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ORIGINAL ARTICLE

Lateral abdominal muscle thickness during breathing maneuvers in women with and without stress urinary incontinence

Mahnaz Tavahomi[1] · **Mehdi Dadgoo**[1] · **Behnoosh Vasaghi-Gharamaleki**[2] · **Saeed Talebian**[3] · **Maryam Emami**[4] · **Sanaz Shanbehzadeh**[1]

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Abstract

Introduction and hypothesis Stress urinary incontinence (SUI) patients predominantly experience involuntary leakage during respiratory functions that induce a rapid increase in intra-abdominal pressure (IAP) such as coughing and sneezing. The abdominal muscles have an important role in the forced expiration and modulation of IAP. We hypothesized that SUI patients have different thickness changes in the abdominal muscles compared to healthy individuals during breathing maneuvers.

Methods This case–control study was conducted on 17 adult women with SUI and 20 continent women. Muscle thickness changes were measured by ultrasonography at the end of deep inspiration and expiration, and the expiratory phase of voluntary coughing for external oblique (EO), internal oblique (IO), and transverse abdominis (TrA) muscles. The percent thickness changes of muscles were used and analyzed with a two-way mixed ANOVA test and post-hoc pairwise comparison at a confidence level of 95% ($p < 0.05$).

Results The percent thickness changes of TrA muscle were significantly lower in SUI patients at deep expiration ($p < 0.001$, Cohen's d = 2.055) and coughing ($p < 0.001$, Cohen's d=1.691). While, percent thickness changes for EO ($p = 0.004$, Cohen's d=0.996) and IO thickness ($p < 0.001$, Cohen's d=1.784) were greater at deep expiration and deep inspiration, respectively.

Conclusions The percent thickness changes of abdominal muscles differed between women with and without SUI during breathing maneuvers. The present study provided information regarding the altered function of abdominal muscles during breathing maneuvers; therefore, it is important to consider the respiratory role of abdominal muscles for the rehabilitation of SUI patients.

Keywords Abdominal muscles · Breathing · Urinary incontinence · Ultrasonography

✉ Mehdi Dadgoo
dadgoo.m@iums.ac.ir

Mahnaz Tavahomi
mahtavahomi@yahoo.com

Behnoosh Vasaghi-Gharamaleki
bvasaghi@gmail.com

Saeed Talebian
talebian@tums.ac.ir

Maryam Emami
Emami59658@yahoo.com

Sanaz Shanbehzadeh
Sanaz_shan@yahoo.com

1 Rehabilitation Research Center, Department of Physiotherapy, School of Rehabilitation Sciences, Iran University of Medical Sciences (IUMS), Tehran, Iran

2 Rehabilitation Research Center, Department of Rehabilitation Basic Sciences, School of Rehabilitation Sciences, Iran University of Medical Sciences (IUMS), Tehran, Iran

3 Department of Physiotherapy, School of Rehabilitation, Tehran University of Medical Sciences (TUMS), Tehran, Iran

4 Department of Urology, School of Medicine, Hasheminejad Kidney Center, Iran University of Medical Sciences (IUMS), Tehran, Iran

Abbreviations

SUI	stress urinary incontinence
PFM	pelvic floor muscle
IPA	intra-abdominal pressure
TrA	transversus abdominis
EO	external oblique
IO	internal oblique
UI	urinary incontinence
STROBE	strengthening the reporting of observational studies in epidemiology
ICIQ-UI ShortForm	International Consultation on Incontinence Questionnaire Urinary Incontinence-Short Form
BMI	body mass index
COPD	chronic obstructive pulmonary disease
IUMS	Iran University of Medical Sciences
mm	millimeters
ICCs	intra-class correlation coefficients

Introduction

Stress urinary incontinence (SUI) is a common type of urinary incontinence, characterized by the complaint of involuntary leakage on effort, exertion, sneezing, or coughing. SUI negatively affects the quality of life (including sexual functioning and social and physical activity), and imposes a financial burden on the healthcare system [1].

The first line of conservative treatment for urinary incontinence concentrates on improving pelvic floor muscle (PFM) function and strength [2, 3]. Nevertheless, a weak association has been reported between PFM strength and urinary continence during tasks that increase intra-abdominal pressure (IAP) [4, 5]. The PFMs do not act in isolation; instead, they are activated in synergy with other muscles surrounding the abdominal cavity during increased IAP [6].

Several studies have explored the voluntary and involuntary activation of abdominal muscles in SUI patients. A systematic review (2019) investigated the co-contraction between abdominal muscles and PFM during abdominal draw-in maneuvers and voluntary PFM contraction. The findings demonstrated the co-contraction of transversus abdominis (TrA) and PFM in healthy individuals; however, this was not present in SUI patients [7]. Furthermore, increased thickness of external oblique (EO) muscles and decreased thickness of TrA/ internal oblique (IO) muscles have been reported in urinary incontinence (UI) patients during voluntary abdominal muscle contraction maneuvers compared to healthy individuals [8, 9]. Therefore, the results have suggested an altered activation of abdominal muscles in UI patients.

SUI patients predominantly experience leakage during respiratory functions that induce a rapid increase in IAP (e.g., coughing and sneezing). The abdominal muscles are the main components of forced expiration. Their contraction increases IAP, thereby pushing the diaphragm toward the thorax, and aiding the expiratory flow. During deep inspiration, the diaphragm contracts and moves downward, increasing the IAP, while the abdominal muscles would be relaxed to allow maximum inspiratory flow [10, 11]. With regard to the respiratory role of abdominal muscles, understanding the function of these muscles during breathing maneuvers in UI patients compared to healthy individuals could help therapists to prescribe the best exercise for abdominal muscle training.

To our knowledge, no study has investigated the abdominal muscle thickness during breathing maneuvers in SUI patients. Therefore, the main objective of this study was to investigate abdominal muscle thickness using ultrasonography during different breathing phases (at the end of deep inspiration, at the end of deep expiration, and an expiratory phase of cough) between women with and without stress urinary incontinence. The study hypotheses were: 1) the increased thickness change of superficial muscle (EO) and decreased thickness change of deep abdominal muscles (IO and TrA) during deep expiration and coughing in SUI patients and, 2) the increased thickness change of all three abdominal muscles during deep inspiration in SUI patients.

Materials and methods

Study design

This case–control study was conducted from September 2021 to March 2022, and followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (Appendix) [12]. Before the study, the Committee approved the ethical considerations for Ethics at the Iran University of Medical Sciences (IR.IUMS.REC.1400.1002).

Participants

All participants were recruited by convenience sampling method. SUI patients were diagnosed using a urodynamic test by urogynecologists at the Urogynecology Outpatient Clinic of Imam Khomeini and Hashemi Nezhad hospitals located in Tehran. If mixed symptoms were present, such as frequency, urgency or nocturia, patients with predominately SUI as a chief complaint were included in the study. Healthy individuals without any form of urinary incontinence using the International Consultation on Incontinence Questionnaire-short form (ICIQ-UI SF) with a score of zero, were recruited from staffs of the same two hospitals where patients were selected. All eligible women aged between 20–55 years, prior to menopause were included in the study. The exclusion criteria for all participants were as follow: body mass index (BMI) > 30 kg/m^2, cesarean labor, pregnant or had delivered in the previous 6 months, diabetes, nervous system problems, urogenital prolapse above grade 2, hysterectomy, pelvic floor surgery in the previous 6 months, taking medications related to UI, breathing disorders such as asthma and chronic obstructive pulmonary disease (COPD), being infected with coronavirus infection which had led to lung damage, smoking, and being a professional athlete [13].

Before the study, all the participants received verbal information about the methods and aims of the study. They filled out the informed consent forms, and were assured that their data would be confidential and that they could leave the study at any time. Ultrasonic evaluations were performed in a center at the School of Rehabilitation Sciences of Iran University of Medical Sciences (IUMS).

Data collection

The lateral abdominal muscle thickness measurements (TrA, EO, and IO) are outcomes measured using A 7.5 MHz linear array transducer of a SONOACE R7 ultrasound (Medison, Samsung, Seoul, Korea). All the data were collected by one physiotherapist under the supervision of a sonographer. The transducer was oriented transversely and perpendicular to the abdominal musculature on the midaxillary line, at the midpoint of the iliac crest and the last rib, and then 2.5 cm in front [14, 15]. This point was marked using a marker to define the exact location of the transducer in all tests. The amount of pressure was applied as lightly as possible on the patient's skin to obtain a clear image. A standardized procedure was used to measure muscle thickness at 15 mm from the right musculofascial junction of the TrA in a hook-lying position [16]. At this point, the muscle thickness was measured as a perpendicular distance within the fascial borders of muscles in millimeters (mm) [16] (Fig.1).

B mode was used to visualize and qualify the illustration and then recorded in cine-mode to view the phasic changes in abdominal muscle thickness on the ultrasound device's monitor during breathing maneuvers. Using cine-mode helped to select the exact frame with the least and most thickness at discrete moments in the breathing phases, and also to avoid abdominal bracing. The measurements were conducted online on the ultrasound device. At first, we have done ultrasonography during quiet breathing without the patient realizing it in order not to control the breathing. Afterward, the participants were asked to perform maximum deep breathing and coughing in a randomized order by flipping a coin. The verbal instruction for deep and maximal breathing was "Breathe in and out maximally as much as possible." The participants were asked to perform one maximum voluntary cough, an effort equivalent to 8 out of 10 on a visual analog scale [14]. The participants did not get additional instruction about how to breathe so that the breathing would not be manipulated. A 3-minute rest between each maneuver and a 30-second

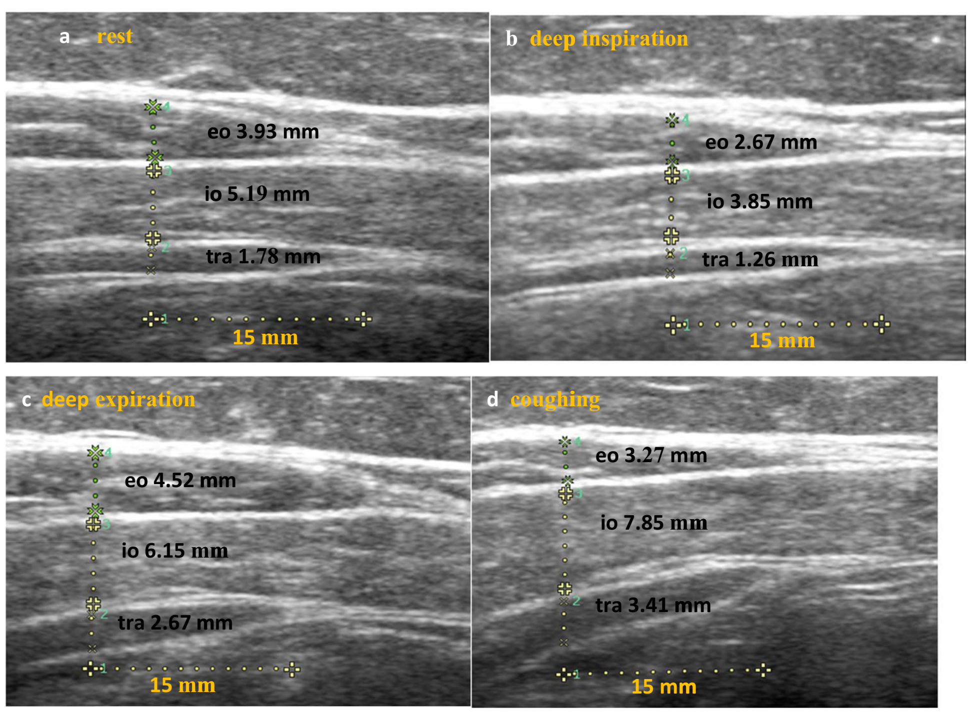

Fig. 1 Ultrasound measurement of the lateral abdominal muscles during breathing maneuvers was present for one healthy woman. *tra*: transverse abdominis, *io*: internal oblique, *eo*: external oblique

rest between every three repetitions were provided to prevent muscle fatigue. The mean of three muscle thickness measurements was obtained; at rest (relaxed expiratory phase), at the end of deep inspiration, at the end of deep expiration, and during an expiratory phase of cough.

The change in thickness of lateral abdominal muscles (TrA, EO, and IO) during breathing phases concerning thickness during rest was used to eliminate the possible effects of individual differences. It was calculated by the following formula: (Thickness at deep inspiration, expiration or cough − Thickness at rest/Thickness at rest ×100) (%) [15].

In order to evaluate the test–retest reliability, ten healthy women were assessed in two sessions, with an interval of 1 week. Intra-class correlation coefficients (ICCs) were calculated to assess intra-rater reliability. The interpretation of the ICCs was as follows: ICCs < 0.40 represents poor, ICCs 0.40–0.59 fair, ICCs 0.60–0.74 good, and ICCs > 0.75 excellent reliability [17].

Statistical analyses

The data were analyzed using the SPSS program (Version 23). The distribution's normality was checked graphically and using the Kolmogorov–Smirnov test. An independent *t*-test was used to examine the mean differences in demographic data. Two-way mixed ANOVA was performed for each muscle with one between factor (SUI and healthy individuals) and one within factors of breathing maneuvers (coughing, deep expiration, and deep inspiration). Post-hoc pairwise comparison analysis using Bonferroni adjustment was used to evaluate significant main interactions and effects. Cohen's d to calculate the effect size was classified as trivial ($d < 0.2$), small ($0.2 < d < 0.5$), medium ($0.5 < d < 0.8$), and large ($d \geq 0.8$) [18]. The significance level was considered at 0.05 for all data analyses. We had no missing data. G*Power (version 3.1.9.4) was used to calculate the sample size with alpha 0.05 and power 0.85, and an effect size of 0.25, as determined by F test (repeated measure, within-between interaction) with two groups (healthy vs SUI group) and 3 measurements (deep inspiration, deep expiration, and coughing). As a result, a total sample size of 32 individuals was required. Considering 30% attrition, the sample size was increased to 42.

Results

In this study, 21 SUI patients and 21 individuals without SU were invited to participate, while only 20 healthy individuals (95.2%) and 17 SUI patients (80.9%) consented to enrollment (Fig. 2). The tests of normality confirmed the normality of data distribution. Both groups had no statistically significant differences in terms of age ($p = 0.26$), BMI ($p = 0.39$), and vaginal deliveries ($p = 0.15$). The demographic data of all the participants are summarized in Table 1.

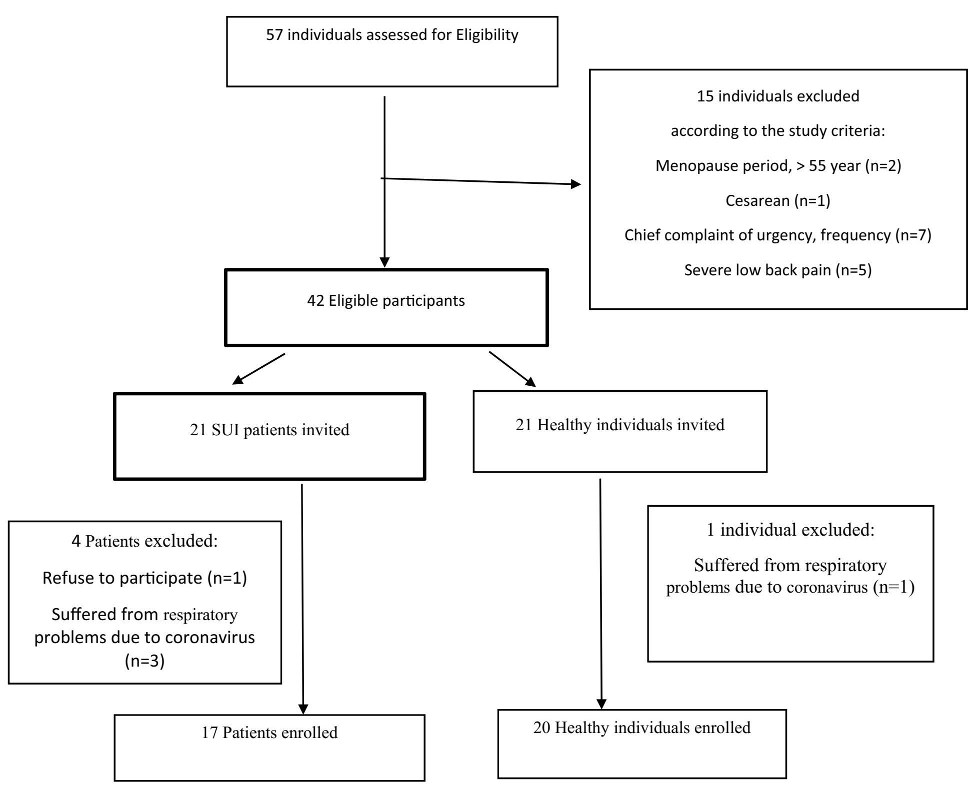

Fig. 2 Flow chart describing the enrollment of SUI patients and healthy individuals

Table 1 Characteristics of women with (n = 17) and without (n = 20) stress urinary incontinence

	Mean (SD)		Sig.
	Without SUI (n = 20)	With SUI (n = 17)	
Age	37.65 (10.32)	41.35 (9.97)	0.26
Height (cm)	162.65 (5.32)	165.06 (4.86)	0.16
Weight (kg)	71.4 (10.86)	76.52 (9.96)	0.14
BMI	25.86 (4.27)	28.05 (3.2)	0.39
		N (%)	
Vaginal deliveries			
No	13 (65%)	7 (41.2%)	0.15
Yes	7 (35%)	10 (58.8%)	

SUI: stress urinary incontinence, cm: centimeter. kg: kilogram, SD: standard deviation, Sig.: significance

The results of ICCs, based on a single-measurement, absolute-agreement, two-way mixed-effects model, demonstrated excellent reliability for all lateral abdominal muscles during all breathing maneuvers. ICC for TrA muscle ranged between 0.75 to 0.84, IO muscle between 0.81 to 0.94, and EO muscle between 0.82 to 0.86 during breathing maneuvers. The high values of reliability could suggest a low measurement error.

The results of two-way ANOVA for TrA muscle revealed significant interaction of group by condition ($F_{1.551}$= 17.473, p = 0.000), the main effect of condition ($F_{1.551}$= 326.157, p = 0.000) and group (F_1= 21.123, p = 0.000). The results of the pairwise comparison (Table 2) showed that healthy individuals have significantly greater TrA thickness change, with a large effect size during deep expiration (p = 0.000, Cohen's d = 2.055) and coughing (p = 0.000, Cohen's d=1.691) compared to SUI patients.

The results for IO muscle revealed significant interaction of group by condition ($F_{1.523}$= 8.256, p = 0.002) and the main effect of condition ($F_{1.523}$= 298.127, p = 0.000); however, the main effect of group was not significant (F_1= 0.917, p = 0.345). SUI patients showed significantly greater IO muscle thickness change with a large effect at end inspiration (p = 0.000, Cohen's d = 1.784). The results for EO muscle revealed no significant interaction of group by condition ($F_{1.581}$= 1.102, p = 0.327); however, the main effect of condition ($F_{1.581}$= 23.797, p = 0.000) and the group was significant (F_1= 5.736, p = 0.022). SUI patients showed significantly greater EO muscle thickness change at end-expiration (p = 0.004, Cohen's d = 0.996). Figure 3 also represents the lateral abdominal muscle percent thickness change in SUI patients and healthy individuals in different breathing maneuvers.

Discussion

The present study compares the thickness change of lateral abdominal muscles using ultrasonography during breathing maneuvers between women with and without SUI. In line with our hypothesis, the findings revealed lower thickness change of TrA muscle in expiration and coughing, greater EO in deep expiration, and greater IO in deep inspiration in SUI patients. Therefore, SUI patients had different abdominal muscle thickness changes to those of healthy individuals during breathing maneuvers.

The thickness change of TrA muscle was greater in healthy individuals compared to SUI patients in deep expiration and coughing. IAP during expiratory efforts requires the proper function of all abdominal muscles [6]. Anatomically, TrA muscle wraps around the abdominal cavity, and the fibers are placed horizontally. Therefore, its contraction could pull in the abdominal wall, reduce the volume of the abdominal cavity, and thus be more effective in generating IAP during forceful expiratory efforts [19]. The transmission of IAP resulting from TrA muscle contraction to supportive structures of the pelvic floor stiffens them. As a result, it increases the urethral pressure and closes the urethra, consistent with strategies for urinary continence [20]. However, in SUI patients, inadequate contraction of TrA during expiration leads to abdominal wall bulging [21], and the PFM is forced

Table 2 Descriptive data of muscle thickness and pairwise comparison between women with (n = 17) and without (n = 20) stress urinary incontinence

Time	Groups	TrA	IO	EO
Cough (%)	With SUI Without SUI	49.9 (15.58) 91.89 (30.53)	46.64 (20.41) 52.76 (17.97)	−15.81 (13.58) −16.22 (13.09)
P value		*P* < 0.001*	0.33	0.92
End deep expiration (%)	With SUI Without SUI	28.55 (16.38) 64.54 (18.42)	17.36 (10.73) 21.35 (11.85)	0.09 (8.21) −7.33 (6.37)
P value		*P* < 0.001*	0.29	0.004*
End deep inspiration (%)	With SUI Without SUI	−31.62 (31.56) −36.33 (12)	−20.49 (8.95) −38.38 (10.85)	−17.3 (8.55) −23.48 (11.77)
P value		0.56	*P* < 0.001*	0.08

SUI: stress incontinence urinary. IO: internal oblique, EO: external oblique, TrA: transverse abdominis, m: millimeters, *:significance level

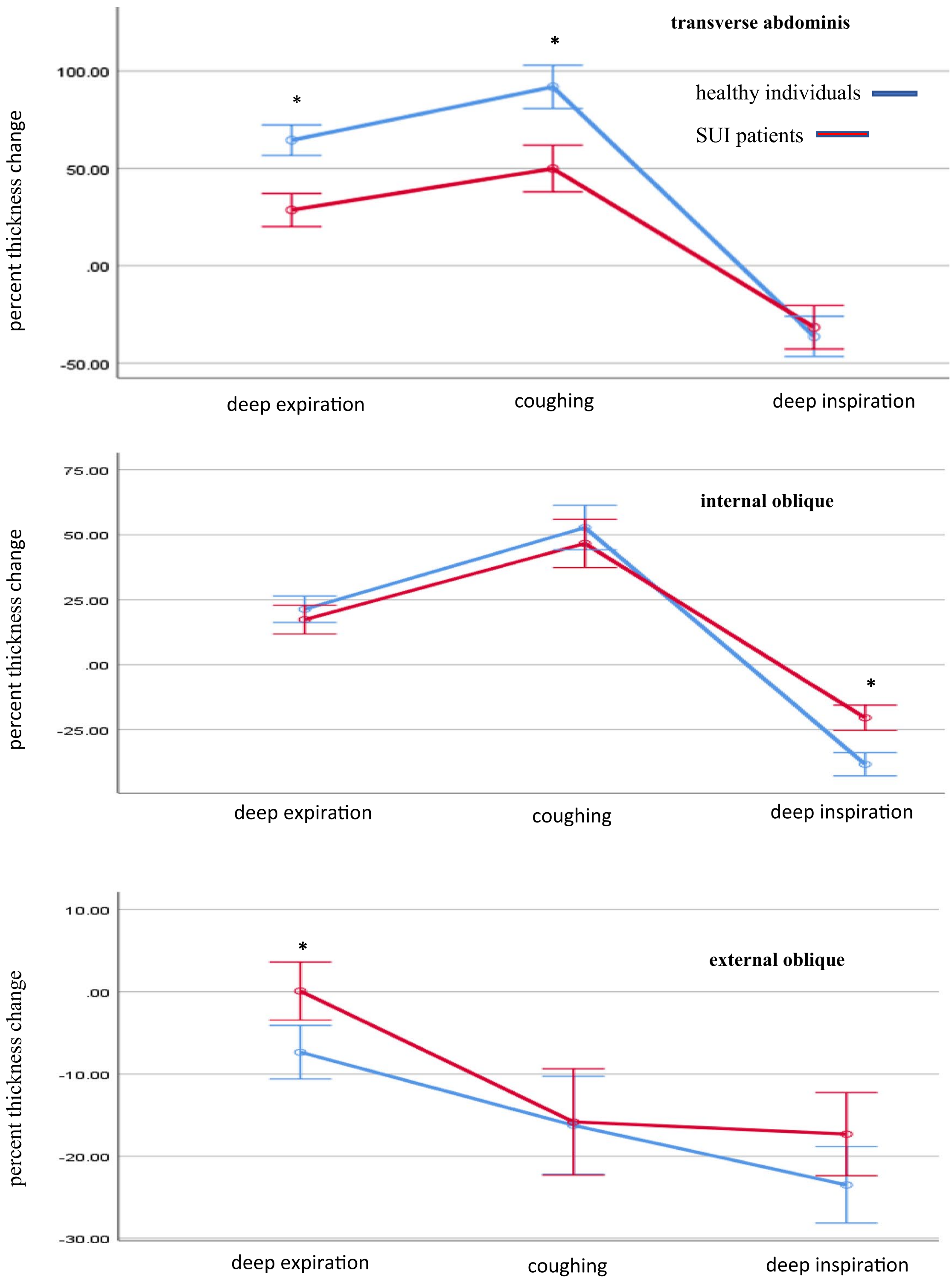

Fig. 3 The percent thickness change of lateral abdominal muscles in SUI and healthy individuals at different respiratory phases. * significance: $p < 0.001$

down, thereby decreasing urethral pressure [20]. Tajiri et al. also noted the importance of TrA muscle, and reported a decrease in its thickness as the predictor of urinary incontinence [22].

On the other hand, the thickness change of EO muscle was greater in SUI patients compared to healthy individuals during deep expiration. Accordingly, the reverse action of the EO muscle would move the lower ribs downward, reduce the transverse diameter of the rib cage to promote the expiration, and compensate for the reduced contribution thickness change of TrA. Despite differences in EO muscle thickness change at deep expiration, there was no difference in coughing between the two groups, which was an exciting finding of this study (contrary to the hypothesis of the present study). Coughing is a rapid respiratory maneuver; therefore, increased elastic recoil of the lung and rib cage may lower the need for EO muscle contribution during coughing [23].

In deep inspiration, the thickness change of all three abdominal muscles is expected to increase in SUI patients; however, it was increased only in the IO muscle. During deep inspiration, abdominal muscles should be relaxed to minimize the increased IAP due to the increased diaphragm muscle contraction and prevent paradoxical movement between the upper and lower ribcage (ribcage distortion) [24]. Some studies have theoretically suggested an altered breathing pattern in SUI patients in which upper rib cage movement is prominent during inspiration [3, 25]. Hwang et al. (2021) demonstrated a more vertical elevation of the sternum than the pump handle in the upper ribcage during inspiratory effort in SUI patients [26]. Among abdominal muscles, the function of TrA/ IO muscles is inspiratory-related modulation [27]. However, due to its location, attachments, and fiber orientation, the IO muscle acts directly onto the ribs to support the lower ribcage movement [28, 29]. IO muscle contraction during inspiration would probably increase IAP [30] and induce overload on the pelvic floor structure, leading to SUI.

To our knowledge, no study has investigated abdominal muscle thickness during breathing maneuvers in SUI patients. However, previous studies have reported a lower thickness change in TrA muscle and a more significant thickness change of EO and IO muscles dedicated in patients with pelvic floor muscle dysfunctions during other functional tasks [7–9], which is consistent with our findings. Therefore, the results of the present study could suggest that retraining of abdominal muscles during breathing is of great importance in the rehabilitation of SUI patients. SUI patients might benefit from biofeedback training, especially visual ultrasound imaging biofeedback recommended by previous studies [31], for improving proper muscle function during each phases of breathing.

Limitations and strengths

The strength of the present study was that we recorded the phasic changes in abdominal muscle thickness during breathing in the cine-mode method to avoid the possible changes due to holding the breath at the end of inspiration and expiration. One of the limitations of the present study was that only patients with stress urinary incontinence were referred from only two hospitals, which limits generalizability (external validity). Another limitation was the inability to control the volume of inspiratory/ expiratory efforts. Since muscle thickness changes were evaluated during maximum inspiration/expiration and coughing, any lower attempts would probably lead to an underestimation of muscle thickness changes. Therefore, it is suggested that a spirometer shoulr be used to reduce a measurement bias related to the breathing efforts. For future studies, it is necessary to investigate the diaphragm movement and chest-wall expansion in SUI patients.

Conclusion

This study indicates altered thickness changes of lateral abdominal muscles during breathing between women with and without SUI. Moreover, reduced TrA and increased EO and IO muscle thickness during breathing phases may influence the mechanism of urinary continence. Hence, it is recommended that the respiratory role of abdominal muscles for the rehabilitation of SUI patients should be considered.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00192-023-05458-9.

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B Vasaghi-Gharamaleki: Project development, Manuscript editing, Final approval

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M Emami: Project development, Final approval

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Declarations

Conflicts of interest None

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