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Do differences in abdominal movement patterns during coughing and forced expiration affect cranioventral bladder neck displacement in healthy nulliparous subjects?

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A R T I C L E I N F O

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A B S T R A C T

Aims: Abdominal movement patterns during coughing and forced expiration (FE) fall into two categories: abdominal inward movement (AIM) and abdominal outward movement (AOM). These abdominal movement patterns are thought to affect cranioventral (CV) bladder neck displacement differently. However, many studies have described an absent or altered PFM response during coughing, assuming PFM dysfunction, without considering the impact of abdominal movement pattern differences. The aim of this study was to observe abdominal movement patterns during coughing and FE and compare the associated (CV) bladder neck displacement patterns.

Method: Participants performed three maximal expulsive coughs, followed by three FEs, during which the respiratory inductive plethysmography (RIP) method was used to identify abdominal movement patterns. Concurrently, perineal 2D ultrasound was applied to assess CV bladder neck displacement. All measurements were done in the standing and crook lying position. Descriptive statistics were computed for abdominal movement patterns and bladder neck displacement. Chi-squared tests were used to compare abdominal movement patterns and CV bladder neck displacement.

Results: One hundred and forty-nine healthy nulliparous women without PFM dysfunction participated in the study. During both coughing and FE in the standing position, women who displayed an AIM pattern had a significantly higher occurrence of CV bladder neck displacement compared to those presenting AOM. In the crook lying position, there was a significantly higher occurrence of bladder neck displacement during coughing in subjects showing AIM compared to those with AOM.

Conclusion: Significant differences were found in abdominal movement patterns during coughing and FE in healthy nulliparous subjects in standing and crook lying positions. Most of the subjects showed AOM during coughing or FE in both standing and lying positions. This is contrary to the existing literature and needs further investigation. Abdominal movement patterns impacted CV bladder neck displacement during coughing and FE while standing and during coughing in the crook lying position. Clinicians should be aware of different abdominal movement patterns, which should be considered for diagnosis and treatment.

1. Introduction

According to the International Continence Society (ICS)/International Urogynecological Association (IUGA) terminology reports on pelvic floor function and dysfunction, an involuntary pelvic floor muscle (PFM) contraction is defined as a contraction that precedes a rise in intra-abdominal pressure (IAP), such as during coughing or sneezing [1]. In continent women, an increase in IAP during coughing or forced expiration (FE) is thought to be associated with a contraction of the PFMs in synergy with the antero-lateral abdominals and a cranial

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movement of the diaphragm [2,3]. Increased IAP may be associated with stress urinary incontinence (SUI) [4]. A study by Miller et al. showed the clinical relevance of a PFM contraction during coughing as well as an voluntary precontraction of the PFMs prior to coughing (Knack manoeuvre), which can prevent or reduce urinary leakage [5]. Some studies have demonstrated differences in PFM activity and bladder neck displacement during coughing in continent and incontinent women [4,6,7]. These studies have described an absent or altered pattern of PFM contraction during coughing in women with weak PFMs [8]. However, to our knowledge, none of the studies investigating the influence of coughing on the pelvic floor have addressed cough pattern [4,6,7,9–11]. In a clinical setting, different activation patterns of the abdominal muscles and PFMs have been observed during coughing and FE. Therefore, it may be incorrect to assume that PFM dysfunction causes an absent or altered involuntary contraction of the PFMs during coughing. Absent or altered activation could be solely related to a specific abdominal movement pattern. The aims of this observational study were to:

1 - Assess the occurrence of different abdominal movement patterns during coughing and FE in young healthy nulliparous volunteers in standing and crook lying positions.

2 - Assess the occurrence of cranioventral (CV) bladder neck displacement during coughing and FE in standing and crook lying positions.

3 - Compare the occurrence of bladder neck displacement (yes/no) for the different abdominal movement patterns (abdominal inward movement (AIM) and abdominal outward movement (AOM).

2. Study design, materials and methods

For this prospective observational cohort study, healthy nulliparous women between the ages of 18 and 35 were recruited from the University online mailing list, advertisements in the Department of Urology at a University Hospital and two private gynaecology outpatient clinics. To be included in the study, participants were required to be nulliparous, in perimenopause state with no present or past history of pelvic floor dysfunction, be able to perform a normal or strong voluntary PFM contraction confirmed by digital palpation and display a CV bladder neck displacement during a voluntary PFM contraction as measured by transperineal ultrasound. Participants were excluded from the study if they were under the age of 18 or over age 35, currently or previously pregnant, or had any form of pelvic floor dysfunction, neurological disorders, pelvic surgery, previous PFM training, or were taking a medication influencing PFM function. The study received ethical approval from the cantonal ethics committee (KEK) of Bern. Each volunteer provided written consent prior to their participation.

2.1. Procedure

Inclusion assessments

Women interested in participating in the study were invited to a one-and-a-half-hour session, where they had to complete the self-administered validated German pelvic floor questionnaire (Deutscher Beckenbodenfragenbogen) that combined questions about bladder, bowel and sexual function, pelvic organ prolapse, symptom severity, most bothersome symptom and condition-specific quality of life [12]. This questionnaire has shown good psychometrics in the studied population with Cronbach's alpha coefficient: bladder domain: 0.86, bowel function: 0.76, prolapse symptoms: 0.82, sexual function: 0.80 [12]. To confirm normal or strong PFM strength, a voluntary PFM contraction was assessed by digital vaginal palpation according to the ICS scale done by an experienced PF-physiotherapist not involved in other measurements. [1] 2D trans-perineal ultrasound was used to confirm CV bladder neck movement during a voluntary PFM contraction. Differences in bladder neck displacement between the resting position and voluntary contraction of the PFMs were documented using a midsagittal view [13].

Study tasks

The included participants were instructed to perform normal or regular breathing for one minute followed by two tasks: coughing and FE. First, the participants performed three maximal expulsive coughs with 10 s of rest between coughs, followed by three FEs by vocalizing "Hey" as loudly as possible with 10 s of rest between vocalizations. During these tasks, the participants were first in their habitual standing posture with their feet shoulder-width apart. Second, they performed the tasks in crook lying position with hips and knees flexed and feet shoulder-width apart and a pillow supporting the participant's head. The respiratory inductive plethysmography (RIP) method was used to monitor the coughing and FE tasks to objectively identify the abdominal movement patterns (AIM or AOM). Simultaneously, trans-perineal ultrasound was used to evaluate bladder neck displacement during the two tasks and for each position.

Abdominal movement pattern measurement

In the present study, the validated RIP method was used to objectively detect abdominal movement patterns during coughing and FE [14]. The RIP method (Nims Respitrace 204) consisted of two insulated sinusoid coils placed within two lightweight elastic and adhesive bands, which were 2.5 cm wide. The transducer bands were placed, (a) around the ribcage under the armpits, and (b) around the lower abdomen above the pubic bone, and both bands were connected to an oscillator. The device converted the change in frequency in the abdomen and rib cage to a digital respiration waveform, where the amplitude of the waveform was proportional to the inspiration volume. At the end of the assessment session, the data was downloaded from the RIP recorder and analyzed by its internal software (Nims RespiEvents 5.2b) to review raw and processed data on a screen. The relative gain in rib cage and abdominal RIP signals during the coughing and FE task was determined by comparing the recorded RIP method to one minute of normal breathing at the beginning of the test session [15]. Then, ribcage abdominal motion was assessed by computing the rib cage contribution and the phase shift between the rib cage and abdominal excursions. With this measurement, coughing or FE were identified and the abdominal wall movement (AIM or AOM) was distinguished as shown in Fig. 1 [14,15].

Bladder neck displacement

Concurrently with the RIP method, trans-perineal ultrasound was used to assess CV bladder neck displacement. The ultrasound measurements were performed with an Echoblaster 128 CEXT, Telemed 2D ultrasound medical system. We used a curved array transducer with a frequency of 7 MHz. As the ultrasound measurements required a full bladder, participants were asked to empty their bladder and then drink 300 ml of water one hour prior to the examination. The examination method described by Schaer et al. was used to ensure measurement repeatability [13]. The ultrasound transducer was covered with a glove and coated with gel, and placed on the participant's perineum, applying only light pressure to avoid affecting the position of the bladder neck or compressing the urethra. The resting position of the bladder neck was documented in midsagittal view using 2D images. During the coughs and FEs, the maximal excursion of the bladder neck was quantified and compared with values at rest. A rectangular coordinate system described by Schaer et al. was used to analyze the movements of the bladder neck (Fig. 2), where the χ-axis (Dχ) shows the displacement in the ventral or dorsal direction and the γ-axis(Dγ) represents the displacement in the cranial or caudal direction. A cranial or no displacement on the y-axis ($Dy \geq 0$) along with a ventral or no displacement on the x-axis ($Dx \geq 0$) of the bladder neck was considered a PFM contraction [13]. Because a cough is a fast movement that is not easily captured sonographically, data were recorded as a cine-loop and exported to Telemed video format (vdt, frame rate 28 Hz). This format allows *post-processing work on the saved video-data with the*

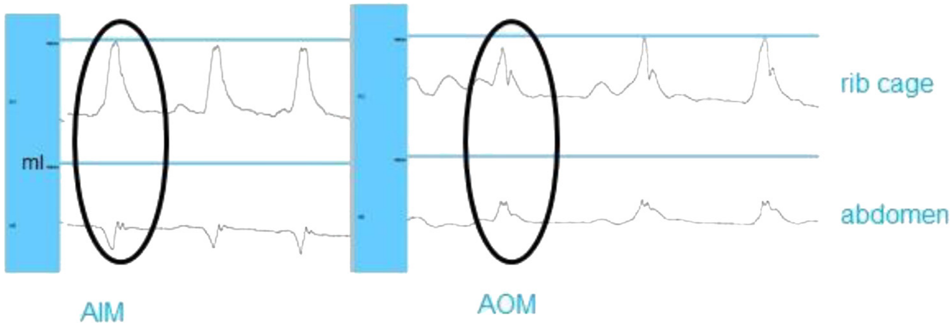

Fig. 1. Abdominal patterns (AIM: abdominal inward movement, AOM: abdominal outward movement) measured by an abdominal and rib cage belt using the respiratory inductive plethysmography (RIP) method.

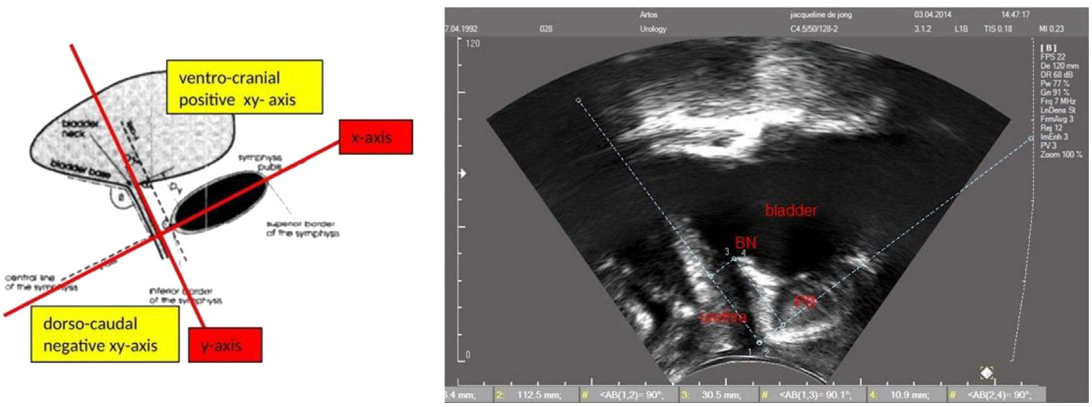

Fig. 2. Left: Measurement perineal ultrasound: Dχ: distance between the γ-axis and bladder neck, Dγ: distance between the χ-axis and bladder neck (adapted from G. Schaer) Right: Displacement of the bladder neck during a cough in crook laying position. Bladder neck (BN) location was determined using the x-axis coinciding with the longitudinal axis of the pubic bone (PB) and y-axis intersecting at the inferior margin of the pubis.

possibility of taking measurements and making calculations. Frames with optimal image quality for the evaluation of bladder neck displacement were identified and captured as JPG images (1000 × 580 pixels). The data was reviewed, analyzed and calculated [13] by an independent researcher in urology (FB) collaborating on this study.

3. Sample size and statistical analysis

Sample size

The calculation was based on a small pilot of 8 subjects, clinical experience and the following assumptions. We expected that the proportion of subjects with a CV bladder neck displacement during coughing and forced expiration is 70%. We aimed to estimate this proportion with a precision of ±7.5%. By this mean that the sample size should be such that in the analysis the width of the 95% confidence interval will be 15%. We used the "ci" command (to calculate confidence intervals) as implemented in Stata to determine which sample size will provide this precision assuming a true value of 70%. With 150 volunteers this proportion will be estimated with a 95% confidence interval of a width of about ±7.5% i.e. if exactly observing 70%, the confidence interval will range from 62.6 to 77.3%. Therefore, this study aimed to include 150 participants.

Statistical analysis

Descriptive statistics (number and %) were computed for the abdominal movement patterns (AIM or AOM) assessed with the RIP method, as well as the cranioventral (CV), ventral (Dx) and cranial (Dy) bladder neck displacement (yes/no) for both tasks (coughing and FE) in the standing and crook lying positions. To compare different abdominal movement patterns (AIM or AOM) and the occurrence of bladder neck displacement (CV, Dx and Dy) measured by perineal ultrasound, we calculated the odds ratio and reported the 95% confidence intervals. P-values were obtained from the chi-square test statistics with one degree of freedom (df) in all presented analyses. P values <0.05 were considered significant.

4. Results

Around 1500 women were approached to participate in the study. One hundred and seventy-two women were recruited, and 22 women did not meet the inclusion criteria or withdrew for personal reasons. Finally, 150 women between the ages of 18 and 35 were included in the study.

One participant did not complete the assessment protocol and was therefore excluded. The mean age of the participants was 26.3 (SD ± 5.6) and the mean BMI was 21.6. (SD ± 4.8). All participants obtained a score of 0 on the German pelvic floor questionnaire confirming the absence of pelvic floor dysfunction. All included participants had normal or strong PFM strength as confirmed by digital vaginal PFM assessment as well as CV bladder neck displacement in the perineal ultrasound.

Abdominal movement patterns

In the standing position during coughing, AIM was observed in 60/149 subjects and AOM was detected in 89/149 subjects. **During FE**, AIM was seen in 56/149 subjects and AOM was detected in 93/149 participants.

Table 1
Comparison of different abdominal patterns and the occurrence of bladder neck displacement measured with perineal ultrasound.

Bladder neck displacement	N	Abdominal inward N/%	Abdominal outward N/%	OR (95% CI)	P value
Coughing standing					
CV[a]	149	10/60 (17%)	2/89 (2%)	8.7 (1.83 to 41.30)	0.002
Dx[b]	149	12/60 (20%)	2/89(2%)	10.88 (2.34 to 50.62)	0.000
Dy[c]	149	24/60 (40%)	8/89 (9%)	6.75 (2.77 to 16.46)	0.000
Coughing crook laying					
CV[a]	149	3/14 (21%)	6/135 (4%)	5.86 (1.29 to 26.72)	0.011
Dx[b]	149	4/14 (29%)	9/135 (%)	5.60 (1.46 to 21.44)	0.006
Dy[c]	149	8/14 (57%)	52/135 (39%)	2.13 (0.70 to 6.48)	0.176
FE standing					
CV[a]	149	28/56 (50%)	17/93 (18%)	4.47 (2.13 to 9.39)	0.000
Dx[b]	149	34/56 (61%)	23/93 (25%)	4.70 (2.30 to 9.60)	0.000
Dy[c]	149	33/56 (59%)	29/93 (31%)	3.17 (1.59 to 6.31)	0.001
FE crook laying					
CV[a]	149	4/12 (33%)	35/137 (26%)	1.46 (0.41 to 5.14)	0.566
Dx[b]	149	5/12 (42%)	43/137 (31%)	1.56 (0.47 to 5.20)	0.465
Dy[c]	149	10/12 (83%)	76/137 (55%)	4.01 (0.85 to 19.01)	0.061

[a]Cranioventral displacement of the bladder neck defined as positive values in *x*- and *y*-axis, incl. subjects with no displacement.
[b]Ventral value (Dx) distance between *y*-axis and bladder neck, incl. subjects with no displacement.
[c]Cranial value (Dy) distance between *x*-axis and bladder neck, incl. subjects with no displacement.

In the crook lying position during coughing, 14/149 subjects displayed AIM and 135/149 presented AOM. **During FE**, 12/149 subjects showed AIM and 137/149 displayed AOM.

Bladder neck displacement

In the **standing position,** CV bladder neck displacement was observed in 12/149 subjects **during coughing** and 45/149 subjects **during FE**.

In the **crook lying position,** CV bladder neck displacement was observed in 9/149 subjects **during coughing** and in 39/149 subjects **during FE.**

Occurrence of CV displacement in comparison to the abdominal movement patterns During coughing in the standing position, significant differences were found between the abdominal movement patterns (AIM vs AOM) and the occurrence of CV bladder neck displacement: 10/60 subjects that presented AIM showed CV bladder neck displacement compared to 2/89 subjects where AOM was observed (p= 0.002). There were also significant differences in the occurrence of ventral (Dx) (p=0.000) and cranial (Dy) (p= 0.000) bladder neck displacement between the two abdominal movement patterns.

During coughing in the crook lying position, significant differences were found in the occurrence of CV displacement between the subjects presenting different abdominal movement patterns: CV displacement was observed in 3/14 subjects that displayed AIM versus 6/135 subjects that presented AOM (p= 0.01). Significant differences were found in the occurrence of ventral (Dx) (p=0.006) but not cranial (Dy) bladder neck displacement between the subjects presenting different abdominal movement patterns.

During FE in the standing position, significant differences were found in the occurrence of CV displacement between subjects presenting different abdominal movement patterns: 28/58 subjects presenting AIM showed CV displacement versus 17/93 subjects that presented AOM (p= 0.000). We also found significant differences in the occurrence in ventral (p= 0.000). and cranial bladder neck displacement (p=0.001) between the abdominal pattern groups.

There were no significant differences in the occurrence of CV displacement between subjects showing different abdominal movement patterns **during FE in the crook lying position**. All results are presented in Table 1.

5. Discussion

To our knowledge, this is the first study identifying differences in abdominal movement patterns during coughing and FE in continent women, in standing and crook lying positions. This is also the first study exploring the influence of abdominal movement patterns on involuntary PFM activity using CV bladder neck displacement as a proxy.

Abdominal movement patterns

In this study, the RIP method was used to identify an inward (AIM) and outward (AOM) movement of the abdominal wall. AOM was observed in the majority of subjects, which is not considered a physiological expiration. According to the European respiratory guidelines, a cough or FE consists of an inspiratory, compressive and expulsive phase [16]. During low-effort breathing, only the inspiratory muscles are active. During coughing or FE, the expiratory muscles become active as well [16]. An increase in IAP during inspiration occurs in conjunction with diaphragm activity, decreasing the abdominal cavity volume. IAP also occurs during expiration with the contraction of the antero-lateral abdominal muscles, leading to an inward movement of the abdominal wall [7,8]. During coughing or FE, a synchronized motion of the ribcage and abdomen is needed, which requires coordination of the activity of abdominal, pelvic floor and diaphragm muscles [2,3,17,18]. Overall, we would have expected an AIM during coughing and FE. Why an AOM was found in the majority of the subjects, is not known and should be more explored.

Furthermore, the results showed a large variance in the occurrence of abdominal movement patterns between the standing and crook lying positions. During coughing, AIM was observed in 40% of participants when standing, compared to 9% in the crook lying position. During FE, AIM was observed in 38% of subjects while standing compared to 8% in the crook lying position. Therefore, a change in body position may modify the length and contraction ability of the PFMs due to gravity, and/or alter the support of trunk muscle activity and movement [3,19,20]. A standing posture results in an increase in the basic activity of the transverse abdominal and internal oblique muscles and PFMs. In the crook lying position, gravity affects the ribcage, which modifies the thoraco-abdominal movement [21].

Bladder neck displacement

Perineal ultrasound is commonly used to evaluate bladder neck displacement, and a CV shift of the bladder neck can be seen as evidence of a PFM contraction [13,22,23]. Overall, we expected to find a higher rate of CV bladder neck displacement for both expiration tasks. Previous studies have shown an absence or altered response of the pelvic floor during coughing in women with SUI [6,7]. However, participants in the present study were healthy nulliparous volunteers without signs of PFM dysfunction. The results showed a lower incidence of CV bladder neck displacement during coughing in standing and crook lying positions compared to FE in both positions. The role and impact of IAP on bladder neck displacement is well recognized [10], with the highest IAP measured during coughing and jumping [24]. This could explain the lower rate of CV bladder neck displacement during coughing compared to FE in both positions. We assume that if the PFMs are unable to counteract a rise in IAP, they will be forced to contract in an eccentric mode, resulting in a caudal, dorsal or dorsocaudal movement of the bladder neck. In the study by Peng and Lovegrove, the ano-rectal angle (ARA) was used to analyze PFM movement [7]. In healthy women, the ARA moved ventrally to the pubic bone during coughing, which was followed by a dorsal movement, probably due to the increase in IAP. The caudal movement of the bladder neck was greater in women with SUI [7].

Occurrence of CV displacement in comparison to abdominal movement pattern

We found a significant difference in the occurrence of CV bladder neck displacement in subjects presenting AIM compared to those showing AOM during coughing and FE ($p<0.000$) in the standing position. This supports Hodges and Sapsford findings, which demonstrated the synergy between the diaphragm, transverse abdominals and PFMs [3, 19]. Further supporting this finding is an MRI study by Talasz, which showed a parallel movement of the diaphragm, abdomen and PFMs during breathing and coughing [25]. Although synergy between the PFMs and the abdominal muscles has been demonstrated [3,25], the effect of postural changes on pelvic floor and abdominal muscle function has been insufficiently studied to date. In the crook lying position, we only found a significant difference in the occurrence rate of CV bladder neck displacement in participants that displayed AIM during coughing but not FE, compared to subjects showing AOM. We also found an overall higher rate of CV bladder neck displacement during FE compared to coughing in participants presenting both abdominal movement patterns in both positions. This may be due to the change in PFM activity in relation to IAP. The rise in IAP was lower during FE compared to coughing and therefore, it may have been easier for the PFMs to counteract the IAP [21]. We assume that the direction and dimension of bladder neck displacement depends on IAP rise and PFM function.

6. Limitations

One limitation of this study is due to the measurement of PFM contractions through CV bladder neck movement. In this study we wanted to identify the association between abdominal movement patterns and bladder neck displacement during coughing and a FE. The CV bladder neck excursion can be influenced by an increase in IAP in the caudal direction, but the PFMs should counteract this IAP rise (19,20) Although 2D ultrasound has been extensively used by different authors in the past to measure voluntary, active PFM contractions [13,22], it may not be as reliable when assessing involuntary PFM contractions during coughing and FE. Previous studies have shown a wide variability in reported bladder neck displacement during coughing [7,26], which may depend on the purpose and time of measurement. Clarity in measurement outcomes is needed and should be confirmed by additional studies.

7. Clinical and research relevance

As shown in this continent nulliparous population, abdominal movement plays a role in bladder neck displacement during coughing and FE in the standing and crook lying positions. We found a significant association between AIM and a CV shift of the bladder neck, which is evidence of a PFM contraction [13,22,23]. The PFMs physiologically act in synergy with the expiratory muscles, contracting during expiration and relaxing during inspiration. Therefore, during a cough or FE, the PFMs should counteract the IAP. In this study, AOM was observed in the majority of the subjects. It seems conceivable that paradoxical abdominal movement (i.e., AOM) during coughing or FE may eventually cause PFM dysfunction. Clinicians should be aware of possible differences in abdominal movement during coughing and FE and pay attention to the physiological abdominal movement to enhance synergy between the abdominal muscles and PFMs. Multiple studies have demonstrated alterations in PFM activity and bladder neck displacement during coughing in continent and incontinent women [4, 6,7]. They indicated that the cause of an absent PFM contraction during coughing in women was due to weak PFMs [8]. Therefore, clinicians and researchers should be careful not to conclude that a dorsocaudal movement of the bladder neck during coughing is a result of a weak pelvic floor.

8. Conclusion

Significant differences were found in abdominal movement patterns during coughing and FE in healthy nulliparous subjects in standing and crook lying positions. Most of the subjects showed AOM during coughing or FE in both standing and lying positions. This is contrary to the existing literature and needs further investigation. Significant differences in CV bladder neck displacement were also found in subjects showing different abdominal movement patterns. We conclude that AIM during coughing and FE appears to have an impact on CV bladder neck displacement and therefore, could affect the supportive function of the PFMs in both standing and crook lying positions. More studies are needed.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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