0.005$) and multivariate analyses ($p = 0.007$). The area under the ROC curve was 0.82 (95% confidence interval [CI]: 0.67–0.96). Using a cut-off point of 11.4 mm, participants' response to PFM training was predicted with a sensitivity of 77% and a specificity of 83%. Incontinent women with a urethro-vesical junction height above this threshold were 35% more likely to respond to PFM training (OR 1.35; 95% CI: 1.08–1.67).
Conclusion In older women with UI, a urethro-vesical junction height at rest of at least 11.4 mm appears to be predictive of PFM training response.

Keywords Morphometry · Pelvic floor muscle training · Physiotherapy · Predictors · Older women · Urinary incontinence

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Introduction

Over 30% of women aged 60 and above are affected by urinary incontinence (UI), one of the most wide-spread health conditions affecting older women, and this figure increases incrementally with age. Among those affected, 44% have symptoms of mixed urinary incontinence (MUI) and 33% have stress urinary incontinence (SUI). Both MUI and SUI are strongly associated with negative consequences on quality of life [1].

Both SUI and MUI can be treated with pelvic floor muscle (PFM) training and/or surgery [2, 4]. High-quality evidence from systematic reviews indicates that supervised PFM

training can lead to cure or improvement in up to 76% of women with UI [3]. However, relatively little is known about how to identify women most likely to benefit from PFM training for UI [4]. Hence, we are currently unable to predict response to PFM training before treatment.

Thus, the aim of this study was to determine if PFM morphometry at baseline could predict response to PFM training in women with SUI or MUI. We hypothesized that PFM morphometry, as measured by pelvic MRI, might predict response to PFM training in women with SUI or MUI.

Materials and methods

Study design and population

This study was a prospective quasi-experimental pre- and post-test pilot cohort study. As is our standard practice, participants who live in the community within the Montreal metropolis are recruited through community-based advertising, such as posters in senior citizens centers and urogynecological clinics, advertisements in newspapers, and professional referrals. Women were selected for the study if they were independently ambulatory, did not live in an assisted environment, had not changed their hormone prescription in the previous 6 months, and were able to understand written and verbal instructions in either French or English. Women were excluded if they had participated in PFM training within the last year, had incontinence with neurological causes, were unable to actively contract their PFM at initial evaluation or presented UI risk factors known to interfere with normal PFM function, such as severe obesity (BMI >35 kg/m^2) [5], chronic constipation [6], or significant genital prolapse (>POP-Q II) [7], as well as any other medical problems that could have interfered with PFM training or MRI scanning such as severe claustrophobia or pacemaker.

To meet the definition of UI, the participants had to report losing urine involuntarily at a minimum of once a week in the preceding 12 weeks. This is a standard defining metric used in cohort studies and randomized control trials on UI [8]. Self-diagnosis using the Urogenital Distress Inventory (UDI) [9] was used to establish the type of UI: SUI was defined as involuntary urine loss on effort, such as exertion, sneezing or coughing, but not on urgency (Q4 and 6) [9], whereas MUI included involuntary urine loss on both effort and urgency (Q3, Q4, Q6, and Q7) [9].

Women interested in participating in the study were invited to contact the research assistant to take part in a screening telephone interview, which included information on the study's objectives and procedures. Based on the criteria above, the research assistant confirmed each woman's eligibility. Research participants received financial compensation for travel expenses at each visit. The study was approved by the institutional review board of the Research Centre of the Institut Universitaire de Gériatrie de Montréal (CRIUGM) and took place between September 2008 and January 2012. All participants provided written, informed consent before the evaluation.

All participants completed a baseline assessment (UI severity and impact, and MRI assessment), participated in a 12-week PFM training program (group PFM training and home PFM exercises) and attended a post-intervention assessment (UI severity and impact).

Baseline assessment

The baseline assessment included a UI severity and impact component in addition to an anatomical MRI assessment. The severity and impact of the participants' UI symptoms were evaluated with a 72-h bladder diary and the Incontinence Impact Questionnaire (IIQ) [9, 10]. The bladder diary, which had to be completed before the baseline assessment session, included questions about the number of leakage episodes per day, for 3 days [10]. Further, women completed the IIQ to assess the presence of various urogenital symptoms and their effect on quality of life. It was scored as described by Shumaker et al. [9], with higher scores indicating lower quality of life. Both the 72-h bladder diary and the IIQ have been found to be valid and reliable measures of incontinence symptom severity and incontinence-related quality of life in women [8].

A physiotherapist taught the participant how to perform PFM contractions and used vaginal palpation to confirm the correct technique. The participant then emptied her bladder and underwent a pelvic MRI examination in the supine position with hips and knees flexed. As was the case in our previous study [11] MRI was performed with a Siemens Magnetom Trio 3.0 T, using an iPAT torso/pelvis coil centered at the symphysis pubis, according to a previously described protocol [12]. Sagittal dynamic acquisitions were acquired: at rest, during a PFM maximal voluntary contraction (MVC), and during straining. At rest, the women were instructed to breathe normally and relax their PFM. During MVC of the PFM, the women were instructed to simulate holding back gas and urine, contracting their PFMs as hard as they could for 10 s. Conversely, to standardize the straining effort, participants were instructed to blow through a Guillarme's tube and to push as if they were straining to defecate for 10 s. MRI acquisition parameters are summarized in Table 1.

Pelvic floor muscle training

The women participated in a 12-week PFM training program, an intervention known to be effective for UI [12]. It

Table 1 Magnetic resonance imaging acquisition parameters in the sagittal plane

Status	Resting	PFM MVC and straining
Pulse sequence	T2-weighted FSE	T2-weighted SSFSE
Field of view (mm)	240 × 240	240 × 240
Matrix	512 × 256	256 × 256
Slice thickness/gap (mm)	6/1	6
Slice number	20	6 cine images
Repetition time (ms)	4,980	3,000
Echo time (ms)	134	109
Bandwidth (Hz/pixel)	130	320
Number of excitations	1	1
Scan duration (s)	146	18

PFM MVC pelvic floor muscle maximal voluntary contraction, *FSE* fast spin echo, *SSFSE* single-shot fast spin echo

involved weekly, 1-h group PFM training (6–8 women), led by an experienced pelvic floor physiotherapist. Participants were required to complete at least ten classes to be considered as having completed the intervention. Each class consisted of a 15-min educational period on UI followed by a 45-min session of static PFM training including MVCs, maximum contractions with superimposed rapid contractions (flicks), controlled PFM contractions to 50%, 100%, 50% of the maximum, and then relaxed (podium exercises) and PFM pre-contraction before coughing (the Knack), performed supine, four-point kneeling, sitting, and standing. The exercises increased in number, intensity and hold duration every 4 weeks to maximize strength resistance training. Breathing, gentle stretching exercises, core-strengthening exercises, and balance exercises were also included in the weekly 1-h PFM exercise class program.

Additionally, the participants performed home PFM exercises for 15–20 min, 5 days a week. The PFM home exercise program included PFM MVCs, flicks, podium exercises, Knack, and targeted strength, power, endurance, and coordination. The number, intensity and body position of the exercises were escalated every 4 weeks: from six repetitions with a 6-s hold performed supine, to eight repetitions with an 8-s hold performed sitting, to, finally, ten repetitions with a 10-s hold performed standing. The physiotherapist monitored adherence to the PFM training sessions and participants recorded their home exercise adherence in a weekly exercise diary. Details of the intervention protocol and progression have been described previously [12].

The results of previous pilot projects confirmed that this intervention was well tolerated and resulted in a significant decrease in the number of urine leakages, in addition to a significant increase in symptoms and UI-specific quality of life, as measured by the bladder diary and IIQ [12].

Post-intervention evaluation

One to 2 weeks post-intervention, the women had to complete a 3-day bladder diary [10] and then, during a post-intervention evaluation session, they completed the IIQ [9].

Improvement following PFM training (treatment response)

In the present study, improvement following a PFM training was calculated using a combined score and defined as: a post-treatment reduction of 50% or more in the mean number of UI episodes per day, as measured in a 3-day bladder diary, and a post-treatment reduction of 50% or more in the original IIQ impact score [9, 10]. Use of a combined score from the bladder diary (an objective primary outcome used in most RCTs) [3, 4] and IIQ impact score (a more subjective outcome) aligns with the 2013 International Consultation on Incontinence recommendation to expand the dimensions of outcome measures to include patients' global ratings [8].

MRI predictors

As in our previous study [11], morphometric measurements of the pelvic floor at rest were taken from the sagittal images, using the mid-sagittal slice in which all reference structures were visible. The mid-sagittal images selected were those that demonstrated the greatest bladder-neck elevation and depression respectively, during the PFM MVC and the straining tasks. A trained evaluator then processed and analyzed the MR images using JmageJ vl.45 software (imagej.nih.gov). The evaluator was blinded to each participant's UI status.

The study assessed eight potential MRI predictors (i.e., baseline PFM MRI morphometric parameters: the pubococcygeal (PC) line, the anorectal angle, the H-line, the M-line, the PCL/H-line angle, the height of the urethro-vesical (UV) junction, the height of the utero-cervical (UC) junction, and the UV junction approximation) under the three conditions rest, PFM MVC, and straining. The measurement descriptions are presented in Table 2 and illustrated in Fig. 1

Statistical analysis

Statistical analysis was conducted using SPSS version 15 for Windows. Potential errors were double-checked with analysis to detect outliers in the frequency distributions and ranges for each measurement. Univariate analysis was used to examine the associations between each of the 24 predictors (3 conditions × 8 predictors) and the dependent variable (response to PFM training). Variables in the univariate analysis that

Table 2 Morphometric measurements

		Measurements	Description
PFM and pelvic organ	Sagittal plane	Pubococcygeal line	Measured from the inferior edge of the pubic symphysis to the anterior aspect of the sacrococcygeal joint line
		Anorectal angle	Measured at the intersection of the lines drawn along the posterior walls of the anus and rectum
		H-line	Measured from the inferior edge of the pubic symphysis to the apex of the anorectal angle
		M-line	Measured perpendicularly from the pubococcygeal line to the apex of the anorectal angle
		Pubococcygeal/H-line angle	Measured as the angle between the H and the pubococcygeal line
		Heights of the urethro-vesical and the utero-cervical junctions	Both measured perpendicularly from the pubococcygeal line to these junctions. In women who have undergone hysterectomies, the height of the vaginal apex was measured instead of the utero-cervical junction
		Urethro-vesical junction approximation height	Measured as the perpendicular distance between the urethro-vesical junction and the long axis of the pubis

indicated a relationship to outcome ($p \leq 0.15$) were screened for multicollinearity; those without multicollinearity were selected. To be entered into a multivariate logistic regression model, each of the independent variables had to have a bivariate correlation lower than 0.7 with the other independent variables [13]. When a bivariate correlation of 0.7 or greater was found, only 1 of the 2 independent variables was included in the model. Predictors that reached significance were subject to a backward stepwise logistic regression analysis to determine which combination of predictors best explained the response. Finally, a receiver operating characteristic (ROC) curve was plotted to estimate the prediction accuracy. Further, the decision threshold that maximized the Youden index was identified and the corresponding sensitivity and specificity were reported.

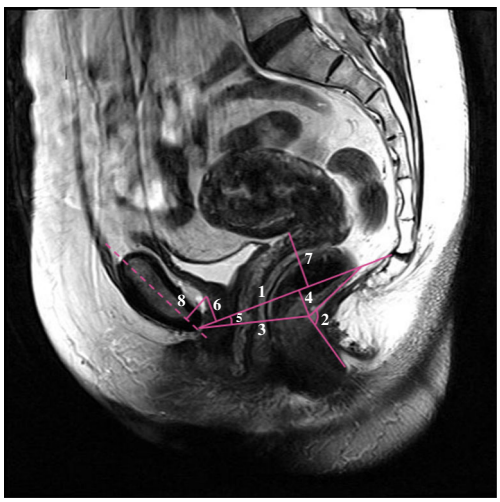


Fig. 1 Morphometric measurements in the sagittal plane. *1* pubococcygeal line, *2* anorectal angle, *3* H-line, *4* M-line, *5* PC/H-line angle, *6* height of the urethro-vesical junction, *7* height of the utero-cervical junction, *8* urethro-vesical junction approximation height

Results

Forty women with a mean age of 68.4 years and SUI or MUI participated in the study. After frequency distributions and ranges for each study measurement were analyzed, it was determined that no outliers could be identified. Table 3 presents the demographic characteristics of the participants.

Table 4 presents the UI outcome measures before and after PFM training. All study participants adhered to the PFM training sessions and home exercise completing at least 90% of the required exercise regimen. The mean number of UI episodes per day (taken from the 72-h bladder diary) and the impact on the quality of life (IIQ impact score) were significantly lower after PFM training ($p < 0.001$). Twenty-five women (62.5%) were classified as responsive following PFM training, 15 (37.5%) were not.

In the univariate analyses, women with a shorter UV junction approximation on straining, a shorter M-line at rest, a smaller PCL/H-line angle at rest, and a higher UV junction height at rest ($p \leq 0.005$) were more likely to respond to PFM training. These four parameters (potential predictors) were retained for multivariate logistic regression analysis. Ultimately, two were associated with responsiveness: UV junction height at rest (perpendicular distance between the anterior aspect of the UV junction and the pubococcygeal line) and UV junction approximation on straining (perpendicular

Table 3 Demographic data of study participants pre-treatment

Demographics	Mean ± SD	Range
Age (years)	68.4 ± 5.3	60–81
BMI (kg/m^2)	25.9 ± 4.0	19.5–35.4
Deliveries (number per subject)	1.5 ± 1.2	0–4

BMI body mass index

Table 4 Outcome measures pre- and post-PFM training

Outcome measures	Baseline	Post-PFM training	*p* value*	*n* (%) responders
Leakage episodes (mean/24 h)	1.89 ± 1.42	0.90 ± 1.07	<0.001	26/40 (65)
IIQ scores (/10)	4.75 ± 2.58	2.83 ± 2.65	<0.001	21/40 (52.5)
Combined score	–	–	–	25/40 (62.5)

IIQ Incontinence Impact Questionnaire

*Level of significance was set at $p < 0.05$

distance between the UV junction and the pubic axis), although the latter did not make a statistically significant contribution to the model. There was a good model fit with a Chi-squared of 20.9 ($p < 0.001$), indicating that, combined, the two predictors had reliably distinguished, pre-treatment, between those participants who responded (improved) and those who did not (no improvement), post-intervention. This model, based on 2 of the 4 PFM morphometric parameters, explained between 42% (Cox and Snell R^2) and 58% (Nagelkerke R^2) of the outcome variability and correctly classified 84.2% of the participants. When the full model was applied (four parameters), the success rate increased to 86%, only a small improvement. Table 5 contains the regression coefficients and odds ratios, with 95% confidence intervals for each predictor. According to the findings, women with a higher UV junction height at rest were more likely to be improved after PFM training.

Finally, the area under the ROC curve was 0.82 ± 0.07 (95% CI: 0.67–0.96; $p < 0.001$) as presented in Fig. 2. Using a cut-off point of 11.4 mm, participants' response to the PFM training was predicted with a sensitivity of 77% and a specificity of 83%.

Discussion

In the present study, the effectiveness of a 12-week PFM training intervention was influenced by participants' pre-treatment PFM morphometry measured with anatomical MRI. Women with SUI and MUI who had a higher UV junction height at rest pre-intervention were more likely to improve with PFM training. For every additional millimeter of UV junction height at rest, as measured before the PFM training, participants were 35% more likely to report improvement after PFM training. Finally, using a UV junction height cut-off point of 11.4 mm at rest, participants' response to PFM training could be predicted with a moderate sensitivity (77%) and specificity (83%).

To date, few studies have specifically investigated the associations between the characteristics of women with UI and PFM training outcomes. Much of the research has focused on a limited set of potential predictors of cure or improvement to PFM training in women with UI, specifically demographic (age, parity, mode of delivery, prolonged second-stage labor, etc.) and clinical (symptom severity and duration, positive cough stress test) [14–26]. However, no consistent pattern of association with PFM training response has emerged from these demographic or clinical variables [14–26].

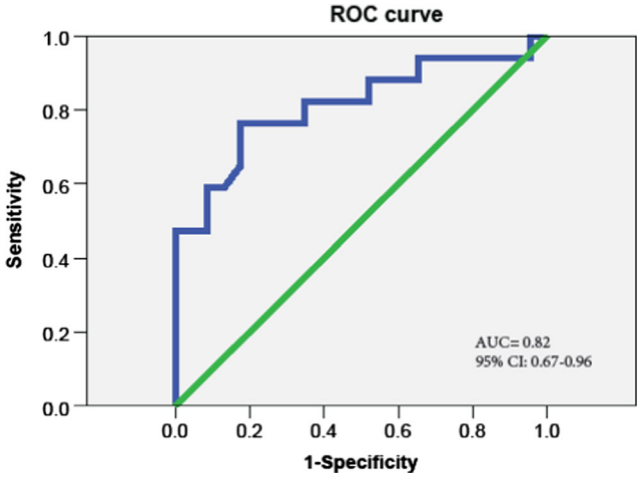
Few PFM function predictors have been studied in women with UI, such as PFM strength, passive force or tone, coordination, and reaction to coughing. PFM strength has long been thought to be a potential predictor of response to PFM training in women with SUI and MUI; however, its predictive value was inconsistent between studies. Lower PFM strength pre-intervention measured digitally or by perineometry has been demonstrated to be a positive predictor of PFM training response in two studies [15, 17], a negative predictor of PFM training response in two studies [16, 20], and was not a significant predictor in one study [16]. Differences in study populations (post-partum women; middle aged, older women), UI types (SUI, MUI or urgency UI), outcome measures (patient reported or clinically reported), and even statistical methods used in these studies could account for these differences. In our study, no morphometric MRI parameter measured during the PFM MVC was identified as a predictor of response to the 12-week PFM training intervention. However, it should be noted that women had to be able contract their PFM at initial evaluation to be included in this study; hence, there is a potential selection bias against women who had significant weakness or no PFM strength at all.

Table 5 Logistic regression model, response to pelvic floor muscle training in older women with stress and mixed urinary incontinence

	Estimated coefficient	OR	95% CI	*p* value*
UV junction approximation on straining	0.228	1.256	0.976–1.615	0.076
UV junction height at rest	0.299	1.349	1.087–1.674	0.007
Constant	−6.476	0.002		0.002

OR odds ratio, *CI* confidence interval, *UV* urethro-vesical

*Level of significance was set at $p < 0.05$



Legend :
ROC : Receiver operating characteristic ; PFMT : pelvic floor muscle training

Fig. 2 Receiver operating characteristic (ROC) curve showing the predictive performance of the urethro-vesical junction height at rest of 11.4 mm or more on pelvic floor muscle training (PFMT) responsiveness in women with stress or mixed urinary incontinence. The area under the ROC curve is 0.82 with a 95% confidence interval of 0.67–0.96

In addition to PFM strength, our research team has identified (in the past and using PFM dynamometry) other functional parameters that predicted PFM training response in women with SUI: passive strength at rest (tone), rate-of-force development before a cough, and the number of rapid contractions (coordination) during a 10-s MVC test [26]. These pre-treatment dynamometric predictors were associated significantly with a positive response (UI cure or improvement) among 71.9% ($p < 0.014$) of young post-partum and middle-aged women with SUI [26]. It can be argued that the morphometric predictor from the present study (the higher UV junction at rest) is in line with the previously found higher passive force (tone) as a predictor, as the PFM is known to be in part responsible for bladder neck support and for maintaining its position at rest [26]. The other PFM functional predictors cannot be linked to the present study results as they were obtained during PFM functional tests different than those conducted in this MRI study.

Until now, no individual demographic, clinical or morphometric variable, as discussed above, has demonstrated a consistent association with PFM training response. Moreover, the *International Consultation on Incontinence* chapter 12 on UI conservative management concluded that "too few trials have appropriately investigated the association between patient characteristics and outcome, hence, it remains unclear if there are any reliable predictors of PFM training outcome" [4]. Therefore, the strong predictive parameter presented in the results of this study, although preliminary, is significant, as it provides novel information on the independent association between PFM morphometry and PFM training response using an important UI outcome of interest and the appropriate statistical method.

Although encouraging, this potential predictor (the height of the UV junction at rest) may be unique to the study's participants (older women with SUI or MUI, this intervention (intensive PFM training delivered in a group setting) or even the motivation and adherence of participants (commitment to PFM training, peer support) [27]. Further, as the threshold was derived from this cohort, the prediction accuracy is expected to be lower in an independent cohort. Hence, for these reasons, predictors of PFM training response must be validated through larger prospective trials in different participant cohorts and with other practitioners to assess their external validity in a clinical prediction rule. Further, given the high cost and unavailability of MRI in clinical settings, proxy variables that can be measured by more cost-effective and widely available clinical tools also need to be identified. Transperineal ultrasound could be an excellent alternative as it provides visual information on PFM morphometry, has been widely studied for its validity and repeatability as a PFM morphometric instrument, is not as costly, and is widely available to clinicians [28].

Conclusion

In older women with SUI or MUI, a urethro-vesical junction height at rest of at least 11.4 mm appears to be predictive of response to PFM training. Larger prospective studies are needed to validate the strength of this pre-treatment prognostic factor. Further, given the high cost of MRI, an alternative modality (e.g., ultrasound) also needs to be identified.

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Compliance with ethical standards

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Conflicts of interest None.

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