

Influence of voluntary pelvic floor muscle contraction and pelvic floor muscle training on urethral closure pressures: a systematic literature review

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Received: 6 April 2014 / Accepted: 23 August 2015 / Published online: 25 September 2015
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Abstract

Introduction and hypothesis Stress urinary incontinence (SUI) is managed with pelvic floor muscle training (PFMT), but the mechanism of treatment action is unclear. Resting maximal urethral closure pressure (MUCP) is lower in women with SUI, but it is unknown whether PFMT can alter resting MUCP. This systematic review evaluated whether voluntary pelvic floor muscle (PFM) contraction increases MUCP above its resting value (augmented MUCP) and the effect of PFMT on resting and augmented MUCP.

Methods Experimental and effect studies were identified using PubMed and PEDro. The PEDro scale was used to assess internal validity of interventional studies.

Results We identified 21 studies investigating the influence of voluntary PFM contraction in women. Comparison was hindered by varying demographics, antecedent history, reporting of confirmed correct PFM contraction, and urethral pressure profilometry (UPP) techniques. Mean incremental increase in MUCP during PFM contraction in healthy women was 8–

47.3 cm H₂O; in women with urinary incontinence (UI), it was 6–24 cm H₂O. Nine trials reporting MUCP as an outcome of PFMT were found. Wide variation in PFMT regimes affected the findings. Two studies found significant improvement in MUCP of 5–18 cm H₂O. Seven studies assessed augmentation of MUCP with PFM contraction; mean increase was –0.1 to 25 cm H₂O.

Conclusions There is no definitive evidence that PFMT increases resting MUCP as its mechanism of action in managing SUI. The degree to which a voluntary PFM contraction augments MUCP varies widely. There was evidence to suggest PFMT increases augmented MUCP. Drawing firm conclusions was hampered by study methodologies.

Keywords Contraction · Exercise · Pelvic floor muscle training · Urethral pressure · MUCP · Urodynamic assessment

Introduction

Level 1 evidence indicates that pelvic floor muscle training (PFMT) is effective in the treatment of female stress urinary incontinence (SUI). Accordingly, PFMT has grade A recommendation from expert consensus bodies, such as the International Consultations on Incontinence (ICI) and the European Association of Urology (EAU), as the first-line treatment for SUI and mixed urinary incontinence (MUI) [1–3]. Despite consensus regarding the efficacy of PFMT in both systematic reviews and meta-analyses, it is less clear how this treatment actually works [4]. A number of theories endeavor to explain its efficacy. First, altered PFM morphology causes a significant lift of both the bladder and rectal ampulla, reduction in the levator hiatus area, increased muscle thickness, and reduced muscle length. This was demonstrated in an assessor-blinded randomized controlled trial (RCT) following 6

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Electronic supplementary material The online version of this article (doi:10.1007/s00192-015-2856-9) contains supplementary material, which is available to authorized users.

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months of PFMT [5]. Second, PFMT prevents descent of the bladder and the urethra during activities that cause increased intra-abdominal pressure (IAP), such as running, jumping, and coughing [4]. Third, it is proposed that PFMT increases the strength of a voluntary precontraction of the pelvic floor muscles (PFM) before increases in IAP (known as the Knack maneuver). A single-blinded randomized controlled trial (RCT) showed that teaching women the Knack, even without strength training, reduced urinary leakage by an average of 98.2 % during a medium cough test and by 73.3 % during a deep cough test [6]. Investigating PFM by electromyography (EMG) and perineal ultrasound revealed that the Knack significantly reduced downward movement of the bladder neck, implying increased structural support during a single PFM contraction [7]. Finally, PFMT facilitates an automatic, unconscious contraction of the PFM, increasing the maximal urethral closure pressure (MUCP) both at rest and during increases in IAP [4]. Recently, a case–control study found that resting MUCP was the one factor that differed most significantly between women with and without SUI, being 43 % lower in women with SUI (40.8 cm H₂O ±17.1 versus 70.2 cm H₂O ± 22.4 in SUI and continent women, respectively) [8]. Furthermore, analysis of data from >9000 women found that resting MUCP was significantly lower in those with SUI compared with continent women (48.2 cm H₂O [95 % confidence interval (CI) 47–49] versus 67 cm H₂O (95 % CI 65–85, $p < 0.001$) [9]. Thus, insight into the influence of both a voluntary contraction and PFMT on MUCP is required.

At present, there is scant understanding of the minimum PFM strength required effectively to prevent leakage during the Knack. There has been little focus on investigating whether there is an association between PFM strength and MUCP. Furthermore, it is not known whether PFMT influences MUCP either at rest or during increases in IAP [10, 11]. Investigating these factors using urethral pressure profilometry (UPP) requires proper patient training and methodological standardization [12], since studies have shown high variation in normal values between different centers [13]. The Fifth International Consultation on Incontinence Committee on Urodynamic testing [10] noted variation of ±10–15 % on test–retest data for a number of different parameters (including volume, pressure, and flow) and recommended that investigators and clinicians take into account the inherent physiological variation of UPP [10]. Evaluating the effect of a PFM contraction during MUCP is difficult, in part because many women perform a PFM contraction incorrectly [14]. This systematic literature review had two aims: (1) to determine the incremental increase in MUCP elicited by a single PFM contraction (augmented MUCP); (2) to evaluate the effect of PFMT on both resting and augmented MUCP.

Materials and methods

A search using PubMed was undertaken using the following search terms: pelvic floor muscles AND female AND urethra. This search was limited to the English language. Inclusion criteria were experimental studies, women, and MUCP increment during a single PFM contraction.

In addition, an advanced search on PEDro was done using the terms incontinence AND clinical trial. Clinical trials including pre- and posttest, randomized, and quasi-controlled trials designed to investigate the effect of PFMT on UPP variables were included. PFMT was defined as sets of PFM exercises over time, including use of biofeedback or weighted vaginal cones. Exclusion criteria were studies in animals, men, children, neurological diseases, pregnancy, and being postpartum. Clinical trials using electrical stimulation, magnetic chair, tibial nerve stimulation, and treatments other than PFMT were also excluded. In addition, we hand searched reference lists of retrieved papers and the reference list in the chapter “Urodynamic testing” of the ICI [10].

Internal validity of clinical trials was rated according to the PEDro scale [15], a 10-point scale giving one point for each of the following criteria for internal validity of intervention studies: random allocation, concealed allocation, baseline comparability, blinding of subjects, blinding of therapist, blinding of assessor, adequate follow-up (≥85 %), intention to treat (ITT), between-groups comparison, point estimates, and variability. The scale contains one additional criterion for external validity: eligibility. Eligibility is not used in scoring methodological quality and risk of bias. Hence, the top score is 10 for internal validity. PEDro is a reliable, valid, and comprehensive method for assessing methodological quality [15].

Two researchers independently assessed and classified the studies. Each study was classified according to preset criteria and are reported in two separate tables: one for experimental studies and one for clinical trials (Tables 1 and 2, respectively). Experimental studies were classified and tabled according to author/year, participants, UPP assessment methods, PFM contraction assessment, subject position, and MUCP findings. Clinical trials were classified and tabled according to author/year, participants, design/PEDro score, intervention, dropout/adherence, urodynamic assessment methods, urodynamic outcome, other outcomes, and comments. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement for reporting systematic reviews was followed [16].

Results

Selection of articles for inclusion in this systematic review is given in Fig. 1.

Table 1 Urethral pressures during voluntary pelvic floor muscle contraction in continent and incontinent women

Author/year	Mean age (years) urinary status (<i>n</i>)	UPP methods	Results (cm H ₂ O unless stated)	MUCP or MUP	Augmented MUCP	Mean increase in augmented MUCP
Constantinou and Govan 1982 [17]	22; healthy (11)	Gap catheter system Variable perfusion 0.1–2.0 ml Withdrawal 1 cm/min 9-F polyvinyl chloride tube	NR	NR	Midurethra MUCP with voluntary holding 140 cm	Pronounced pressure increase in urethra
Colstrup 1985 [18]	45.5; healthy (16)	Catheter size 10 F, Water perfusion 2 ml/min	MUP 52 at 60 % of UL <i>n</i> =22, 40 (±3 SE)		MUP 60 (40–92 95 % CI) 57 (±4 SE)	8 18
Benvenuti et al. 1987 [19]	50.8; USI (26)	Brown and Wickham method	<i>n</i> =45 52.6±16.8		60.0±17.1	7.4
Wilson et al. 1987 [20]	46.7; USI (60)					
Bump et al. 1991 [14]	53.6; UI (47)	Multichannel urethrocytometry, microtip transducer Withdrawal 0.5 mm/sec 5.0 mm/s in PFM contraction	Effective PFMIC 35.0±3.2 Ineffective PFMIC 32.2±3.5		Effective PFMIC 51.5±3.7 Ineffective PFMIC 30.7±3.6	Effective PFMIC 16.5±2.4 (<i>p</i> <0.01) Ineffective PFMIC 1.5±1.4 (NS) Between group <i>p</i> <0.01
Lose 1991 [21]	49; USI (30)	Specialty designed probe Perfusion rate 2 ml/s Withdrawal speed 3 mm/s	Bladder neck 35±12 Midurethra 44±13 Distal urethra 28±15		NR	Bladder neck 17±9 (<i>p</i> <0.01 vs healthy) Midurethra 16±10 (<i>p</i> <0.01 vs healthy) Distal urethra 9±7 (NS vs healthy) SD between groups NR
Lose & Colstrup 1991 [22]	42; healthy (30)	8-F single-lumen catheter Perfusion rate 2 ml/s Withdrawal speed 3 mm/s	Bladder neck 60±26 Midurethra 71±23 Distal urethra 35±16 (<i>p</i> 0.01)		NR	Bladder neck 30±17 Midurethra 24±16 Distal urethra 16±10; (<i>p</i> 0.01)
Mayer et al. 1994 [23]	56; SUI, MUI, UUI (208)	6-F dual microtransducer Withdrawal speed 2 mm/s Pull-through squeeze (5 mm/s)	Supine 36.89±15.97 Standing 34.95±17.88		Supine: static 45.71±23.29; pull through 42.63±21.96 Standing: static 47.03±26.19; pull through 45.17±24.0	Supine: static 8.82; pull through 5.73 Standing: static 12.07; pull through 10.22 Statistical comparisons NR
Bø and Talseth 1997 [24]	49.4; SUI (12)	Double lumen 8-Ch catheter Perfusion 3 ml/h Secured at the site of MUCP	NR		NR	23.2±8.4
Van Loenen and Vierhout 1997 [25]	No major POP (48) POP grade ≥2 (24)	Gaelic microtip catheter Withdrawal speed 2 mm/s	Group 1 51.8±21.2 Group 2 45.3±20.2		Group 1 62.0±24.6 Group 2 61.8±33.2	Group 1 9.2 <i>p</i> 0.05 Group 2 16.5 <i>p</i> 0.05 Statistical comparisons NR
Elsner et al. 1999 [26]	61; USI, DO, or both (204)	Multichannel urodynamics 8-F microtip transducer	Group 1 32±17 Group 2 36±20 Group 3 31±15 NS		Group 1 32±20 Group 2 31±17 Group 3 34±29 NS	Group 1 0 Group 2 -5 Group 3 3 NS
Kuo 2000 [27]	54.4; SUI and UUI (116)	8-F triple-lumen UPP catheter Perfusion rate 4 ml/min Withdrawal speed 1 mm/s Brown and Wickham technique	SUI 65.0±10.5 Non SUI 103.5±23.5 (<i>p</i> <0.05)		NR	SUI 23.5±11.3 Non-SUI 47.3±13.9 (<i>p</i> <0.05)
Amaro et al. 2003 [28]	54.; SUI (30)		45.1 (range 24–84)		Midstream stop test 61.4 (range 34–120)	16.3

Table 1 (continued)

Author/year	Mean age (years) urinary status (n)	UPP methods	Results (cm H ₂ O unless stated)		
			MUCP or MUP	Augmented MUCP	Mean increase in augmented MUCP
Teleman et al. 2003 [29]	57; SUI, MUI, OAB, controls (88)	Microtip transducer catheters 6- or 7 Ch	Controls 52±3.2 Incontinent 48±1.9 NS	NR	Controls 22.0±4.0 Incontinent 15.0±2.2 NS
Miller et al. 2004 [30]	55.7; pubococcygeal muscle fully intact/absent (46)	Gaelic 8 microtip transducer Manual pull through	57.1±10.8	68.1±25.5	11.1
Baessler et al. 2005 [31]	54; USI, DO, MUI, normal (104)	Gaelic microtip dual transducer Withdrawal speed 1 mm/s	51.2±23.5 (16–126)	67.7±29.8 (17–160)	16.5 (±19.8)
Dannecker et al. 2005 [32]	28; primips postepisiotomy (146) a. Only fetal indications b. Plus tear imminent	Flexible multisensory microtip Withdrawal speed 1 mm/s	68 reported a. 98±24 b. 101±28 NS	a. 95±30 b. 103±38	a. ↓3 b. ↑2 NS
Teleman and Mattiasson 2007 [33]	57.4; (108)	Microtip catheters and 8-Ch fluid catheters	Continent Young 107.1±4.4 Middle aged 52.0±3.2 Incontinent 48.1±1.9 (<i>p</i> < 0.001)	NR	Continent: young 33.3±4.2; middle aged 22.4±4.0 Incontinent middle aged 13.6±2.2
Zahariou et al. 2008 [34]	42; USI (50)	Withdrawal speed 1 mm/s	33±20	39±19	6
Brincat et al. 2011 [35]	Primip; denovo SUI, continent., LA defects (160)	Gaelic microtip dual transducer Manual pull through	No LA defect 73.8±24.0 Any LA defect 72.2±31.3 NS	NR	No LA defect 13.2±18.9 Any LA defect 12.8±21.6 NS
Dietz and Shek 2012 [36]	56; SUI/DO/voiding dysfunction (300)	Neomedix Acquadata Withdrawal manual over 5–10 s	<i>n</i> =275 36±19 (range 2–111)	42±23 (range 4–125)	6 80 had reduction despite repeated PFMT (<i>r</i> =0.24, <i>p</i> < 0.01)

CI confidence interval, DO detrusor overactivity, EMG electromyography, FUL, functional urethral length, LA levator ani, MRI magnetic resonance imaging, MUI mixed urinary incontinence, MUCP maximal urethral closure pressure, MUP maximal urethral pressure, NR not reported, NS not statistically significant, OAB overactive bladder, PFM pelvic floor muscle, PFM pelvic floor muscle contraction, PFMT pelvic floor muscle training, POP pelvic organ prolapse, PT physiotherapist, SD standard deviation, SE standard error, SUI stress urinary incontinence, UPP urethral pressure profile, UI urinary incontinence, US ultrasound, USI urodynamics stress incontinence, UUI urge urinary incontinence, UL urethral length

Table 2 Effect of pelvic floor muscle training on maximal urethral closure pressure at rest and during a voluntary pelvic floor muscle contraction, functional urethral profile length, or cough pressure transmission in women

Author/year	Mean age (years), urinary status (<i>n</i>)	Design (PEDro score)	Intervention	Urodynamic assessment	Urodynamic outcome
Benvenuti et al. 1987 [19]	50.8; USI (26)	Pre- posttest	3 months 30-min clinic visits, 5 days/week for 2 weeks, once a week for the next 2.5 months; home exercises	Catheter size 10; perfusion rate 2 ml/min; bladder volume 100 ml; MUCP at rest and during PFMC; FUL at rest	MUCP at rest (cm H ₂ O) 40→58 <i>p</i> <0.01 MUCP with PFMC 48→73 <i>p</i> <0.01 FUL (mm) 27→32 <i>p</i> <0.01
Wilson et al. 1987 [20]	46.8; USI (60)	Non-RCT (PEDro 2/10)	6 weeks PT-taught PFMT home exercises 5–10 contractions every 30 min daily Groups 1–3 also received 12 sessions with PT: 1. Supervised PFMT and manometry 2. Interferential 3. Faradism 4. Home exercise	Brown and Wickham technique, bladder volume 150 ml	MUCP at rest (cm H ₂ O) 1. 49.6→51.5 (NS) 4. 49.8→53.4 (NS) MUCP with PFMC (cm H ₂ O) 1. 58.3→62.3 (NS) 4. 57.6→62.2 (NS)
Bø et al. 1990 [49]	45.9; USI (52)	Stratified RCT (PEDro 5/10)	6 months 1. Home exercise, PFMT, 8–12 close-to-maximal contractions 3 times/day, training diary; 7 sessions with PT 2. Intensive exercise as above, plus weekly 45-min exercise class with PT using max contractions 6- to 8-s hold with 3–4 fast contractions on top Vaginal palpation by PT	Tip transducer 2 1 K62; perfusion rate NR; withdrawal speed NR; bladder volume NR; position NR	MUCP at rest (cm H ₂ O) 1. 38.3→39.8 (NS) 2. 38.8→43.4 Sig (<i>p</i> <0.02) MUCP with PFMC NA FUL (mm) 1. 23.2→22.7 (NS), 2. 22.5→21.2 (NS) CPT Fewer women in intensive group had negative closure pressure (<i>p</i> <0.01)
Bø et al. 1999 [39]	49.5; USI (107)	Stratified RCT (PEDro 8/10)	6 months 1. PFMT 8–12 near-maximal PFMCs, 3 sets/day, 45-min exercise class with PT 2. Electrical stimulation 30-min daily 3. Vaginal cones 20 min daily 4. Control: vaginal palpation by PT	Fibreoptic microtip transducer; withdrawal speed NR; bladder volume NR; position NR	MUCP at rest (NR) MUCP with PFMC (NR) NS changes in resting MUCP or MUCP during cough for any group
Elser et al. 1999 [26]	61; USI, DO, or both (204)	Stratified RCT (PEDro 5/10)	12 weeks 1. BT; progressive voiding schedule 2. PFMT including 4 biofeedback sessions using vaginal pressures: 10 fast PFMCs, 40 sustained (10-s) contractions with 10-s rest periods performed daily across two sessions 3. BT and PFMT as above	Multichannel urodynamics: 8-F microtip transducer, perfusion rate NR; withdrawal speed 1 mm/s; bladder volume maximal cystometric capacity; position supine	MUCP at rest (cm H ₂ O) 1. 3.2→3.2, 2. 3.6→3.5, 3. 3.1→3.1 MUCP with PFMC (cm H ₂ O) 1. 3.2→3.1, 2. 3.1→3.0, 3. 3.4→3.2 FUL (mm) 1. 2.3→2.2, 2. 2.3→2.1, 3. 2.3→2.3
Kuo 2003 [40]	45; SUI±UII (40)	Pre- posttest	12 weeks 6 biofeedback sessions; home exercise of 15 reps, 10-s PFM contraction with 10-s rest, 3 sets daily with treatment logs.	8-F double-lumen catheter; perfusion rate 4 ml/min; withdrawal speed 1 mm/s; bladder volume 200–250 ml; position not stated	MUCP at rest (cm H ₂ O) 75.5→76.9 (NS) MUCP with PFMC 15.7→23.0 (NS) FUL (mm) 43.5→36.6 (NS)
Teleman et al. 2003 [29]	57; SUI, MUI, OAB, controls (88)	Pre- posttest	4 months Home exercises of PFMT 3 sets of repeats daily (2-, 5-, 10-s holds; 1 30- to 60-s hold supine/sitting/standing, 10 sit-ups with PFMC); vaginal palpation	Laterally 2–4 o'clock or 8–10 o'clock with microtip transducer catheters (6/7 Ch); bladder volume 200 ml; position supine lithotomy	In incontinent subjects <i>n</i> =60 MUCP at rest (cm H ₂ O) 48→49 (NS) MUCP with short PFMC 15→24 <i>p</i> =0.001

Table 2 (continued)

Author/year	Mean age (years), urinary status (n)	Design (PEDro score)	Intervention	Urodynamic assessment	Urodynamic outcome
Moreno et al. 2004 [41]	48; USI (27)	Pre- posttest	12 weeks Twice-weekly group session 45 min; PFMT protocol not stated; vaginal palpation	Bladder volume full; position gynecologic	FUL (mm) 28→28 (NS) MUCP at rest (NR) FUL (NR)
Zahariou et al. 2008 [34]	42; USI (50)	Pre – posttest	12 months PFMT 2 sets 5 quick/10 sustained, moving to 2 sets 5 quick/20 sustained Monthly 30-min biofeedback with nurses Vaginal palpation and perineal US	Equipment type NR; perfusion rate NR; withdrawal speed 1 mm/s; bladder volume empty; position half sitting	MUCP at rest (cm H ₂ O) 33→36 (NS) MUCP with PFMC 39→ (NR/NS) FUL (mm) 22→21 (NS) CPT 85±12 %→108±14 %

BT bladder training, *CPT* cough-pressure transmission, *FUL* functional urethral length, *MUI* mixed urinary incontinence, *MUP* maximal urethral pressure, *MUCP* maximal urethral closure pressure, *NA* not assessed, *NR* not reported, *NS* not statistically significant, *PFM* pelvic floor muscle, *PFMC* pelvic floor muscle contraction, *PFMT* pelvic floor muscle training, *PT* physiotherapist, *RCT* randomized controlled trial, *Sig* statistically significant, *SUI* stress urinary incontinence, *UPP* urethral pressure profile, *US* ultrasound, *USI* urodynamic stress incontinence, *UTI* urinary tract infection, *UII* urgency urinary incontinence

Experimental studies

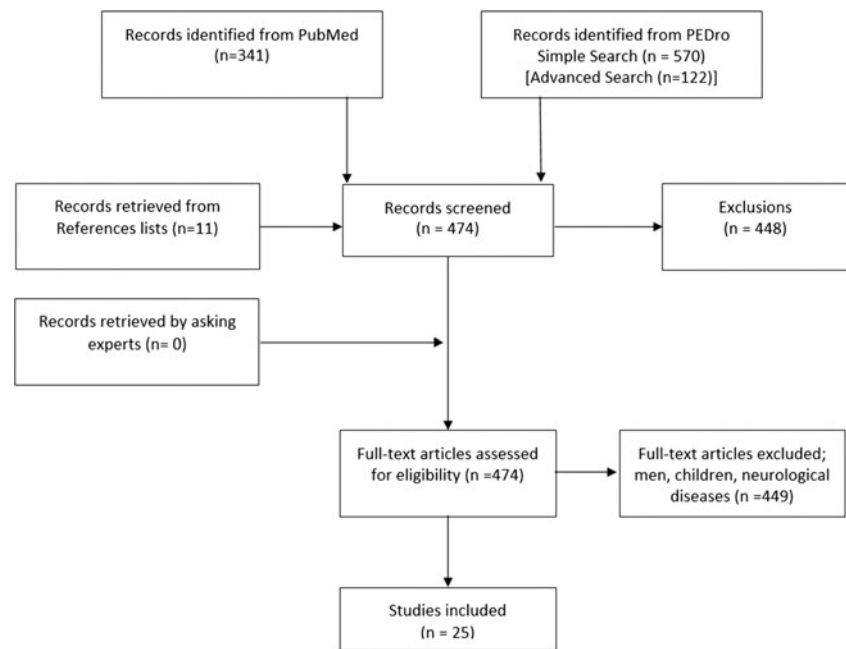
Twenty-one studies investigating augmented MUCP were found (Table 1) [14, 17–36]. One study was excluded because the results combined values for men and women [37]. Studies were published between 1982 and 2012. The number of participants ranged from 11 [18] to 300 [14], and participants' ages ranged from 18 to 90 years. In several studies it was not clear as to whether the investigators assessed the ability of patients to perform a PFM contraction correctly, either before or during urodynamic studies [14, 17, 18, 20–22, 25, 26, 30, 33].

Urodynamic methodology differed between studies. Prior to 2002, there was a lack of consensus regarding both a definition of the concept of urethral pressure and standardization of the measurement methodology [12, 38]. Two studies assessed UPP with the patient in the standing position [17, 23], but the majority was performed supine. In six studies, the bladder was empty [18, 21, 22, 31, 34, 36]. In contrast, Amaro et al. [28] obtained their findings with the bladder full. Three studies failed to state bladder volume [24, 27, 33].

Augmentation of MUCP by pelvic floor contraction

Mean incremental increase in MUCP during PFM contraction in healthy women ranged between 8 [18] and 47.3 cm H₂O [27]. Incremental range in women with UI varied from 6 to 23.5 cm H₂O [27, 34, 36]. Elser et al. [26] found increase in MUCP during a PFM contraction. Three studies compared women with SUI with continent women [21, 29, 33]. Across the studies, continent women had a higher augmented MUCP by 7–8cm H₂O; however, only two studies found a statistically significant difference ($p < 0.01$, p value not reported) [21, 33]. Lose [21] investigated women with SUI only; the other study compared women with a range of etiologies with age-matched controls.

One study defined whether their patients achieved an effective PFM contraction, judged as an arbitrarily defined increase to at least 120 % of resting MUCP [14]. When this criterion was applied to women with either SUI or prolapse, between 39 % and 60 % achieved an effective contraction. Furthermore, a number of studies reported a reduction in MUCP during PFM contraction compared with the resting measurement [14, 26, 32, 36]. All of these studies included women with possible injuries to the pelvic floor. Miller et al. [30] found a significantly lower increase in MUCP in those with complete absence of pubococcygeal muscle [assessed by magnetic resonance imaging (MRI)]; Brincat et al. [35] found no significant differences between women with and without major defects. Implicitly, inability to contract the pelvic floor voluntarily would preclude changes in MUCP with attempted pelvic floor contraction. However, alterations in MUCP may be detectable in some women unable to contract their pelvic

Fig. 1 Articles identified and selected for systematic review

floor. This observation may reflect an effect on MUCP of associated dynamics, such as downward pressure on the pelvic floor caused by abdominal straining. Two studies excluded women who were judged as being unable to perform an effective PFM contraction during vaginal palpation [23, 24]. In these studies, mean incremental increase in MUCP during a PFM contraction ranged from 9 to 23 cm H₂O, which is comparable with the overall range across all studies of 8 cm H₂O [18] to 47.3 cm H₂O [27]. Mayer et al. [23], in their study of >200 women, found that age negatively correlated with both MUCP and augmented MUCP. Several studies investigated the increase in closure pressure at different points along the urethra and were unable to ascertain where along the urethra the greatest increment in closure pressure occurs during a PFM contraction [17, 18, 21, 22].

PFMT clinical trials

Nine clinical trials reporting UPP as an outcome of PFMT were published between 1987 and 2008 (Table 2) [19, 20, 26, 29, 34, 39–42]. Three were RCTs [26, 39, 40], one was a nonrandomized controlled trial [20], and five were pre-and posttest designs [19, 29, 34, 41, 42]. The number of participants ranged from 26 to 204 [19, 26] and participant age ranged from 19 to 79 years [20]. The majority of trials investigated patients with urodynamic SUI [19, 20, 34, 39, 40, 42]. The remaining studies assessed patients with a range of diagnoses [26, 29, 41]. Six studies stated that PFM contraction was confirmed by vaginal palpation [19, 29, 34, 39, 40, 42]; the remaining studies did not report whether this was performed [20, 26, 41]. PEDro scores for controlled trials ranged between 2 and 8, with the three RCTs scoring ≥ 5 . Only one trial

published after 2002, by Teleman et al. [29], stated they adhered to International recommendations [12, 38].

There was wide variation in the PFMT regimes across the nine clinical studies. The time given to PFMT ranged from 6 weeks to 12 months [20, 34]. Five of the nine studies assessed the effect of PFMT after 3–4 months [19, 26, 29, 41, 42]. The amount of supervision provided by a physiotherapist or nurse varied from twice weekly [42] to one assessment followed by home exercises only [29]. The protocol for home exercises varied from 5–10 contractions every 30 min daily [20], to 8–12 repetitions three times per day [39, 40]. Two studies did not state whether participants were encouraged to perform home exercises [26, 42].

Effect of PFMT on resting MUCP

Only Benvenuti et al. [19] and Bø et al. [39] found a statistically significant improvement in MUCP following PFMT. The increase in MUCP in Bø et al.'s [39] study was 4.6 cm H₂O in the intensive PFMT group compared with no significant increase in the home exercise group ($p < 0.02$). Benvenuti et al. [19] reported a greater increase—of 18 cm H₂O—but there was no control group.

Effect of PFMT on augmented MUCP

Seven studies assessed MUCP with a PFM contraction [19, 20, 26, 29, 34, 40, 41]. Mean increase in augmented MUCP following PFMT varied from -0.1 cm H₂O [26] to 25 cm H₂O [19].

Effect of PFMT on other UPP measures

Of the five pre- and posttest studies that assessed functional urethral profile length (FUPL), only Benvenuti et al. [19] found a significant improvement. Two RCTs measured FUPL and neither found a significant change [26, 39]. Three studies, including two RCTs [26, 39], measured cough-pressure transmission ratio (PTR) as an outcome of PFMT. There were contradictory findings in the two RCTs; the study that found a significant difference only investigated women with SUI [39], while the other included women with a range of diagnoses [26]. Both studies used the microtip transducer technique for measuring UPP. One RCT investigating women with urodynamic SUI found that significantly fewer women had negative pressure in the intensive PFMT group ($p < 0.01$) [39]. In the pre- posttest study by Zahariou et al. [34], which included women with SUI, cough PTR significantly improved from 85 to 108 %, but this study had no control group.

Discussion

We conducted a systematic review to assess both the influence of a voluntary PFM contraction on MUCP and the effect of PFMT on MUCP and augmented MUCP. The wide inclusion criteria ensured a comprehensive systematic analysis of both a single PFM contraction and PFMT on MUCP across healthy women and those with either SUI or MUI. This allowed us to explore UPP findings within each of these categories of participants. Pooled analysis of UPP data suitable for meta-analysis was not possible due to the broad heterogeneity of urodynamic methods and urodynamic diagnoses. In particular, methods of UPP differed substantially between centers, which made direct comparison invalid. Moreover, there was wide variation in PFMT protocols throughout the clinical trials, and this likewise made it invalid to pool results for meta-analysis.

Experimental studies

Our results indicate that there was a wide variance in augmented MUCP—from 8 to 33 cm H₂O—in healthy women. Women with UI appear to produce a statistically significant smaller increment in augmented MUCP (by 7–8 cm H₂O) than healthy women. It was not possible to make a meaningful prediction regarding the minimum augmented MUCP required to maintain continence for two reasons: the number of studies that compared healthy women with incontinent women were small, and methodologies used for UPP were varied, precluding pooling of analyses. MUCP value is dependent upon the type of catheter used, its orientation in the urethra, the quantity of fluid in the bladder, and patient examination position [12].

Studies evaluated in this review varied across all these parameters.

There is inherent variation in MUCP measurement of between 10 and 15 %. Indeed, both fluid perfusion and microtip urodynamic techniques may have low reliability [10]. Resting UPP measurement (including MUCP) using the fluid-perfusion technique produces a standard deviation (SD) that ranges from 3.3 to 8.1 cm H₂O, with an approximate average of 5 cm H₂O (95 % confidence limits ± 10 cm H₂O), or ± 5 %. Using the microtip transducer technique produces an even greater range in SD 3.3–16.5 cm H₂O. This means that the 95 % CI can be as large as ± 33 cm H₂O. Furthermore, the coefficient of variance with this technique is 17 % (95 % confidence limits ± 34 %) [10]. Despite the inherent difficulties with study reliability, women with SUI are consistently found to have a lower MUCP [9].

The influence of age on MUCP has been documented [9, 43]. Despite this, only four studies had an age range of <10 years [18, 30, 34, 36]; the largest range was 69 years [36]. One study investigated the relationship between augmented MUCP and age and found a negative correlation [33], similar to other findings on resting MUCP [44–46]. Clearly, influence of age on augmented MUCP needs to be evaluated.

When attempting to determine the effect a PFM contraction has on MUCP, it is vital to confirm the presence of a correct PFM contraction, since significant numbers of women will not perform a PFM contraction correctly despite good verbal teaching [14]. Indeed, a number of studies found that MUCP reduced with a PFM contraction. Without evaluating whether women are performing a PFM contraction correctly, it is difficult to determine whether this reduction is caused simply by a Valsalva causing shift in the relative position of the recording catheter, or whether other mechanisms are at play. Regardless, nearly half of the studies reviewed did not report whether this was carried out.

It remains unclear whether significant injury to the PFM affects MUCP. A small study showed women with complete absence of pubococcygeus had a significantly lower increase in pressure than those with a fully intact muscle. However, when a defect was present, rather than complete absence, augmented MUCP was not significantly affected [35].

Clinical studies

While there was evidence to suggest that PFMT increased augmented MUCP—with the increment ranging from 4 to 25 cm H₂O—the various studies showed wide variation in the extent of effect on MUCP and the reporting of comparative information for the extent of change in MUCP parameters for subgroups (most notably, whether SUI symptoms resolved or otherwise). Thus, we are unable to state that published evidence supports these mechanisms of action as the basis of successful treatment of SUI by PFMT. It remains conceivable

that increased MUCP is a factor in PFMT response, but future research assessing this idea must have a robust experimental design standardizing urodynamic methodology, PFM assessment, compliance with PFMT, and outcome reporting.

It was not possible to conclude whether a minimum increase is required to achieve continence, because subgroup analysis comparing successful with unsuccessful outcome was not available.

It was also difficult to draw firm conclusions, because key aspects that ensure that PFMT was effective were not used consistently: confirmation of a correct contraction, adherence, training duration, and dosage [11]. Slightly fewer than half the studies did not report whether vaginal palpation was performed to confirm a correct contraction. PFMT can only be effective when it is actually performed. Previous research has demonstrated that adherence can vary widely [11]. Only two studies reported adherence rates; indeed, no study investigating augmented MUCP reported this data. Adaptation to strength training appears to proceed in a linear way during the first 6 months of training [47], and only three studies were carried out over this period [34, 39, 40]. Just two studies used muscle training regimes according to recommendations by the American College of Sports Medicine: three sets daily of 8–12 repetitions [48].

There is a lack of consensus regarding UPP as a diagnostic test, and so it is mainly used in specialized centers as an adjunctive technique in clinical urodynamic assessment. However, for the purposes of this review, we assessed whether UPP can help explain PFMT mechanism of action, regardless of the limited clinical use of UPP. The clinical trials in this review often included only scant data about UPP methodology, making it impossible to ascertain whether similar urodynamic methodology was used. There is no agreed-upon approach to ensure high quality (reliable and valid) urodynamic testing during PFM contraction and MUCP measurement before and after PFMT. The ICS published standards on urethral pressure measurement in 2002 [12, 38], but internal and external consistency, retest reliability, and sensitivity to change have never been quantified. Accordingly, centers adapt methodology according to various influences, and extrapolation of findings between centers is thus unreliable.

Conclusion

There is wide variation in the degree to which a PFM contraction augments MUCP. There is minimal evidence to support the theory that PFMT produces a significant increase in MUCP. However, both PFM strength [49] and UPP [12, 38] are difficult variables to measure with objective reliability. There are also problems with validity when evaluating whether women perform a PFM contraction correctly during the procedure, as this factor was not documented. Future

investigations of the association between measured PFM strength and different forms of urethral pressures is required, with the use of reliable and valid methods, using standardized UPP measurements and correct instructions to patients.

Acknowledgments The senior author received a travelling fellowship from the International Continence Society. The first and second authors contributed equally to the preparation of this manuscript.

Funding An ICS Fellowship awarded to Prof K. Bø funded a 4-week visit to Bristol Urological Institute to undertake this systematic review.

Conflicts of Interest MJD is speaker and advisory board member for Allergan, Apogepha, Astellas, Ferring, and Pfizer. The other authors have no conflict of interest.

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