Test-retest and intra-observer repeatability of two-, three- and four- dimensional perineal ultrasound of pelvic floor muscle anatomy and function

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ABSTRACT

The aims of the present study were to evaluate test- retest intra-observer repeatability of ultrasound measurement of the morphology and function of the pelvic floor muscles (PFM). Seventeen subjects were tested twice. Two-, three- and four- dimensional ultrasound recorded cough, huff, muscle morphology and PFM contraction, respectively. Analyses were conducted offline. Measurements of levator hiatal dimensions demonstrated ICC values of 0.61, 0.72, 0.86 and 0.92, for anteroposterior dimension, transverse dimension, resting area and narrowing during contraction, respectively. Muscle thickness showed variable reliability. ICC values for measurement of the position of bladder neck were 0.86 and 0.82 at rest in the vertical and horizontal direction. Displacement of the bladder neck during PFM contraction, huff and cough demonstrated ICC values of 0.56, 0.59 and 0.51, respectively. Perineal ultrasound is a reliable method for measuring most of the tested parameters of morphology and function of the pelvic floor muscles.

Key words: ultrasound, reliability, test- retest, pelvic floor muscle contraction, cough, huff

Brief summary:

Perineal ultrasound is a reliable method for measuring most of the tested parameters regarding morphology and function of the pelvic floor muscles.

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INTRODUCTION

As early as in 1956 Kegel suggested that with adequate pelvic floor muscle training (PFMT) "the women learns to maintain the perineum, bladder and uterus in a higher position, the slack in the supportive muscles will be taken up, and the vagina will become longer and tighter" [1] . However, today there is scant knowledge of possible changes in morphology and function of the pelvic floor muscles (PFM) following PFMT [2]. Until recently, magnetic resonance imaging (MRI) was the only imaging method capable of assessing the levator ani in vivo [3]. Both normal anatomy [4] and levator trauma [5-8] have been shown by MRI. However, because of cost, access and contraindications (e.g. metallic implants, pregnancy) MRI has not been adopted in clinical practice [9]. In the meantime ultrasonography has developed to become a more practical alternative for pelvic floor assessment. For more than 10 years translabial or perineal two- dimensional (2D) ultrasound have been used to assess bladder neck position at rest and movement during valsalva manoeuvre and cough [10-13;13]. Three- dimensional (3D) ultrasound has the advantage of allowing multi planar imaging [9]. The term "four dimensional (4D) ultrasound" refers to real-time imaging of manoeuvres such as a PFM contraction, in any user-definable plane and this is one of the most significant advantages of this technology. In addition ultrasound has the advantage of allowing assessment in the upright position, using standard equipment.

The International Continence Society (ICS) Clinical Assessment Group recommends studies on test-retest, intra-observer variability for ultrasound measurement of the pelvic floor muscles [14]. Other suggested research areas are the relationship of ultrasound imaging to treatment outcome and bladder neck function [15]. To date there is limited data on test- retest reliability of the morphology, function and anatomical localisation of the PFM, especially regarding the positions of the pelvic organs at rest and during PFM contraction. Only few research groups have used translabial/ perineal ultrasound and reported values of test- retest data regarding biometry of the PFM, position of bladder neck at rest and bladder neck displacement during PFM contraction and cough [9;10;16;16-20]. Only two studies have used 3D ultrasound [9;20]. The authors are not aware of any studies regarding reliability on 4D ultrasound or the huff manoeuvre. Image quality may vary among 3D static volumes and 4D real time images, and there is a need for studies regarding reliability of these measurements.

Measurement of the decent of the levator plate on ultrasound during coughing is challenging as the forces developed may differ between tests. Standardization may be achieved using a peak flow meter which records peak expiration flow (PEF) during a maximal huff (fast, maximal expiration) test.

The aims of the present study were to evaluate test- retest and intra-observer repeatability of 2D, 3D and 4D ultrasound imaging of pelvic floor muscle morphology and function, including:

1. dimensions of the levator hiatus (LH)
2. cross- sectional area (Csa) of the pubovisceral muscle (thickness)
3. resting position of the bladder neck
4. bladder neck elevation and narrowing of the LH during PFM contraction
5. pelvic organ descent during coughing and “huffing”

MATERIALS AND METHOD

Design

This is a test- retest study to evaluate the intra-observer repeatability of two-, three- and four-dimensional ultrasound of pelvic floor muscle anatomy and function. There were two test series performed with an interval on 7 to 35 days. The assessor was blinded to the results of test 1 during test 2.

Subjects

A convenient sample of 17 healthy female volunteers was recruited for the study. Inclusion criterion was ability to contract the pelvic floor muscles. Correct contraction was defined as inward lift of the levator ani as assessed by ultrasound. Exclusion criterion was inability to understand instructions given in the Norwegian language. No volunteers had to be excluded. To avoid a possible effect of training/ de-training the participants were asked not to change PFMT habits between testing days. The Regional Medical Ethics Committee approved the study, and all subjects gave written informed consent to participate.

Apparatus

A GE Voluson 730 expert ultrasound system (GE Healthcare, Oslo, Norway) with 4-8 MHz curved array 3D/4D ultrasound transducer (RAB 4-8 l/obstetric) was used. The probe was covered with a condom and placed on the perineum in the sagittal plane. The field of view angle was set to its maximum of 70 º in the sagittal plane and volume angle to 85 º in the coronal plane.

Procedure

One gynaecologist (MM) performed the ultrasound examinations. A physiotherapist (IHB) gave instructions to the participants and supervised the test procedure on both days. Participants were told to void before the examination. They were not tested during their menses. All participants answered a short questionnaire regarding age, weight, height, birth history, symptoms of pelvic organ prolapse and education.

Three 3D static volumes were recorded in the lithotomy position while participants were resting. Automatic image acquisition took about 3 seconds each. Subsequently the participants were asked to stand upright with their legs slightly abducted. In this position the participants were asked to perform a maximum voluntary contraction of the PFM, a cough and a huff. The PEF values were obtained with a peak flow meter (GlaxoSmithKline AS, Oslo, Norway) during a huff (Fig 1). Participants were encouraged to reach the same PEF value at test 2. Each of the three tests (PFM contraction, cough and huff) was performed and recorded at least three times. A PFM contraction took approximately 10 seconds to perform and was recorded using 4D real time ultrasound. Cough and huff were recorded as 2D cine loops and each test took less than one second. The reason for choosing 2D cine loops in the cough and huff was the need for a higher temporal resolution (76 Hz) which could not be achieved from the 4D real time volumes.

Ultrasound analyses

Analyses of 2D, 3D, and 4D ultrasound volumes and cine loops were conducted offline on a laptop by one investigator (IHB), using the software “4D View v 5.0” (GE Healthcare, Oslo, Norway), blinded to clinical data. Each of the three manoeuvres (PFM contraction, cough and huff) was recorded three times and the best of the three records was analysed three times. The best PFM contraction was defined as the one with the most cranial displacement, and the best cough and huff was defined as the one with most caudal displacement. Like Armstrong et al.

[19] some modifications of the method were implemented to improve repeatability. In order to detect the bony borders of the SP, structures were observed closely during PFM contraction, cough and huff. Connective, clitoral and adipose tissue moves during the manoeuvre, while the bone remains immobile. All volumes and images were previewed and excluded from analysis unless a significant portion of the pubovisceral muscle was visible in the axial plane and more than 50% of the SP was visible in the sagittal plane when measuring according to the method of Schaer et al. [10]. Approximate 6% of the 3D volumes and 35% of the 2D cine loops were excluded. None of the 4D real time volumes were excluded.

Dimensions of the levator hiatus

The levator hiatus was defined and measured as the area bordered by the pubovisceral muscle, symphysis pubis (SP) and inferior pubic ramus in the axial plane of minimal hiatal dimensions. Analyses were conducted from 3D static images recorded in the lithotomy position. Area of LH was additionally obtained using 4D volumes in standing position. The anterior/posterior diameter (LHap) and the diameter from right to left (LHrl) were measured (Fig 2; a, b). The plane of minimal hiatal dimensions was identified as the minimal distance between the hyperechogenic posterior aspect of the SP and the hyperechogenic anterior border of the pubovisceral muscle, as described by Dietz et al. [9].

Cross- sectional area (Csa) of the pubovisceral muscle

The Csa of the pubovisceral muscle were analysed from the 3D static volumes recorded with the woman in lithotomy position. Six measurements of Csa were analysed in the axial plane. In the plane of minimal hiatal dimensions the thickness was measured lateral to the vagina on the right and left side perpendicular to the presumed LA fibre direction (Fig 2; c). The thickness was also measured posterolateral to the vagina and rectum in the plane of maximal pubovisceral thickness (4 measurements), as described by Dietz et al.[9].

Bladder neck position at rest

2D cine loops were recorded in the standing position, and the position of the bladder neck was quantified by locating the urethrovesical junction (bladder neck) on a rectangular coordinate system in the mid-sagittal plane (Fig 3). The x-axis is defined as the central axis of the SP, and the y-axis is placed perpendicular to this at the dorsocaudal margin of the symphysis pubis, as described by Schaer et al. [10].

PFM contraction

PFM contractions were recorded in the standing position with 4D real time volumes. At rest and on maximum contraction the position of the urethral meatus (middle of the bladder neck) was identified in the mid-sagittal plane relative to a horizontal reference line to the screen image, at the level of the inferoposterior margin of the SP, as described by Dietz et al. [21]. During the contraction the displacement of the bladder neck was measured as the hypotenuse of a right-angled triangle (Disp = square root ($\Delta x^2+\Delta y^2$)). The levator plate angle was measured and defined as the angle between two lines, one line from the inferoposterior margin of the SP to the anorectal angle, the other being the previously described horizontal reference line. The anorectal angle is formed by the pubovisceral muscle and can be seen in the sagittal images as the junction between the rectum and anal canal. Only a minor part of the SP was scanned in order be able to include the back sling of the pubovisceral muscle. Displacement of levator plate angle was calculated as the difference in this angle from maximum contraction to resting position. The narrowing of the LH area was measured in the axial plane of minimal hiatal dimensions as the difference between measurements at maximal contraction and at rest.

Cough and huff

The cough and huff were recorded in the standing position with 2D cine loops and analysed according to Peschers et al. [11] which expanded the method developed by Schaer et al. [10]. Dorsocaudal displacement of the bladder neck during cough and huff was evaluated from rest to maximum descent. The distance between these two positions was calculated as the hypotenuse of a right-angled triangle (Disp = square root $(\Delta x^2+\Delta y^2)$).

Statistical analysis

Statistical analysis was performed using SPSS version 13. All parameters were analysed three times, with the mean being used for test-retest analyses. Test-retest intra-tester reliability was analysed using intra-class correlation coefficient (ICC, repeated measures) with 95% confidence interval (CI), and by coefficient of variation (CV). The scale from Altman [22] was used in classification of the reliability values. ICC values under 0.20 were considered poor, 0.21- 0.40 fair, 0.41-0.60 moderate, 0.61-0.80 good, and 0.81-1.00 very good.

RESULTS

Seventeen healthy female volunteers (mean age 47.9 yrs; range 29-71, mean parity 1.8; range 0-4) were examined. Background variables are given in Table 1. The intervals between the two tests varied between 7 to 35 days (mean 15.9 days).

Dimensions of the levator hiatus

Intraclass correlation coefficient (ICC) values for the two hiatal diameters demonstrated good reliability, both in the anterior- posterior and transverse direction (Table 2). The area of the LH analysed from the 4D volumes in standing position, demonstrated better ICC value than measurements from 3D volumes in lithotomy position, 0.86 (95% CI 0.49-0.97) compared to 0.56 (95% CI 0.13-0.81), respectively.

Cross- sectional area of the pubovisceral muscle

Table 3 shows test- retest values and reliability for all six measurements of the Csa. The two ICC values of muscle thickness in the plane of minimal hiatal dimensions demonstrated less variability than the four measurements conducted in the plane of maximal muscle thickness.

Position of bladder neck at rest

The location of the bladder neck at rest was 1.26 cm (SD 0.70) on the x-axis (central axis through the symphysis pubis) and 2.23 cm (SD 0.47) on the y-axis. Test-retest values demonstrated good reliability along the x-axis (ICC: 0.73; 95% CI: 0.32-0.91) and very good reliability along the y-axis (ICC: 0.80; 95%: CI 0.47-0.94).

PFM contraction

The narrowing of the area of LH during PFM contraction demonstrated very good reliability (ICC = 0.92; 95% CI 0.68-0.98). Measurement of the bladder neck displacement in the cranio-ventral direction from rest to maximum contraction showed moderate reliability (ICC = 0.56; 95% CI 0.13-0.81). The change in the levator plate angle from rest to maximum contraction also showed moderate reliability (ICC = 0.46; 95% CI 0-0.86).

Cough and huff

Bladder neck displacement was 1.33 cm (95% CI: 1.17-1.49) during cough and 1.23 cm (95% CI: 0.94-1.53) during huff, in a caudo-dorsal direction and did not differ significantly. Both tests demonstrated moderate reliability (ICC Cough: 0.59; 95% CI 0.08-0.86 vs ICC Huff: 0.51; 95% CI: 0-0.84) (Table 4). Good to very good reliability of the position at maximal cough and huff was established for the x-axis and y-axis.

DISCUSSION

The present study demonstrated good to very good reliability of all measurements of the size of LH at rest and narrowing during contraction. Measurements of Csa of the pubovisceral muscle showed more variable results. The position of the bladder neck at rest, cough and huff demonstrated good to very good reliability. During PFM contraction the displacement of the bladder neck and levator plate showed moderate reliability. Finally, measurement of bladder neck mobility during huff and cough were moderately repeatable.

Thomas et al. [23] emphasize four different sources of measurement errors: the subject, the testing, the scoring and the instrumentation. To reduce measurements error we tried to standardize the position of the pelvic girdle, the transducer position, applied pressure of the transducer against the perineum, bladder volume, instructions given to the participants, room temperature and the whole testing procedure. Errors in scoring relate to the competence, experience and dedication to the scorers as well to the nature of scoring itself [23]. Like Armstrong et al. [19] we have encountered the same four inherent sources of variance when drawing out the reference line trough the SP, according to the method of Schaer et al. [10]. Variance in drawing the x-axis often can come from asymmetric pubic bone, and often only the proximal half of the bone is visible on the scan. Additionally the shape of the bone may vary from picture to picture in the cine loop and the connective tissue can obscure the tip of the bone. To ensure external validity, different age groups and subjects with different parities and hormonal status were included in the present study.

There is a need for methodological and mechanical studies regarding ultrasound of PFM morphology and function [14;15]. Studies reporting values of test- retest data have shown that the reproducibility is high for measuring bladder neck position, displacement of the bladder neck and dimensions of levator hiatus. Muscle thickness may seem to be the most difficult variable to measure [9;10;16-18;20]. A voluntary PFM contraction comprises both a squeeze (narrowing of LH) [24] and a lift [18;25;26]. Hence, it is important to have reliable test methods to evaluate both dimensions of the contraction.

The present study demonstrates that both the narrowing of LH and the lift can be measured reliably. Regarding the resting area of levator hiatus the present study demonstrated lower reliability coefficient using 3D static imaging in lithotomy (ICC: 0.56) compared to what Dietz et al. [9] (ICC: 0.74) and Yang et al. [9;20] (ICC: 0.63) found, nevertheless the present study showed higher reliability coefficient using 4D real times volumes in standing position (ICC: 0.86). Hence, this shows that both 3D and 4D ultrasound are reliable methods for evaluating size of levator hiatus. The mean ICC value for muscle thickness found in our study corresponds with the results of Dietz et al. [9] and Yang et al. [9;20].

In 1995 found Schaer et al. [10] good inter-observer agreement for detecting bladder neck position at rest. The present results correspond with their findings. The same measurement method was used, in this intra-observer study. Peschers et al. [16] showed an ICC value of 0.96 for measurement of bladder neck displacement during cough. Even though we applied the same reference line when analysing the cough, only moderate reliability was found for this variable.

Thompson et al. [18] achieved ICC values of 0.91 for measurement of bladder neck displacement during PFM contraction, analysed from 2D cine loops using the reference line through the SP. The present study did not achieve their good result. The main reason for this is problaby that we used different methods for quantifying bladder neck mobility. In the present study the whole pubovisceral muscle was recorded four dimensionally, implicating that a very small amount of the SP was scanned; thereby a horizontal reference was used. One of the most important advantages with 4D ultrasound imaging is that the pubovisceral muscle morphology can be identified without pre-defining axial planes. The present study confirms this by obtaining excellent reliability regarding narrowing of LH, in the axial plane, during PFM contraction. We have not been able to find other test-retest repeatability studies regarding the narrowing of LH and displacement of levator plate during contraction. One research group has investigated the inter-observer reliability of the distance between the lower end of the SP and the anorectal angle and defined it as the anterior-posterior length of the urogenital hiatus measured by 3D ultrasound [24]. They found a strong correlation between measurements of the urogenital hiatus length, obtained by the two investigators.

In the present study we have introduced a new method to standardize a rise in sub maximal abdominal pressure, and defined it as a huff manoeuvre. Our results indicate that this test may be easier to standardize than a cough. Using the PEF value to standardize the increase in abdominal pressure ensures that the woman repeats the manoeuvre with the same intensity. Conversely, the intensity of the cough may vary between test 1 and test 2. Using a huff manoeuvre may be of clinical importance in detecting changes in stiffness of the pelvic floor or automatic response of PFM before and after PFMT.

Today there is scant knowledge of possible changes in morphology and function of the PFM after strength training [2]. Several RCTs shows increased strength after PFMT [27-29]. Increased Csa (thickness) of the PFM after PFMT has been shown in one uncontrolled study [30], although Bernstein probably did not measure any component of the levator ani muscle. In another uncontrolled study, Balmforth et al. [31] showed significant elevation of the bladder neck at rest after PFMT. These studies indicate that morphological changes may occur, and we need reproducible methodologies to study such potential changes.

Based on the results of the present study we recommend to record the PFM contraction in two different ways; one scan including the back sling of the puboviseral muscle to measure narrowing of the LH and levator plate displacement, and one scan including the whole SP to measure the lift of the bladder neck. Measurements of the Csa of the puboviseral muscle showed variable results. Nevertheless, we obtained moderate reliability when thickness was measured in the axial plane of minimal hiatal dimensions, and we therefore recommend this measurement site.

CONCLUSIONS

Good to very good intra-rater repeatability was obtained for measuring levator hiatal dimensions at rest and during PFM contraction, the position of the bladder neck at rest and at maximal contraction, and two of the measurements of muscle thickness. During PFM contraction both displacement of the levator plate and bladder neck showed moderate reliability. Measurement of bladder neck displacement during a huff manoeuvre is a method that may be helpful in standardising intra-abdominal pressure. Two- three- and four-dimensional perineal ultrasound may therefore be used to detect changes in pelvic floor muscle morphology and function following pelvic floor muscle training.

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Table 1. Background variables. Means with 95% confidence interval (CI) unless stated otherwise. N=17.

Age (years)	47.9 (range 29-71)
Body mass index (kg/m^2)	22.8 (20.7-24.9)
Parity	1.8 (range 0-4)
Highest birth weight (g)	3849 (3637- 4580)
Remembered duration 2. stage (min)	45 (28-61.3)
Forceps deliveries	1/30
Vacuum deliveries	0/30
Cesarean section	1/30
Pre menopausal (n)	8/17
No symptoms of POP	15/17
College/ university	11/17
Strenuous physical work	9/17

Table 2. Test- retest analyses for dimensions of levator hiatus (LH) at rest. Mean with 95% confidence interval (CI) are chosen. Intraclass correlation coefficient (ICC) with 95% CI and coefficient of variation (CV), N=17.

	Test 1 (cm)	Test 2 (cm)	ICC	CV (%)	Assessment mode	Position
LHap	6.04 (5.75-6.33)	6.16 (5.86-6.45)	0.61 (0.21-0.84)	5.8	3D static	Lithotomy
LHrl	4.61 (4.34-4.86)	4.46 (4.20-4.73)	0.72 (0.39-0.88)	5.7	3D static	Lithotomy
LHarea (cm^2)	19.08 (17.78-20.38)	19.13 (17.89-20.37)	0.56 (0.13-0.81)	8.8	3D static	Lithotomy
LHarea (cm^2)	19.74 (16.81-22.67)	20.46 (17.49-23.42)	0.86 (0.49-0.97)	7.1	4D real time	Standing

LH= Levator hiatus, ap= anterior –posterior diameter, rl= right- left transverse diameter
N= number of women

Table 3. Test- retest analyses for cross- sectional area (Csa) of the pubovisceral muscle at rest. Mean with 95% confidence interval (CI) are chosen. Intraclass correlation coefficient (ICC) with 95% CI and coefficient of variation (CV), N=17.

	Test 1 (cm)	Test 2 (cm)	ICC	CV (%)	Plane
CsaL	0.85 (0.73-0.96)	0.96 (0.75-1.18)	0.61 (0.21-0.84)	22.5	minLH
CsaR	0.91 (0.77-1.04) (n=16)	0.98 (0.80-1.17) (n=15)	0.56 (0.11-0.83) (n=15)	20.9	minLH
CsaLv	0.85 (0.75-0.94)	0.89 (0.79-0.99)	0.70 (0.36-0.88)	11.8	maxCsa
CsaRv	0.88 (0.81-0.96) (n=16)	0.92 (0.81-1.04) (n=16)	0.37 (0-0.73) (n=15)	16.5	maxCsa
CsaLr	0.80 (0.74-0.85)	0.83 (0.76-0.89)	0.59 (0.18-0.83)	8.9	maxCsa
CsaRr (n=16)	0.84 (0.79-0.90)	0.90 (0.84-0.97)	0.13 (0-0.56)	12.3	maxCsa

Csa= cross- sectional area (thickness), L= left, R= right, v= assessed lateral of vagina, r= assessed lateral of rectum, minLH= plane of minimal hiatal dimensions, maxCsa= plane of maximum muscle thickness

Table 4. Test – retest analysis of bladder neck movement and position at maximal descent during cough and huff, analysed from 2D cine loops using a reference line through the SP. Mean with 95% confidence interval (CI) are chosen. Intra class correlation coefficient (ICC) with 95% CI.

	Test 1 (cm)	Test 2 (cm)	ICC
BnXcough	1.78 (1.44-2.12)	1.61 (1.26-1.96)	0.67 (0.16-0.90)
BnYcough	1.01 (0.59-1.42)	1.00 (0.65-1.35)	0.79 (0.38-0.94)
BnDispcough	1.35 (1.01-1.63)	1.32 (1.13-1.51)	0.51 (0-0.84)
BnXhuff	1.66 (1.25-2.07)	1.63 (1.27-1.99)	0.88 (0.59-0.95)
BnYhuff	1.14 (0.70-1.58)	1.14 (0.72-1.587)	0.74 (0.34-0.92)
BnDisphuff	1.23 (0.94-1.53)	1.22 (0.95-1.49)	0.59 (0.08-0.86)

Bn= bladder neck, X= values on the x-axis (central axis of symphysis pubis), Y= values on y-axis, Disp= caudo- dorsal displacement during cough and huff

Legends to figures

Figure 1: Recording of a “huff”.

Figure 2: Axial plane of minimal dimensions of levator hiatus (LH). Measurement a= LHap (anterior –posterior diameter). Measurement b= LHrl (right- left transverse diameter). Measurement c = Csa (thickness, assessed lateral of vagina)

Figure 3: Mid-sagittal plane quantified the bladder neck position at rest. The x-axis goes through the central axis of the SP and a y-axis perpendicular to this at the proximal and distal tip of the bone.