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Impact of preoperative pelvic floor muscle strength and endurance on urinary continence after radical prostatectomy: A sub-analysis of a randomized clinical trial

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Introduction To assess the impact of preoperative pelvic floor muscle (PFM) strength on urinary incontinence (UI) after radical prostatectomy (RP).

Material and methods A total of 127 men who underwent surgical treatment for clinically localized prostate cancer in a tertiary university hospital were included in a sub-analysis. PFM strength (cmH_2O) and endurance (s) were measured using a perineometer on the day before and at 1, 3, and 6 months after surgery. UI volume was measured using an 8-hour pad test. The primary outcome was continence, defined as 0–5 grams of urine during the 8-hour pad test at 6 months post-RP. The association between baseline PFM strength and continence was analyzed using Spearman's correlation coefficient, receiver-operating characteristic analysis, and logistic regression analysis.

Results At 6 months post-RP, 45 of 127 (35.4%) men were continent. UI showed a strong negative (r = –0.7; p <0.001) association with preoperative PFM strength and a medium negative (r = –0.55; p <0.001) association with PFM endurance. PFM strength (odds ratio [OR] = 1.16, p <0.0001), PFM endurance (OR 1.6, p <0.0001), and preoperative prostate-specific antigen (OR = 0.87, p = 0.03) were the most significant predictors of continence in the univariate regression analysis. In the multivariate analysis, only PFM strength remained a significant predictor (OR = 1.13, p <0.001) of UI. The thresholds for PFM endurance and strength were 9.6 seconds and 98.9 cmH_2O, respectively.

Conclusions Preoperative PFM strength and endurance demonstrated significant associations with postoperative UI. Objectively measured preoperative PFM conditions could help identify patients at increased risk of UI after RP.

Key Words: pelvic floor muscle strength ‹› pelvic floor muscle endurance ‹› urinary continence ‹› prostate cancer ‹› radical prostatectomy

INTRODUCTION

Urinary incontinence (UI) after radical prostatectomy (RP) is one of the most debilitating complications, significantly affecting quality of life and potentially influencing the choice of RP as a treatment option [1]. UI after RP varies from 5% to 60%, depending on the criteria used for defining incontinence and the timing of postoperative assessment [2, 3]. The prevalence and severity of UI decrease with postoperative time: 83–84% of patients experience UI at 3 months [4], 8–87% at 6 months, and 5–44% at 12 months postoperatively [5]. A more recent systematic review documented incontinence rates at 12 months ranging from 4% to 31% [6]. Introducing new surgical techniques, such as robot-assisted laparoscopic prostatectomy (RALP), did not reduce the UI rate compared to open RP [7, 8], leaving men after any type of RP at an increased risk of UI. In this context, preoperative anatomical variables and PFM conditions may play significant roles in continence after RP. Membranous urethral length (MUL), measured preoperatively via magnetic resonance imaging (MRI) or transperineal ultrasound, is among the most important predictors of UI [9–14]. PFM strength and endurance could also serve as predictors of UI, given their clear role in the normal physiology of the continence mechanism. However, evidence-based data on the association between objectively measured preoperative PFM conditions and UI after RP is limited [15–18].

We hypothesized that PFM strength and endurance before RP could predict UI after surgery. This report presents a sub-analysis of prospective randomized clinical trial data evaluating the importance of preoperative PFM strength and endurance as predictors of postoperative continence.

MATERIAL AND METHODS

A total of 148 men with clinically localized prostate cancer who underwent open retropubic RP between 2010 and 2012 at a tertiary university hospital were invited to participate in a prospective randomized clinical trial. Five senior urologists performed open RP during the study. The nerve-sparing technique was used in all cases where local disease was suspected based on digital rectal examination, the number of positive biopsy cores, and biopsy Gleason scores. Routine preoperative prostate MRI was not performed during the study period. No special surgical techniques were employed to ensure urinary continence. All men postoperatively underwent one of three exercise-based physiotherapy programs (pelvic floor muscles training vs diaphragm muscle training vs. abdominal muscle training) with a 1 : 1 : 1 ratio for 6 months.

In the pelvic floor muscles training group, the exercises were performed in various positions: laying on the back with bent legs and a lifted pelvis, laying on the back with bent legs, sitting on a gym ball, standing, walking and using the stairs. The activation of the PFMs consisted of short dynamic contractions, 2–3 sets in one session with a 1-minute break, and gradually increasing repetitions. During urination, we recommended that patients stop the flow 2 times. PFM contraction was ensured by asking the patient to make the pelvic floor “concave”.

In the diaphragm muscles training group, the breathing exercises were performed in various positions: lying on the floor with bent or extended legs, in a quadruped position, and performing small squats holding the arms on the thighs. We used the diaphragm's strong and hard concentric and eccentric contractions with resistance. For activation of the diaphragm, patient was instructed to do the following: inhale through the nose, exhale slowly through the mouth, inhale through one nostril, exhale through the mouth, inhale and exhale through the nose, inhale through the nose, and exhale through the mouth while limiting the chest expansion with a belt.

In the abdominal muscles training group, patient was taught correct activation of the abdominal muscles: retraction of the abdomen was performed during the expiration while the pelvic and torso area remained stable. Lower limb movements were introduced to progress the training. A concentric muscle contraction regimen was applied. Activation exercises of the transversus abdominis muscle were performed in different positions: with patient lying on the back with bent and straight legs; lying on the abdomen; on the knees with the hands placed on the ground; standing with the body and shins insignificantly bent and with the arms resting on the thighs; walking; and climbing the stairs.

Since no differences in UI were observed among the physiotherapy programs, all patients who completed the study were eligible for the sub-analysis presented here. Patient selection, trial design, procedures, and initial results have been previously described in detail [15, 18].

One day before surgery, PFM strength (cmH_2O) and endurance (s) were measured using the Peritron 9300A perineometer (Cardio Design Pty. Ltd., Australia). PFMs strength and endurance were measured with the patient lying on the left side with thighs and shins bent at an angle of 45°. The anal sensor of a perineometer was inserted into the anus. In order to get the most accurate results, during repeated testing, the patient’s position and the depth of the sensor were not changed. To evaluate pelvic PFMs strength, the subject was asked to contract the muscles of the anus as maximally as possible. The maximal result was recorded over the period of 1.8 s. PFMs strength was measured in cmH_2O. To evaluate PFMs endurance, the subject was asked to hold the contracted muscles of the anus as long as possible. The endurance result was recorded when the maximal value dropped by more than 5 cmH_2O. PFMs endurance was measured in seconds. To avoid excessive activation of puborectalis muscle or external anal sphincter during PFMs contraction, the patient was encouraged by using specific instructions, such as “shorten the penis” – predicted to target striated urethral sphincter, and “stop the flow of urine” – predicted to target striated urethral sphincter and puborectalis muscle. We focused on the striated urethral sphincter using specific verbal instructions during the testing of PFMs strength and endurance because striated urethral sphincter lies at the inferior end of the prostate, generates the greatest urethral pressure of the striated muscles, and is most important for urinary continence. UI was measured using the 8-hour pad test (g) at all scheduled visits. Patients were considered continent if the 8-hour pad test was ≤5 g (<1 g per hour) and incontinent if >5 g at 6 months post-surgery.

PFM strength and endurance measurements taken the day before surgery and 6 months after RP, changes in PFM strength and endurance over 6 months, age, prostate volume, BMI, prostate-specific antigen (PSA), pathological Gleason score, and stage were analyzed for each group.

Before surgery, all men were continent. Only three patients had used medical treatment for lower urinary tract symptoms (treated with α-blocker tamsulosin), and none were treated for overactive bladder symptoms. All PFM and UI measurements, except the first pad test after catheter removal, were performed and recorded by one investigator.

Statistical analysis

The study endpoint was the urinary continence rate 6 months post-surgery and its relationship with baseline PFM strength and endurance. Data were presented as medians and interquartile ranges. Spearman's correlation coefficient was calculated to estimate the correlation between two quantitative variables. Univariate and multivariate binary logistic regression analyses were applied to predict the probability of UI. receiver-operating characteristics (ROC) analysis was used to calculate cutoff points. Analyses were performed using IBM SPSS 26.0 software with a two-sided significance level set at $p < 0.05$.

Bioethical standards

The study protocol was approved by the Biomedical Research Ethics Committee of Lithuanian University of Health Sciences (Protocol ID BE-2-61), and the data were processed with permission from the State Data Protection Inspectorate (Protocol ID 2R-1697). The trial was registered in the ClinicalTrials.gov database (NCT03858452). All patients provided written informed consent before study enrollment.

RESULTS

A total of 127 of 148 men completed the study, and 45 of 127 (35.4%) men were continent at the end of the study. Patient characteristics are presented in Table 1. There were no differences in clinical parameters between continent and incontinent men except for PFM strength and endurance measured the day before and 6 months after surgery (Table 1). During the study, changes in PFM strength (median [interquartile range]: 24 [16–33] vs 23.5 [16–38] cmH_2O, p = 0.7) and endurance (7 [4.5–10] vs 7 [6–8.3] s, p = 0.9) were not significantly different between continent and incontinent men.

Spearman's correlation coefficient showed a strong negative (R = –0.7; p <0.001) correlation between preoperative PFM strength and UI at 6 months after RP (Figure 1) and a medium negative (R = -0.551; p <0.001) correlation between preoperative PFM endurance and UI (Figure 2).. PFM strength was directly associated with PFM endurance (R = 0.683; p <0.001).

Univariate and multivariate binary logistic regression analyses were performed to assess predictors of UI after RP. In the univariate analysis, preoperative PSA (odds ratio [OR] 0.87, p = 0.003), PFM strength (OR 1.16, p <0.0001), and PFM endurance (OR 1.6, p <0.0001) were significant predictors of UI. In the multivariate analysis, only PFM strength remained a significant predictor (OR 1.13, p <0.001, Table 2).

Cutoff values for PFM strength and endurance were determined. The threshold for PFM endurance was 9.6 s. Men who could hold PFM contraction for more than 9.6 s before surgery were more likely to be continent 6 months post-RP (Figure 3A). The threshold for PFM strength was 98.9 cmH_2O. Men with higher PFM strength had a higher probability of continence post-RP (Figure 3B).

DISCUSSION

UI after RP remains one of the most debilitating complications, significantly affecting patients' quality of life. Introducing new surgical techniques such as RALP has not significantly reduced UI rates. A systematic review and meta-analysis of urinary recovery after RALP reported 12-month UI rates ranging from 4% to 31%, depending on the definition of continence used [6]. A direct comparison of open RP vs RALP techniques in a prospective non-randomized controlled trial showed no significant difference in UI rates at 12 months (20.2% vs 21.3%) [7]. Recent randomized controlled trials also found no significant differences in functional outcomes between open RP and RALP at 12 and 24 months, with pad-free rates of 91% and 95% versus 90% and 91%, respectively [8]. These data suggest that novel intraoperative techniques alone cannot eliminate the risk of incontinence after RP, emphasizing the need to identify additional factors to improve continence outcomes.

Table 1. *Patient characteristics*

Parameter	All patients (n = 127)	Continent group (n = 45)	Incontinent group (n = 82)	p
Age (years) Median (IQR)	64 (59–67)	61 (58–67)	64 (61–68)	0.06
Prostate volume [ml] Median (IQR)	36 (32–44)	36 (31.5–43.5)	38 (32.8–47.8)	0.3
BMI [kg/m^2] Median (IQR)	27.6 (25.7–30.5)	27.7 (25.2–30.7)	27.5 (25.7–30.2)	0.9
PSA (ng/ml) Median (IQR)	5.8 (5.0–9.1)	5.5 (4.9–7.0)	6.6 (5.0–9.9)	0.08
Pathological GS, n (%) GS 6 GS 7 (3 + 4) GS 7 (4 + 3) GS 8	 23 (18.1) 82 (64.6) 16 (12.6) 6 (4.7)	 6 (13.3) 30 (66.7) 7 (15.6) 2 (4.4)	 17 (20.7) 52 (63.4) 3 (11.0) 4 (4.9)	0.7
Pathological stage, n (%) pT2 pT3a pT3b	 78 (61.4) 44 (34.7) 5 (3.9)	 26 (57.8) 19 (42.2) –	 52 (63.4) 25 (30.5) 5 (6.1)	0.1
PFMs strength (cmH_2O) 1 day before RP Median (IQR)	94 (84–102)	102 (97.5–106)	87 (77.8–94.3)	<0.001
PFMs strength (cmH_2O) 6 months after RP Median (IQR)	117 (108–130)	128 (118.5–136)	111 (104–122.3)	<0.001
PFMs strength 6 months –1d Median (IQR)	24 (16–35)	24 (16–33)	23.5 (16–38.3)	0.7
PFMs endurance (s) 1day before RP Median (IQR)	8 (6–10)	10 (8–11)	7 (5.8–9)	<0.001
PFMs endurance (s) 6 months after RP Median (IQR)	15 (13–17)	17 (14–19)	14 (12.8–16)	<0.01
PFMs endurance (s) 6 months –1 d Median (IQR)	7 (5–9)	7 (4.5–10)	7 (6–8.3)	0.9

6 months – 1 d – difference between value of day before surgery and 6 months after surgery; BMI – body mass index; GS – Gleason Score; IQR – interquartile range; PFMs – pelvic floor muscles; PSA – prostate specific antigen; RP – radical prostatectomy

Table 2. *Univariate and multivariate logistic regression for prediction of continence after radical prostatectomy*

Parameter	Univariate		Multivariate	
	OR (95% CI)	p	OR (95% CI)	p
PFMs strength (cmH_2O) 1 day before RP	1.16 (1.10–1.23)	<0.0001	1.13 (1.06–1.21)	<0.0001
PFMs endurance (s) 1 day before RP	1.6 (1.31–1.92)	<0.0001	1.2 (0.94–1.49)	0.16
Preoperative PSA [ng/ml]	0.87 (0.78–0.98)	0.03	0.87 (0.75–1.02)	0.08
Age (years)	0.9 (0.89–1.01)	0.1	0.96 (0.88–1.04)	0.3
Body mass index	1 (0.91–1.09)	0.9	–	–
Prostate volume [ml]	1 (0.96–1.02)	0.4	–	–
Pathological stage pT2 pT3a	 (Referent) 1.5 (0.71–3.25)	 0.3	–	–
Pathological GS GS 3 + 3 GS 3 + 4 GS 4 + 3 GS 4 + 4	 (Referent) 1.6 (0.58–4.59) 2.2 (0.57–8.56) 1.4 (0.20–9.82)	 0.4 0.3 0.7	–	–

CI – confidence interval; GS – Gleason Score; OR – odds ratio; PFMs – pelvic floor muscles; PSA – prostate specific antigen; RP – radical prostatectomy

Continence recovery after RP is complex and influenced by multiple risk factors, including bladder outlet obstruction, preoperative detrusor condition, BMI, age, preoperative urinary incontinence, and anatomical conditions such as urethral functional length or pelvic diaphragm thickness. Postoperative detrusor dysfunction or intrinsic urethral sphincter deficiency may also play roles [19–24]. Recent studies have proposed new insights into the mechanism of incontinence in men, the impact of RP on continence, and the potential role of PFM training [25]. According to Hodges et al. [25], RP removes the prostatic urethra, including surrounding smooth muscles, shortens the urethra, potentially disrupts the bladder neck, damages the striated sphincter or its neurovascular supply, disrupts connecting tissues or ligaments, and modifies detrusor contractility. These factors are key elements of the continence mechanism and require compensation after surgery. Training striated PFMs has been proposed as an intervention to improve continence recovery post-RP [25]. Evidence for the effectiveness of PFM training programs in preventing and restoring continence after RP remains inconsistent [26].

In this context, identifying potential preoperative predictors of UI is critical. MUL is one of the most evaluated pelvic anatomical parameters. Most recent studies have identified MUL as a significant predictor of early or late continence after RP [9–14].

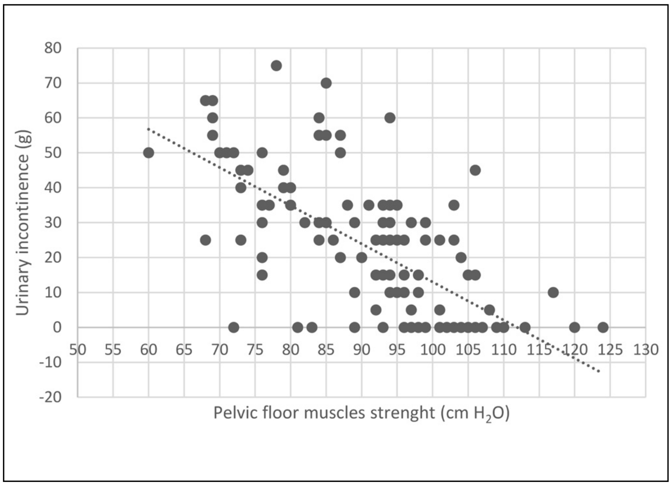

Figure 1. *The association of urinary incontinence at 6 months after surgery and pre-operative pelvic floor muscles strength.*

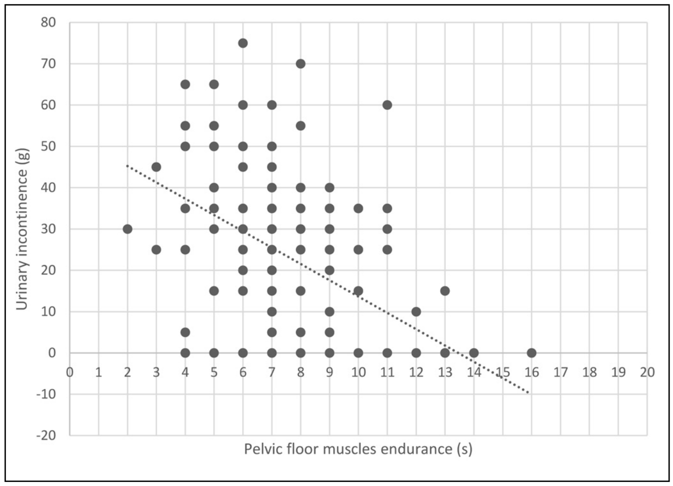

Figure 2. *The association of urinary incontinence at 6 months after surgery and pre-operative pelvic floor muscles endurance.*

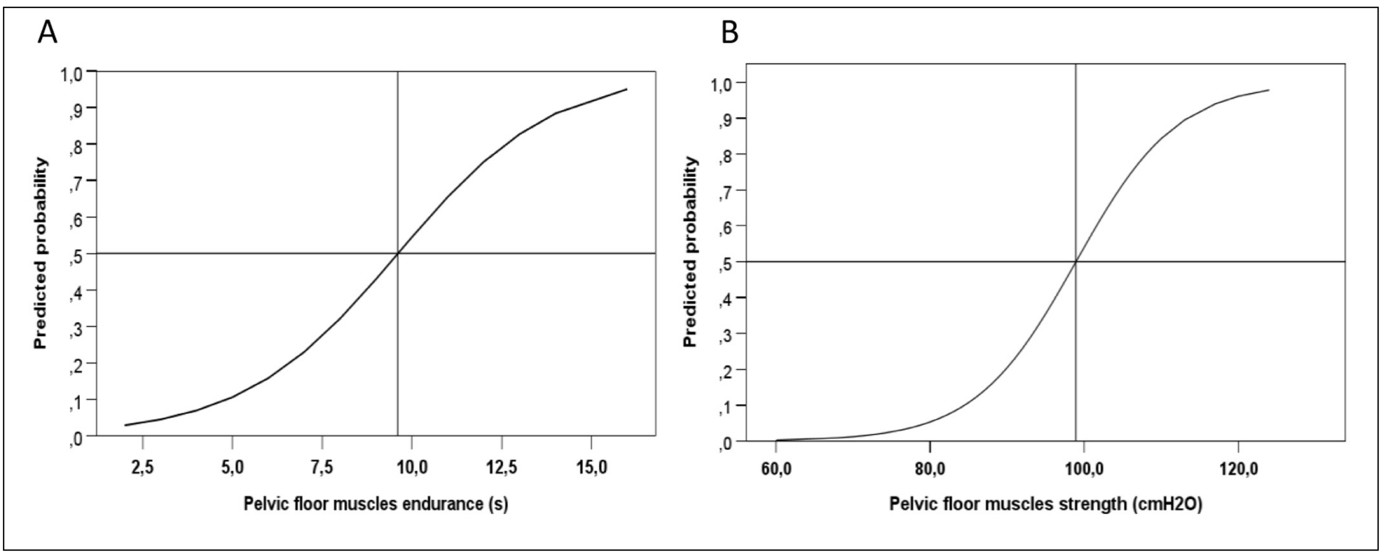

Figure 3. *The prognostic curve of predicted probability of continence and threshold of pre-operative pelvic floor muscles endurance* **(A)** *and strength* **(B)**.

Fonseca et al. reported that a MUL threshold >15 mm was associated with a 5% risk of UI compared to a 25% risk when MUL was <10 mm [14]. Similar results were observed by Barakat et al. [12], who assessed MUL using transperineal ultrasound. Preoperative MUL >15 mm (95% CI: 1.28–1.33; p = 0.03) and postoperative MUL >14 mm (95% CI: 1.2–1.16; p = 0.05) were significantly associated with early continence recovery at 3 months post-surgery [12]. These findings highlight the potential importance of MUL for more precise patient counseling before RP.

Stafford et al. [27] demonstrated that men who are continent after RP exhibit greater shortening/activation of the striated urethral sphincter, bulbocavernosus, and puborectalis during voluntary contractions and coughing than men who are incontinent or men without a history of prostate cancer. This suggests that preoperative PFM functional capacity may reflect the risk of UI. The sub-analysis presented here aimed to assess the relationship between preoperative PFM strength and endurance, measured via perineometer, and postoperative continence. Perineometry is a valid and objective tool for measuring PFM strength and endurance. Sigurdardottir et al. concluded that perineometry has high intraobserver reproducibility, making it suitable for clinical and scientific practice [28]. Similarly, Macedo et al. [29] demonstrated a strong correlation between perineometric and electromyographic findings. Few studies to date have assessed the relationship between objective PFM measurements and postoperative UI in prostate cancer patients [16–18].

In our study, preoperative PFM strength ranged from 60 to 124 cmH_2O and endurance from 3 to 16 s. Comparing continent versus incontinent men, median preoperative PFM strength was 102 vs 87 cmH_2O ($p < 0.001$), and median PFM endurance was 10 vs 7 s ($p < 0.001$), respectively. These baseline parameters showed significant negative correlations with urine loss (g) at 6 months post-RP: R = –0.7, $p < 0.001$, and R = –0.55, $p < 0.001$, respectively. Given that all men were continent before RP, worse preoperative PFM conditions appear unable to compensate for the removal or damage to anatomical structures involved in continence. If this hypothesis is correct, the identified thresholds for PFM strength (98.9 cmH_2O) and endurance (9.6 s) could be crucial for predicting increased UI risk. In multivariable analysis, preoperative PFM strength (OR 1.13, 95% CI: 1.06–1.21, $p < 0.0001$) was the most significant predictor of UI. The possible explanation for such findings could be that the endurance of the PFM is directly related to its strength. However, the contribution of strength to continence is associated with active muscle contraction and the activity of fast-twitch muscle fibers, which are more abundant in the PFM compared to slow-twitch fibers. The primary function of slow-twitch fibers is to provide tonic and supportive action, while fast-twitch fibers are more dynamic and capable of quicker contractions.

It is important to note that the initial study aimed to evaluate the effect of three physiotherapy programs on PFM strength, endurance, and UI. Study results indicated equal effects of the training programs on UI. Moreover, PFM strength and endurance improvements were similar among incontinent and continent men [18]. These findings suggest that PFM training is not the primary determinant of postoperative UI; preoperative PFM conditions may be more influential. For this reason, the sub-analysis included all preoperative data, and the presented results are considered reliable and applicable to daily clinical practice.

Several key findings warrant further investigation. PFM conditions varied widely among patients before surgery. The identified thresholds significantly differentiate patients at higher risk of UI. Preoperative physiotherapy programs or alternative radical prostate cancer treatments could be considered for men with lower PFM thresholds.

There are limitations to this study. The relatively short 6-month duration could be one, though UI rates at 12 or 24 months in other studies have not significantly differed from those at 6 months [6]. Thus, our 6-month findings are likely reliable. The absence of a control group prevents the assessment of natural recovery after RP, which could be a limitation. Despite limited evidence for the effectiveness of PFM training programs, it is unlikely that continence rates would be higher in men without rehabilitation compared to those receiving training. Additionally, our use of an 8-hour pad test, rather than the standardized 1-hour test, might raise concerns. However, the 8-hour test more accurately reflects real incontinence rates compared to questionnaire-based studies, justifying the relatively high UI rate in this study. Finally, radiological measurements such as MUL and other potential anatomical predictors of UI were not included in our analysis.

Strengths of this analysis include its randomized prospective design, strict methodology, and the same investigator conducting all measurements. To our knowledge, this is the first report analyzing the impact of preoperatively measured PFM strength and endurance on continence after RP using a perineometer. More studies are needed to confirm the relationship between preoperative

PFM condition and continence post-RP. These findings suggest that objective PFM measurements should be incorporated into future studies examining the effects of different surgical modalities or PFM training programs on UI.

CONCLUSIONS

Pelvic floor muscle strength and endurance before radical prostatectomy demonstrated significant associations with postoperative urinary continence. Objectively measured preoperative PFM conditions could help identify patients at increased risk of urinary incontinence after radical prostatectomy.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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ETHICS APPROVAL STATEMENT

The study was approved by the Biomedical Research Ethics Committee of Lithuanian University of Health Sciences (Protocol ID BE-2-61).

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