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ORIGINAL ARTICLE

Reliability and validity of pelvic floor muscle displacement measurements during voluntary contractions

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Abstract

Introduction and hypothesis Understanding the functioning of pelvic floor muscles (PFM) is crucial in female PFM rehabilitation. The aim of this study was to determine the intra-session retest reliability and validity to evaluate the quantity of PFM displacement.

Methods This cross-sectional observational study examined the PFM displacement of 17 young healthy nulliparous women in the midsagittal plane. Three maximal voluntary contractions (MVCs) and five fast voluntary contractions (FVCs) were simultaneously examined with an electromagnetic tracking system (ETS) and transabdominal ultrasound (TAUS) and expressed in millimeters (mean, SD). To evaluate reliability and validity, the analysis of variance, intraclass coefficient (2,1), standard error of measurement (SEM), and minimal detectable difference (MDD) were calculated.

Results Maximal voluntary contractions and FVCs in supine position measured by an ETS (TAUS) showed a displacement of MVC: 3.5 ± 1.9 mm (7.8 ± 4.5 mm), FVC: 3.5 ± 2.4 mm (7.6 ± 5.3 mm), and during standing of MVC: 5.2 ± 1.6 mm (9.4 ± 3.8 mm) and FVC: 4.8 ± 2.5 mm (9.7 ± 4.1 mm). Intraclass correlation for the ETS (TAUS) measurement varied between 0.79 and 0.89 (0.61 and 0.74), SEM 0.52 and 1.03 mm (1.54 and 3.2 mm), and MDD 1.54 and 3.2 mm (6.64 and 7.53 mm). The correlation between an ETS and TAUS varied between 0.53 and 0.67.

Conclusions For MVC and FVC, ETS measurements are highly reliable and TAUS measurements are moderately reliable for both contraction types. The correlation between the TAUS and ETS measurements is moderate. An ETS seems to be a reliable and valid measurement tool for evaluating PFM displacement during voluntary contractions. In future studies, the reproducibility and validity of ETS measurements need to be investigated in impact activities.

Keywords Ultrasound · Reproducibility of results · Movement · Gynecology · Rehabilitation

Abbreviations

PFM	Pelvic floor muscles
MVC	Maximal voluntary contraction
FVC	Fast voluntary contraction
ETS	Electromagnetic tracking system
TAUS	Transabdominal ultrasound
MRI	Magnetic resonance imaging
EMG	Electromyography

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Introduction

Understanding processes and mechanisms involved in the functioning of female pelvic floor muscles (PFMs) is crucial in therapy regimens for pelvic floor dysfunctions [1–3]. To conduct precise measurements and consequential diagnosis, reliable, valid tests and instruments are important [4, 5]. This is especially true for muscle action form (concentric, eccentric, isometric or eccentric–concentric) and the derived optimal muscle exercises. Normal PFM function has been described as the ability to perform a voluntary contraction and to present reflex activity preceding increased intra-abdominal pressure. The movement can be described as a closure around the pelvic openings and an inward–upward lift of the perineum and pelvic floor structures [6–8]. No visible movement of the pelvis should emerge during an isolated maximal voluntary contraction (MVC) of the PFMs [5]. According to Crotty et al. an instruction of PFM contraction including a posterior cue (squeeze and lift from the back as if stopping the escape of wind) generates a maximal displacement of the PFMs [9]. Pelvic floor muscle contraction during MVC, Valsalva, straining, and coughing, reflected by the movement of the bladder neck, bladder base or anorectal angle, can be evaluated by ultrasound in a valid manner [1, 3, 10–15]. Chehrehrazi et al. reported transabdominal ultrasound (TAUS) to be a reliable tool for quantifying PFM displacement by means of the bladder base movement [16]. According to Frawley et al., TAUS is even more sensitive than digital palpation for assessing the lifting action of the PFMs [6]. Leitner et al. applied an electromagnetic tracking system (ETS) to measure PFM displacement during running, as they concluded that ultrasound, intra-vaginal digital palpations or MRI are inapplicable for measuring PFM displacement during whole-body movements [17]. However, the evidence of an ETS in measuring PFM displacement is not yet established.

The aim of this study was to determine the intrasession retest reliability and validity of an ETS in measuring PFM displacement during voluntary contractions by means of an ETS to warrant the use of an ETS during whole-body movements, which gives the necessary background knowledge of the PFM muscle action form and the consequent therapy regimens.

Materials and methods

Study design and participants

This study was designed as a cross-sectional observational intra-session retest, intra-rater reliability, and exploratory study and was approved by the Ethics Committee of the Canton of Bern (Switzerland, No. 059/12).

A single measurement session of 30 min for each participant took place within 3 months. Seventeen healthy women aged between 18 and 30 years participated in this study. Only those women who were healthy, nulliparous and had a body mass index between 18 and 30 kg/m^2 were included. Women who had latex and nickel allergies, current pregnancy, current menstruation, urogenital or anal surgery, and vaginal infections were excluded. The participants were recruited ad hoc by flyer and personally from October to December 2012 in Berne, Switzerland. They did not receive any compensation for their engagement. See Table 1 for the demographics of the participants.

Table 1 Demographics

Variable (unit)	*n* or mean ± standard deviation
Included women (*n*)	17
Age (years)	26.7 ± 3.4
Weight (kg)	61.2 ± 8.3
Height (m)	1.68 ± 0.07
Body mass index (kg/m^2)	21.8 ± 2.6

Instrumentation

Ultrasound

The most accurate measurement for directly quantifying PFM displacement is magnetic resonance imaging (MRI) [14]. Unfortunately, in this study fMRI was not applicable because of the electromagnetic field, its slow acquisition speed, and its high costs. Transperineal ultrasound, which is considered to be more reliable than TAUS, could not be used because of the practicability [1, 12]. Therefore, TAUS was taken as the reference standard measurement tool. Real-time ultrasound examinations to evaluate the pelvic floor structures, via midsagittal ultrasound, were performed by two experienced urogynecologists (M.M. and K.D.). A Voluson E8 (GE Medical Systems, Zipf, Austria; performing up to 25 volume scans per second), equipped with a 5- to 8-MHz curved array transducer was used. Despite the claim from Sherburn et al. [10] that no bony landmark is visible when using a TAUS approach, the pubic symphysis was visualized. The transducer was placed midsagittal transabdominally touching the upper border of the pubic symphysis and a 10–15º volume acquisition angle was adjusted. Ultrasound videos were stored for later analyses. From the TAUS videos snapshots of the resting and maximal voluntary contraction (MVC) positions of the PFM were taken and analyzed for each woman. The upper border of the pubic symphysis was used as a reference point and compared with the position of the lower end of the vaginal probe (position of the ETS sensor) to express PFM displacement (Fig. 1).

Electromagnetic tracking system

An ETS using 3D guidance trakSTAR™ (class 1, type B; Ascension Technology Corporation, Milton, VT, USA) measures in six degrees of freedom with an update rate of up to 420/s. Data were analyzed to express the midsagittal plane (Fig. 2). The static accuracy is 1.4 mm root mean square (RMS) and the sampling rate 100 Hz. One ETS sensor (model 800) was fixed at the end of a single-use vaginal surface electromyography (EMG) probe (Periform®; Neen UK, Oldham,

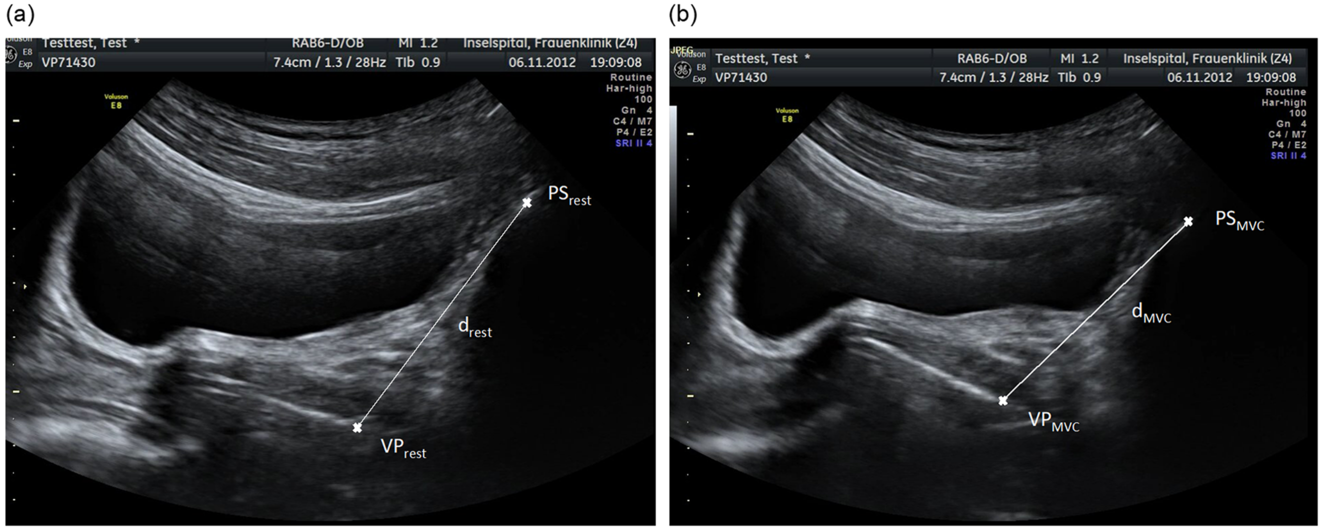

Fig. 1 Determination of reference points of ultrasound snapshots during **a** rest and **b** maximal voluntary contraction (MVC) to calculate the displacement of the vaginal probe from the variation of the distances (d_{rest}, d_{MVC}) in the midsagittal plane (Fig. 2). VP_{rest} lower end of the vaginal probe during rest; PS_{rest} pubic symphysis during rest; VP_{MVC} lower end of the vaginal probe during MVC; PS_{MVC} pubic symphysis during MVC

UK), which was used as an anchorage point. Another ETS sensor (model 180) was adhered to the sacrum of the woman. The sagittal plane coordinates of the PFM displacement (distance in millimeters) from the vaginal surface EMG sensor and sacrum sensor were taken as variables. To avoid influences such as deviations of the electromagnetic field of the trakSTAR™ by metal objects, a wooden massage table was used in supine position.

Procedures

Before the measurement session, each woman had individually and extensively been instructed to conduct a correct isolated maximal PFM contraction. This was evaluated visually and by digital palpation according to the PERFECT scheme [18]. Thirty minutes before the measurements and after receiving the test information

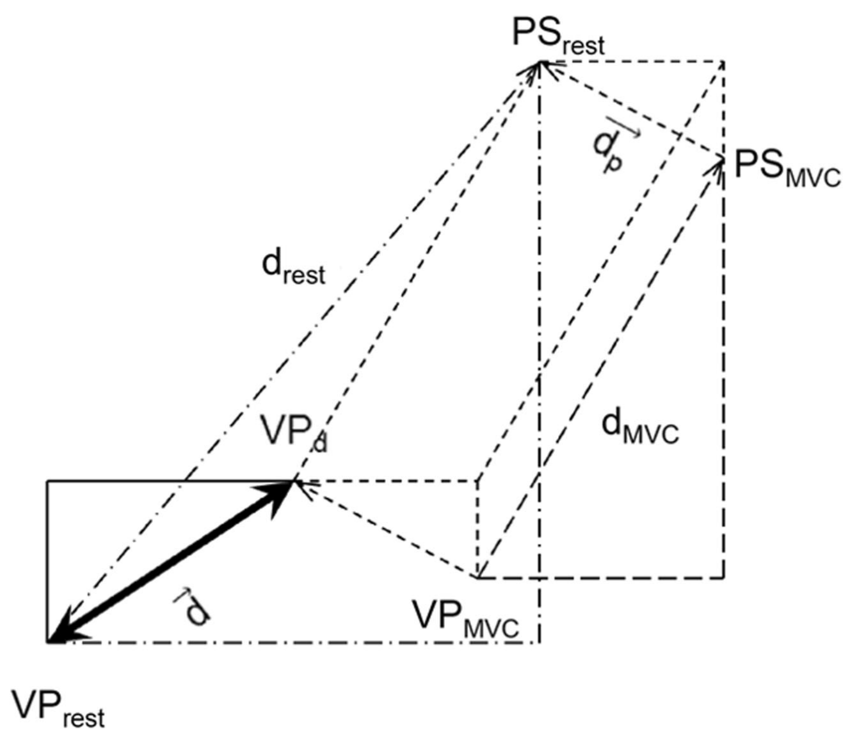

Fig. 2 Calculation method for estimating the pelvic floor muscle (PFM) displacement in the mid-sagittal plane. PS_{rest} pubic symphysis in resting position (rest), PS_{MVC} pubic symphysis at MVC, VP_{rest} lower end of the vaginal probe at rest, VP_{MVC} lower end of the vaginal probe at MVC, VP_d displaced vaginal probe at MVC, d_{rest} distance from PS_{rest} to VP_{rest} in resting position, d_{MVC} distance from PS_{MVC} to VP_{MVC} in MVC position, d_p displacement from PS, d displacement from VP

and giving their written informed consent, the women emptied their bladder, conducted a pregnancy test and drank 500 ml of water to obtain an optimal bladder volume [19]. All women were instructed in the vaginal insertion of the prepared EMG probe. Using ultrasound lubrication, they performed the insertion themselves and the correct position was visually controlled. During the measurements the women wore loose clothing. Three MVCs, each contraction lasting 5 s with 15-s rest intervals in between were followed by five fast voluntary contractions (FVCs) with 5 s of rest intervals in between to test intra-session retest reliability. Each contraction was assessed in supine and standing positions (four test series). Between each test series, a resting period of 2 m was taken. PFM contractions were simultaneously assessed using an ETS and TAUS in supine position with a support under the knees and in standing position with bended knees. The women leaned against the wall to ensure a stable pelvis position. All measurement procedures were conducted in a standardized manner.

Data reduction

Electromagnetic tracking system data were processed using the software package "Analoge und digitale Signalverarbeitung" (ADS) version 1.12 (uk-labs, Kempen, Germany). The signals were low-pass filtered with a cut-off frequency of 10 Hz. TAUS data were processed by a custom-made MATLAB program (MATLAB R2011b; The MathWorks, Natick, MA, USA). ETS and TAUS data were calculated as maximal distance (mm) by the formula $d = \surd(d_{rest}^{2} + d_{MVC}^{2}$; Fig. 2) for the TAUS data and for the ETS data. Eight variables were selected based on the rest and MVC positions of the PFM (Table 2); from these variables the distance of PFM displacement in the midsagittal plane was calculated for an ETS and TAUS (Fig. 2). Data from an ETS (midsagittal plane, distance in millimeters) and TAUS (midsagittal plane, distance in millimeters) were compared.

Statistical methods

Demographic data were analyzed by parametric descriptive statistics (mean, SD). Shapiro–Wilk test was used to test normality of distribution before inferential statistics. According to the recommendations of Weir [20], the intraclass correlation coefficient ($ICC_{(2,1)}$; relative reliability) was calculated as an indicator for the intra-session retest reliability (3x MVCs, 5x FVCs) and intra-rater retest reliability (2x TAUS). To identify possible systematic errors between the repeated measures of each variable, a two-way analysis of variance (ANOVA) was performed initially. To test the absolute reliability, the standard error of the measurement (SEM) of the true score, also called «the standard error of estimate, was calculated [20]. The minimal detectable differences (MDDs) using a 95% confidence interval were calculated based on the standard error of prediction. TAUS analysis was effectuated twice and to evaluate the correlation (intra-rater retest reliability) between the two TAUS scores an $ICC_{(2,1)}$ was calculated. The same procedure was applied to evaluate the external concurrent validity of the means of the repeated measures from an ETS and the means of the mean of both TAUS scores. This was conducted for each subgroup of contraction (MVC and FVC supine and standing). As a general guideline, Portney and Watkins suggest that ICC values above 0.75 might indicate good reliability and below 0.75 poor to moderate reliability [21]. The significance level of the ANOVA was set at $p < 0.05$. SPSS 24 for Mac (SPSS; Chicago, IL, USA) was used for all statistics calculations in addition to Microsoft Excel for Mac 2011 (Microsoft, Redmond, WA, USA). There were no missing data from any of the measurements.

Results

Descriptive statistics, reliability and validity calculations are presented in Tables 3, 4, and 5. For MVC and FVC

Table 2 Variables, descriptions, and units of variables derived from an electromagnetic tracking system (*ETS*) and transabdominal ultrasound

Variables	Descriptions	Units
PS_{rest}	Upper border of PS at rest	x-y coordinates (mm)
PS_{MVC}	Upper border of the PS at MVC	x-y coordinates (mm)
VP_{rest}	Lower end of the VP at rest	x-y coordinates (mm)
VP_{MVC}	Lower end of the VP at MVC	x-y coordinates (mm)
ETS VP_{rest}	ETS sensor (model 800) fixed on the VP at rest	x-y coordinates (mm)
ETS VP_{MVC}	ETS sensor (model 800) fixed on the VP at MVC	x-y coordinates (mm)
ETS S_{rest}	ETS sensor (model 180) fixed on the sacrum at rest	x-y coordinates (mm)
ETS S_{MVC}	ETS sensor (model 180) fixed on the sacrum at MVC	x-y coordinates (mm)

MVC maximal voluntary contraction, *PS* pubic symphysis, *VP* vaginal probe

Table 3 Descriptive statistics (mean and SD in mm) and intra-session retest reliability indexes (intraclass correlation coefficient [*ICC*], standard error of measurement [*SEM*], and minimal detectable difference [*MDD*] in millimeters), and test for systematic error (analysis of variance [*ANOVA*], significance) for distance variables (millimeters) in the midsagittal plane of three MVC and five fast voluntary contraction (*FVC*) repetitions

Variable	Mean	SD	ICC	SEM	MDD	ANOVA
ETS						
MVC supine	3.5	1.9	0.811	0.7	2.3	0.237
MVC stand	5.2	1.6	0.874	0.5	1.5	0.943
FVC supine	3.5	2.4	0.890	0.7	2.3	0.577
FVC stand	4.8	2.5	0.794	1.0	3.2	0.763
Mean TAUS						
MVC supine	7.8	4.5	0.627	2.2	7.5	0.370
MVC stand	9.4	3.8	0.611	1.9	6.6	0.385
FVC supine	7.6	5.3	0.739	2.3	7.5	0.063
FVC stand	9.7	4.1	0.613	2.0	7.1	0.013

SD standard deviation, *TAUS* transabdominal ultrasound, *Mean TAUS* mean of both TAUS measurements

displacement measured by an ETS (TAUS), the mean ranged from 3.5 to 5.2 mm (7.6 to 9.7 mm), SD 1.6 to 2.5 mm (3.8 to 5.3 mm), SEM ranged from 0.5 to 1.0 mm (1.9 to 2.3 mm), and MDD 1.5 to 3.2 mm (6.6 to 7.5 mm). The analysis of systematic errors within repeated measures revealed nonsignificant values for all ETS variables. TAUS mean variables showed a significant effect for only FVC during standing. ICCs of the subgroups of contractions ranged from 0.79 to 0.89 for an ETS and from 0.61 to 0.74 for mean TAUS. The ICC from the first and second TAUS scores ranged between 0.59 and 0.94, the absolute differences between 0.1 to 1.8 mm. ICCs from an ETS compared with TAUS scores ranged between 0.18 and 0.70 (all $p < 0.05$).

Discussion

Key results

To our knowledge, this study is the first to investigate the reliability and validity of PFM displacement measured by an ETS during MVC and FVC. Good reliability due to a high ICC and low SEM and MDD could be shown for ETS measurements during voluntary contractions. Moderate reliability (moderate ICC, moderate SEM, high MDD) was demonstrated for TAUS measurements. ICCs from the first and second TAUS measurement scores showed moderate to high intra-rater retest reliability. A low to moderate score for the concurrent validity was found to validate PFM displacement measured by an ETS.

Table 4 Descriptive statistics (mean and SD in millimeters), external concurrent validity (ICC with 95% confidence interval), and systematic difference (*t* test) for distance variables (mm) in the midsagittal plane of the ETS and TAUS comparison

Variables	Mean ± SD ETS	Mean ± SD TAUS	ICC	95% confidence interval		*p* value
				Lower	Upper	
MVC supine	3.5 ± 2.8	7.8 ± 4.3	0.535	−0.255	0.843	0.004
MVC stand	3.9 ± 2.2	9.4 ± 3.6	0.388	−0.190	0.732	0.009
FVC supine	4.8 ± 6.3	7.6 ± 4.4	0.212	−0.909	0.699	0.601
FVC stand	4.9 ± 2.5	9.7 ± 4.1	0.380	−0.252	0.753	0.028
MVC supine 1	3.8 ± 3.8	8.6 ± 5.1	0.505	−0.255	0.819	0.024
MVC supine 2	3.1 ± 1.9	7.6 ± 5.2	0.464	−0.252	0.798	<0.001
MVC supine 3	3.6 ± 2.9	7.1 ± 4.7	0.535	−0.281	0.757	0.134
MVC stand 1	5.1 ± 3.3	10.1 ± 4.8	0.390	−0.263	0.754	0.070
MVC stand 2	5.2 ± 2.9	8.9 ± 3.4	0.468	−0.257	0.804	0.031
MVC stand 3	5.2 ± 2.9	9.2 ± 4.4	0.488	−0.239	0.810	0.023
FVC supine 1	3.3 ± 3.3	6.6 ± 3.8	0.290	−0.407	0.700	0.362
FVC supine 2	3.7 ± 3.4	6.7 ± 3.7	0.604	−0.177	0.861	0.016
FVC supine 3	3.6 ± 3.9	7.7 ± 5.2	0.418	−0.263	0.787	0.137
FVC supine 4	3.1 ± 2.6	8.8 ± 6.2	0.180	−0.391	0.616	0.375
FVC supine 5	3.5 ± 3.8	7.7 ± 5.2	0.461	−0.228	0.790	0.069
FVC stand 1	4.8 ± 2.6	9.5 ± 6.0	0.197	−0.424	0.635	0.363
FVC stand 2	4.5 ± 2.5	9.7 ± 4.7	0.324	−0.253	0.710	0.057
FVC stand 3	4.9 ± 2.6	9.3 ± 4.6	0.418	−0.257	0.767	0.051
FVC stand 4	5.0 ± 2.9	11.7 ± 5.8	0.341	−0.260	0.728	0.037
FVC stand 5	5.0 ± 3.0	7.9 ± 3.0	0.700	−0.192	0.913	0.001

Table 5 Descriptive statistics (mean and SD in millimeters), intra-rater retest reliability indexes (ICC with 95% confidence interval) and systematic difference (*t* test) for distance variables (mm) in the midsagittal plane derived from ultrasound analyses 1 und 2

Variable	Mean ± SD TAUS 1	Mean ± SD TAUS 2	ICC	95% confidence interval		*p* value
				Lower	Upper	
MVC supine 1	7.8 ± 5.3	9.4 ± 6.3	0.699	0.195	0.890	0.022
MVC supine 2	7.5 ± 5.5	7.6 ± 5.3	0.924	0.788	0.973	<0.001
MVC supine 3	7.1 ± 5.0	7.2 ± 4.8	0.914	0.760	0.969	<0.001
MVC stand 1	10.9 ± 5.3	9.4 ± 4.7	0.875	0.644	0.955	<0.001
MVC stand 2	9.2 ± 4.5	8.6 ± 3.4	0.599	−0.132	0.856	0.084
MVC stand 3	10.1 ± 6.2	8.3 ± 4.0	0.593	−0.061	0.850	0.055
FVC supine 1	7.3 ± 4.6	5.9 ± 3.8	0.777	0.406	0.918	0.003
FVC supine 2	6.2 ± 3.6	7.2 ± 4.6	0.741	0.305	0.905	0.009
FVC supine 3	7.9 ± 5.3	7.6 ± 6.3	0.747	0.286	0.909	0.012
FVC supine 4	8.7 ± 5.9	8.9 ± 7.0	0.923	0.786	0.972	<0.001
FVC supine 5	8.6 ± 5.2	8.3 ± 6.0	0.869	0.619	0.954	0.001
FVC stand 1	10.0 ± 6.2	9.9 ± 6.7	0.925	0.790	0.973	<0.001
FVC stand 2	10.3 ± 5.6	9.5 ± 4.4	0.820	0.510	0.935	0.001
FVC stand 3	9.5 ± 5.6	8.2 ± 4.6	0.833	0.552	0.939	0.001
FVC stand 4	11.6 ± 6.5	11.8 ± 5.4	0.936	0.815	0.978	<0.001
FVC stand 5	7.8 ± 3.2	7.9 ± 3.5	0.820	0.473	0.937	0.003

Interpretation

Good quality of PFM displacement measured by an ETS during voluntary contractions was shown by high reliability indexes. The moderate intra-session and low to high intra-rater retest reliability of the TAUS could be explained by analyzing the procedure from the TAUS data and the transabdominal access. Differences in the measurement scores arose between supine and standing positions. Transabdominal ultrasound measurements seem to be more precise in supine position. FVCs in standing position even showed a significant value according to the systematic error test (Table 3). Owing to the low to moderate ICCs for concurrent validity, additional investigations should be done to control whether an ETS really measures the PFM displacement. One reason for the moderate ICC between ETS and TAUS could be the moderate intra-session and the moderate to high intra-rater retest reliability of TAUS. Furthermore, the moderate correlation could be due to the different reference points (pubic symphysis and sacrum) from the vaginal probe taken by TAUS and ETS measurements. Despite an individual and extensive instruction of an isolated PFM, the quality of the contraction could have been moderate and therefore influencing the reliability of the measurements. There is a broad consensus in the literature concerning the direction of PFM displacement [14]. The lift and elevation in the cranial and ventral direction during an MVC seems established. In studies that measured PFM displacement by TAUS (the lift component) of PFM during MVC in supine position ranged from 3.7 [16] to 9.3 mm [10]. Positional differences from supine position of 4.6 mm versus 6.9 mm in standing position were illustrated [22]. Displacement of the pubo-coccygeus muscle during MVC in supine position measured by MRI varied between 1.6 and 4.3 mm [14] and the elevation of the bladder neck during MVC in standing position measured by transperineal ultrasound was 4.5 mm [23]. In this study, TAUS measurement of the displacement (anterior–cranial) ranged from 7.6 to 9.7 mm. There could have been higher values because the probe was taken as the reference and not the bladder base, and the displacement and not the lift was calculated.

In future studies, ETS measurements combined with EMG and an accelerometer could provide insights into the complexity of PFM activity. In the long term, an ETS could be used in clinical application as a biofeedback. Further investigations need to be carried out concerning the validity of PFM displacement measurements with an ETS and reproducibility during whole-body movements.

Limitations

There are several limitations to this study:

1. The repeatability of TAUS was based on snapshots. Therefore, only the distance and not the three-dimensional direction of PFM displacement could be assessed. This signifies that the direction of the PFM displacement was not considered for comparison, only the distance.

2. Because the vaginal probe is not fixable onto the PFM, minimal shifts of the vaginal probe could interfere with the ETS. However, the attachment with tape of the ETS to the vaginal probe seemed to be sufficient.
3. Owing to the wobbling mass of the skin, the ETS sensor fixed onto the skin of the sacrum and not onto the bone itself, and may not reflect the displacement of the sacrum.
4. Despite TAUS being a valid method of evaluating PFM displacement, the question of its precision has not been conclusively investigated [1, 10, 11, 16]. Owing to the practical application, MRI (electromagnetic field) and transperineal ultrasound (the ETS sensor attached to the vaginal probe was outside of the vagina), estimated to be more precise [1, 12, 14], could not be applied.
5. The pubis bone and vaginal probe were visible on the TAUS pictures but not always clearly locatable. This could have influenced the analysis procedure.
6. The vaginal probe was taken for TAUS as a reference for PFM displacement because of its proximity to the ETS vaginal sensor, instead of the bladder base, as described in the literature, where several authors mentioned the amount of bladder base movement as an indicator of PFM contraction [10–12]. The assumption that the vaginal probe reflects the PFM displacement needs to be explored.
7. Even with the standardized procedure applied concerning bladder volume, which was observed during TAUS, it varied among women. This may influence the contractility performance of the PFM and TAUS accuracy.
8. The quality of PFM displacement varied for each woman, even with precise previous instruction. This could influence the consistency of the amplitude from PFM displacement.
9. The vaginal probe could additionally affect the amplitude of the PFM displacement.
10. The lower end of the vaginal probe and the ETS vaginal sensor were not exactly in the same position; there was a difference of about 2 cm.

Generalizability

An ETS provides new opportunities for investigating PFM displacement during isolated voluntary contractions and whole-body movements.

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Authors' contributions H Moser: project development, data collection, manuscript writing; H Luginbuehl: project development, support of data collection, support of final draft; J-P Baeyens: adviser, support of final draft; L Radlinger: project development, contribution to study design, technical support, support of final draft.

Compliance with ethical standards

Conflicts of interest None.

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