TEST-RETEST RELIABILITY OF PELVIC FLOOR MUSCLE CONTRACTION MEASURED BY 4D ULTRASOUND

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INTRODUCTION

A correct pelvic floor muscle (PFM) contraction was described by Kegel (1) as an inward lift and squeeze around urethra, vagina and rectum. In addition, DeLancey (2;3) suggested that a PFM contraction may press the urethra against the pubic symphysis (PS), further mechanically increasing urethral pressure. Traditionally PFM function and strength have been assessed by visual observation, digital palpation and use of different manometers and dynamometers (4). None of these measurement methods are capable of simultaneously measuring both the lifting and squeezing function in a responsive, reliable and valid way. Neither can any of these methods measure muscle morphology. Today imaging techniques such as ultrasound and magnetic resonance imaging have the potential of yielding more detailed information about muscle morphology and action during PFM contraction. 3D and 4D ultrasound allow multi planar imaging, assessment in an upright body position and utilizing a rapid sampling time. In addition, there are few contraindications and it may, due to relatively low cost, therefore be adopted into future clinical practice (5). To date, mainly the lift of the bladder neck (BN) has been investigated (6;7). To our knowledge only one study has quantified pubovisceral muscle length reduction (8), and no studies have quantified narrowing of levator hiatus (LH) area and transverse distance during contraction. Position of cervix uteri, rectal ampulla or back sling of the puborectal muscle has not been assessed, neither has the magnitude nor the direction of the displacement of these organs during PFM contraction.

The aims of the present study were to evaluate test-retest measurements of functional aspects of PFM contraction using 4D real time ultrasound by:

1. Measuring puboviscеral muscle length, LH area, antero-posterior and transverse dimensions at rest and maximal contraction (axial plane)
2. Measuring lift (displacement) of the BN, cervix uteri, rectal ampulla and back sling of the puborectal muscle (sagittal plane)

MATERIALS AND METHODS

The study was designed as a test-retest intra-tester study. Two test series were performed with an interval of 7 to 35 days. The participants received a random identification number. The assessor was blinded to the results of test 1 during test 2.

Subjects

Seventeen female volunteers were recruited for the study. Inclusion criterion was ability to contract the PFMs. Correct contraction was defined as inward lift of the PFM as assessed by ultrasound. Exclusion criterion was inability to understand instructions given in the Norwegian language. No volunteers had to be excluded. The study was approved by the Regional Medical Ethics Committee, and the Data Inspectorate of Norway. 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 field of view angle was set to its maximum of 70 º in the sagittal plane and volume acquisition angle to 85 º in the coronal plane (frame rate was 3 Hz).

Procedure

Prior to the ultrasound examination all participants answered a short questionnaire regarding age, weight, height, birth history, symptoms of pelvic organ prolapse and education. Pelvic organ prolapse quantification (POPQ was not performed in this study. One gynaecologist (MM) performed the ultrasound examinations. A physical therapist (IHB) gave instructions to the participants and supervised the test procedure on both days. Participants were instructed to void before the examination. The PFM contraction was performed in the standing position and recorded at least three times. It took approximately 10 seconds to perform and was recorded using 4D real time ultrasound. The ultrasound transducer was placed on the perineum in the sagittal plane directed cranially. Only a minor part of the PS was scanned in order to include the back sling of the puborectal muscle.

Ultrasound analyses

Analyses of 4D real time volumes 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. The PFM contraction with the most cranial displacement was analysed. All volumes were previewed and excluded from analysis unless a significant portion of the pubovisceral muscle was visible.

Analyses in the axial plane

Measurements were performed in the axial plane of minimal hiatal dimensions (Fig 1), going from the inferio-posterior margin of the PS to the anorectal junction, as described by Dietz el al.(5). Measurements were done at rest and at maximal contraction. At contraction the inclination of the axial plane increases because the anorectal junction elevates. The back sling of the puborectal muscle forms a “bump” posterior to the rectum in the mid-sagittal plane (9), which forms the anorectal junction. In order to ensure that the minimal hiatal dimensions were found, the marker dot was placed at the inferio-posterior margin of the PS and the sagittal plane was rotated, whereas the axial plane was carefully observed until the whole pubovisceral muscle was visualised and the LH had its minimum antero-posterior distance. The area of LH is bordered by the pubovisceral muscle, PS and inferior pubic ramus (Fig 1). The transverse distance was measured at the widest part of LH. The length of the pubovisceral muscle was measured as the inner border of the muscle sling, from the right to the left inferior pubic ramus around the rectum (contractile elements only).

Analyses in the sagittal plane

At rest and on maximum contraction the position of the BN (internal urethral meatus) was identified in all three planes. The rectal ampulla has a “valley” shape, and was mainly identified in the mid-sagittal plane. It was necessary to view the sagittal planes lateral to the mid-sagittal to ensure that the lowest part of the rectal ampulla was identified. In addition, the axial plane was carefully observed to ensure that the rectal ampulla was located in the rectum (Fig II), as it can be misinterpreted as the cervix uteri located in the vagina. Cervix uteri has a “wide W” shape that can be visualised on high quality ultrasound images (Fig III). It was identified simultaneously in at least the sagittal and coronal planes. In order to detect cervixes that are not centred, sagittal planes lateral to the mid-sagittal plane were viewed. The back sling of the puborectal muscle was identified viewing the sagittal and axial planes simultaneously. The movement of the urethra against the PS was quantified by a horizontal distance drawn from the infero-posterior margin of the PS to the mid urethra.

Positions of all the structures in the sagittal plane were analysed using two different systems. The position of the structures were analysed in a horizontal (x-axis) and vertical position (y-axis) relative to a horizontal reference line, at the level of the inferio-posterior margin of the PS, as described by Dietz et al. (10) (Fig III). The levator plate angle was defined as the angle between the horizontal reference line and the line from the inferio-posterior margin of the PS to the anorectal angle. In addition, displacement of the structures was assessed with an on-screen vector-based method described by Reddy et al. (11). This system provides information about the magnitude of the displacement, not about direction of the lift.

Statistical analysis

Statistical analysis was performed using SPSS version 15. Test-retest intra-tester reliability was analysed using intra-class correlation coefficient (ICC, repeated measures) with 95% confidence interval (CI). 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 are given as mean values with 95% CI for test 1 values. Wilcoxon nonparametric test was used to test the hypothesis that the two variables have the same distribution, analysed from test 1. P values <0.05 were considered significant. We were not able to find any studies measuring constriction of levator hiatus during voluntary muscle contraction. In line with other published reliability studies in this area we included between 15 – 20 participants (n=17). An a-posteriori power calculation using observed standard deviations from a former study (12) was preformed. With 80 % power and 5 % significance level, a least detectable change of 1.49 cm^2 for the levator area constriction and 0,92 cm^2 for muscle shortening was found.

RESULTS

The mean age of the participants was 47.9 yrs (range 29-71), mean number of births 1.8 (range 0-4) and body mass index 22.8 kg/m^2 (95%CI =20.7-24.9). One participant had undergone a forceps delivery, and another a caesarean delivery. Two (11.7 %) of the women reported that they sometimes experienced minor bulging of the rectum. Eight women were pre-menopausal. Eleven had college/university education and nine experienced strenuous physical work. The interval between the tests was 15.9 days (range 7-35).

Measurements in the axial plane

ICC values and measurements of the hiatal dimensions in the axial plane are given in Table 1. Very good reliability vas found for measurements of narrowing of LH area during contraction, LH area and transverse distance at rest and antero-posterior distance at maximum contraction. Shortening of the antero-posterior, transverse distance and pubovisceral muscle length demonstrated good reliability, as did the measurement of the antero-posterior distance and muscle length at rest and area of LH at maximum contraction. Reduction in LH transverse distance and muscle length shortening from rest to contraction showed poor and fair reliability, respectively.

The LH area at rest measured 19.7 cm^2 (95% CI=16.8-22.7). During maximum contraction the whole area was reduced by 25% (95% CI=18-32) to 14.70 cm^2 (95% CI=12.82-16.58). The LH antero-posterior distance shortened 22%, from 5.9 cm (95% CI=5.5-6.3) to 4.6 cm (95% CI=4.2-5.1). The transverse distance of LH shortened 6 % (95% CI=3-10). The length of the pubovisceral muscle (contractile elements only) was 12.5 cm (95% CI=11.1-13.8) at rest, and shortened 21% (95% CI=15-26) to 9.70 cm (95% CI=8.73-10.67) during contraction.

Measurements in the sagittal plane

Test-retest values from measurements in the sagittal plane (Table 2) showed good and very good reliability, using the method of Reddy et al. (11), and showed more variable results using the method of Dietz al. (10). The position of the cervix uteri was only detected in three pairs of 17 volumes, and therefore was not analyzed.

The distance from the mid urethra to the PS was 1.1 cm (95% CI= 1,0-1.2) at rest, and the distance shortened significantly by 1.1mm (95% CI= 0.1-2.2) during contraction (p=0.03). Quantifying of the lift and direction of the displacement for BN, rectal ampulla and back sling of the puborectal muscle are presented in Table 2. During PFM contraction the BN demonstrated a displacement of 1.1 cm (95% CI=0.8-1.4), whereas the back sling of the muscle moved 2.0 cm (95% CI=1.6-2.4), rectal ampulla moved 2.0 cm (95% CI=1.5-2.6) and cervix uteri moved 1.5 cm (95% CI= -0.85-3.88). All the pelvic organs moved in a cranio-anterior direction. The rectal ampulla and back sling of the muscle moved significantly more than the BN (p=0.004, 0.002, respectively). During PFM contraction the BN moved 2.8 (95% CI =1.4-4.2) times more in the cranial direction than the anterior direction (p= 0.002). Rectal ampulla moved 2.0 (95% CI =1.2-5.2) times, and the back sling of the muscle moved 2.7 (95% CI =1.53-3.8) times as much in the cranial compared to the anterior direction (p= 0.002 and 0.001, respectively).

The antero-posterior distance of LH can be measured both in the axial and sagittal plane (Fig II and III). In the sagittal plane, this distance was 5.7 cm (95% CI=5.2-6.1) at rest, and during contraction it shortened 19% (95% CI=14-24). The total muscle length shortening was 1.5 (95% CI=0.5-2.4) times greater than the shortening of antero-posterior distance of LH. The increase in levator plate angle during contraction was 13 degrees (95% CI= 7-18).

DISCUSSION

In the axial plane of minimal hiatal dimensions the reliability was good to very good for LH area, LH antero-posterior dimension, LH transverse dimension, pubovisceral muscle length and LH narrowing. Reduction of LH transverse distance and shortening of muscle length showed poor and fair reliability, respectively. During a PFM contraction the LH area was reduced by 25%. This reduction occurred mainly as a result of shortening of the antero-posterior distance. The pubovisceral muscle length shortened 21 %. In the mid sagittal plane the displacement of BN, rectal ampulla and back sling of the poborectal muscle measured with on-screen vector assessment demonstrated good reliability. The pelvic organs moved twice as much, or more, in the cranial direction compared to the anterior direction. During PFM contraction the back sling of the muscle rotated 13 degrees upwards around the PS, like a windscreen wiper. This means that the organs positioned at the furthest distance from the PS (back sling of the muscle and rectal ampulla) moved more than the BN, which is positioned closer to the PS. Additionally the circle reduces its diameter during contraction by approximately 20% (LH antero-posteror distance).

Our results regarding reliability of BN displacement correspond with the reliability values of Reddy et al. (11),using the same measurement system. Since the present study is a test-retest reliability study it does not seek to demonstrate correlation with clinical symptoms or specific patient populations. The reliability coefficient for the resting area of LH demonstrated higher values (ICC: 0.86) compared to those found by Dietz et al. (5) (ICC: 0.74) and Yang et al. (13) (ICC: 0.63). The values for BN displacement during contraction found by Bo et al.(14), Dietz (15), and our values are higher than those found by other research groups (6;10;11). The differences may be due to different populations.

Searches on PubMed database did not reveal any studies regarding pubovisceral muscle length, muscle length reduction, narrowing of LH area and transverse distances, nor elevation of cervix uteri, rectal ampulla or back sling of the muscle during PFM contraction. The current lack of evidence for lift of the posterior compartments of the pelvic floor may be due to image techniques. When using ultrasound to measure the position and movement of the back sling of the muscle - the rectal ampulla and the cervix uteri - the method developed by Schaer et al. (16) cannot be used, since the whole PS is not totally scanned. To date, there are two possible ultrasound techniques than can be used for this purpose, both relatively independent of the position of the PS (11;17).

We suggest that a possible way to evaluate the function of the puborectal muscle is to analyse muscle length shortening in the axial plane. An indirect reduction of muscle length shortening can be analysed in the sagittal plane (LH antero-posterior distance), using standard 2D ultrasound. The LH antero-posterior shortening will increase the tension in the anococcygeal ligament, and this can result in an anterior rotation of the coccygeal bone, as demonstrated with MRI by Bo et al. (18). The puborectal muscle thereby can lift, in addition to the main squeeze function. The lift of the pelvic organs mainly occurs due to shortening of the cranial orientation of the pubovaginal, puboperineal and puboanal muscles (19;20). The iliococcygeal muscle elevates the central region of the posterior pelvic floor, hence it will not provide much lift to the cervix uteri or BN (21). The relationship between the strength of the PFM and the degree of LH narrowing and lift of the pelvic organs remains to be further elucidated.

A limitation of the present study can be the selection and number of participants. This study was not designed to define values for the normal population, but rather to evaluate test-retest reliability for measurements of the action of the levator ani muscles and pelvic organ motions during PFM contraction. The present study demonstrates that not only the BN, but also the posterior compartment of the pelvic floor can be investigated and located using 4D ultrasound.

While the measurable data most often showed acceptable reliability, one can question the reliability due to the high technical failure rate for measurements of the rectal ampulla and back sling of the puborectal muscle. The cervix uteri was identified in only three out of 17 records, and was therefore the most difficult organ to identify. When analysing the volumes we realised that if the transducer had been placed further posteriorly, less of the PS and more of the posterior compartments would have been scanned. Another explanation for the relatively high technical failure rate for some measurements can be difference in morphology among women. The larger size of the LH the harder it is to capture both the anterior and posterior compartments with a perineal transducer. Data should not be extrapolated to women with pelvic floor dysfunction, since it is likely that these women may have greater variability in anatomy and biomechanics.

Several randomized controlled trials (RCTs) and systematic reviews have shown that pelvic floor muscle training (PFMT) is effective in treatment of stress and mixed urinary incontinence in women (22;23). However, to date there is scant knowledge whether the exercises affect muscle morphology (24). Possible long term effects of PFMT may be narrowing of the LH, increased cross sectional area, elevated position of the pelvic organs at rest and increased stiffness of the muscles and connective tissue. To test these hypotheses reliable measurements are needed. Randomized controlled trials using these measurements are under way.

CONCLUSIONS

4D ultrasound is capable of reliably measuring muscle length, narrowing of LH area, reduction of LH antero-posterior dimension and lift of BN, rectal ampulla and back sling of the puborectal muscle. Hence it is possible to use ultrasound to increase the knowledge about long term mechanisms of cure and improvement of the outcomes of PFMT. During contraction the LH area narrowed 25% and the muscle length shortened 21%. In addition the back sling of the muscle and the rectal ampulla moved more than the BN and the displacement of the pelvic organs were two times, or more, greater in the cranial versus anterior direction.

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Legends to figures

Figure I: Measurements in the axial plane of minimal hiatal dimensions. Levator hiatus area (LH area) is marked with lines. LH ap= levator hiatus; antero-posterior diameter. LH rl= Levator hiatus; transverse diameter right-left. PS= pubic symphysis.

Figure II: Identifying rectal ampulla simultaneously in the sagittal, coronal and axial plane. The marker dot is marked as a star. The axial plane can be viewed to ensure that the rectal ampulla is located in the rectum (arrow).

Figure III: Identifying and measuring the back sling of the puborectal muscle (PRB), levator hiatus antero-posterior distances (LH ap), levator plate angel (LPA), rectal ampulla (RA), cervix uteri (CU), bladder neck (BN, internal urethral meatus) in the mid-sagittal plane.

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Table 1. Test-retest analyses for measurement in the axial plane during pelvic floor contraction. Mean values with 95% confidence interval (CI) and ICC with 95% CI are shown.

	Test 1	Test 2	ICC	Technical failure rate
LH area rest (cm^2)	19.74 (16.81-22.67) (n=11)	20.46 (17.49-23.42) (n=13)	0.86 (0.49-0.97) (n=8)	29% (10/34)
LH area contraction (cm^2)	14.70 (12.82-16.58) (n=17)	15.24 (12.78-17.69) (n=15)	0.79 (0.50-0.92) (n=15)	6% (2/34)
LH area narrowing (%)	24.91 (18.13-31.70) (n=11)	28.66 (20.71-36.59) (n=13)	0.92 (0.68-0.98) (n=8)	
LH ap rest (cm)	5.87 (5.45-6.27) (n=15)	6.10 (5.62-6.59) (n=13)	0.70 (0.23-0.91) (n=11)	18% (6/34)
LH ap contraction (cm)	4.58 (4.20-4.96) (n=16)	4.64 (4.21-5.07) (n=16)	0.92 (0.78-0.97) (n=15)	6% (2/34)
LH ap reduction (%)	21.14 (17.00-25.28) (n=15)	26.97 (19.97-33.96) (n=13)	0.63 (0.09-0.89) (n=11)	
LH rl rest (cm)	4.25 (3.78-4.72) (n=16)	4.36 (3.95-4.76) (n=17)	0.82 (0.57-0.93) (n=16)	3% (1/34)
LH rl contraction (cm)	3.97 (3.54-4.39) (n=16)	4.19 (3.77-4.70) (n=17)	0.73 (0.39-0.90) (n=16)	3% (1/34)
LH rl reduction (%)	6.34 (2.94-9.74) (n=16)	4.05 (1.22-6.89) (n=17)	0 (0-0.34) (n=16)	
Muscle length rest (cm)	12.45 (11.12-13.79) (n=15)	12.85 (11.52-14.18) (n=14)	0.76 (0.37-0.92) (n=12)	15% (5/34)
Muscle length contraction (cm)	9.70 (8.73-10.67) (n=16)	9.57 (8.54-10.60) (n=16)	0.79 (0.50-0.93) (n=15)	6% (2/34)
Muscle length shortening (%)	20.62 (15.29-25.95) (n=15)	27.41 (21.59-33.23) (n=14)	0.40 (0-0.78) (n=12)	

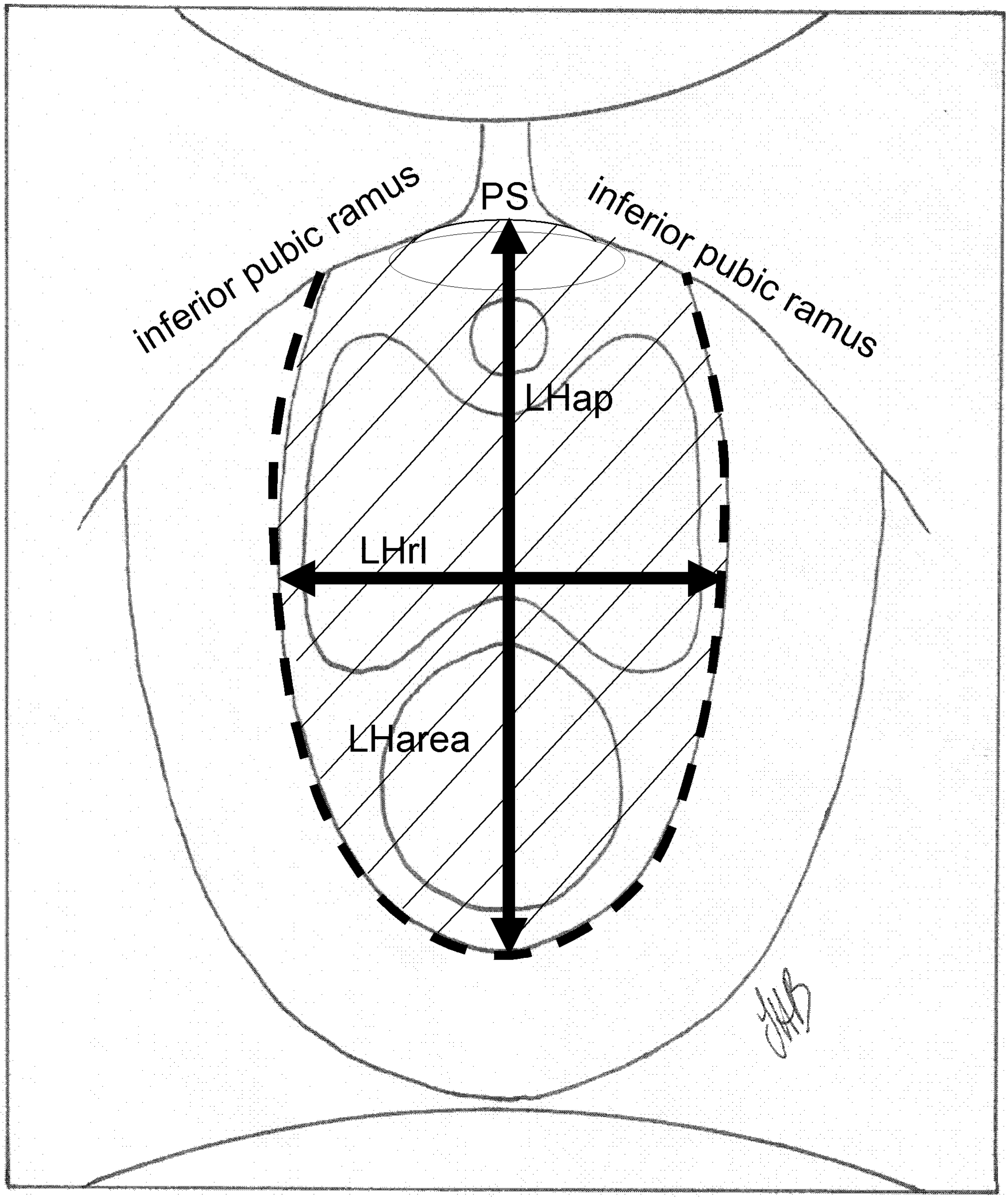
LH= Levator hiatus, ap= antero-posterior distance, rl= right-left transverse distance.

Table 2. Test-retest analyses for displacement of the pelvic organs in the sagittal plane during pelvic floor contraction. The on screen vector method developed by Reddy et al (11) are being compared the method with a horizontal reference line developed by Dietz et al. (10). Mean with 95% confidence interval (CI) are chosen.

	On screen vector				Horizontal reference line			
	Test 1 (cm)	Test 2 (cm)	ICC	Technical failure rate	Test 1 (cm)	Test 2 (cm)	ICC	Technical failure rate
BN	1.13 (0.83-1.43) (n=16)	1.17 (0.92-1.41) (n=17)	0.81 (0.54-0.93) (n=16)	3% (1/34)	1.01 (0.73-1.30) (n=17)	1.01 (0.81-1.20) (n=17)	0.56 (0.13-0.81) (n=17)	
BN Anterior direction					0.90 (0.61-1.19) (n=17)	0.78 (0.56-1.00) (n=17)	0.61 (0.20-0.84) (n=17)	0%
BN Cranial direction					0.34 (0.18-0.50) (n=17)	0.49 (0.30-0.68) (n=17)	0.49 (0.04-0.78) (n=17)	0%
Rectal ampulla	2.04 (1.46-2.61) (n=13)	2.09 (1.60 - 2.57) (n=12)	0.80 (0.44-0.94) (n=11)	26% (9/34)	1.96 (1.29-2.64) (n=12)	2.29 (1.72-2.86) (n=11)	0.68 (0.17-0.91) (n=10)	
Rectal ampulla Anterior direction					1.64 (0.98-2.30) (n=12)	1.52 (0.85-2.19) (n=12)	0.25 (0-0.72) (n=11)	29% (10/34)
Rectal ampulla Cranial direction					0.94 (0.54-1.33) (n=12)	0.97 (0.11-1.84) (n=11)	0.31 (0-0.77) (n=10)	32% (11/34)
Puborectalis back sling	1.98 (1.59-2.39) (n=13)	1.94 (1.32-2.56) (n=11)	0.75 (0.25-0.94) (n=9)	29% (10/34)	1.82 (1.39-2.25) (n=13)	2.13 (1.55-2.71) (n=11)	0.75 (0.26-0.94) (n=9)	
Puborectalis back sling Anterior direction					1.64 (1.23-2.05) (n=13)	1.94 (1.37-2.51) (n=11)	0.69 (0.14-0.92) (n= 9)	29% (10/34)
Puborectalis back sling Cranial direction					0.75 (0.53-0.96) (n=13)	0.78 (0.49-1.07) (n=11)	0.84 (0.47-0.96) (n=9)	29% (10/34)

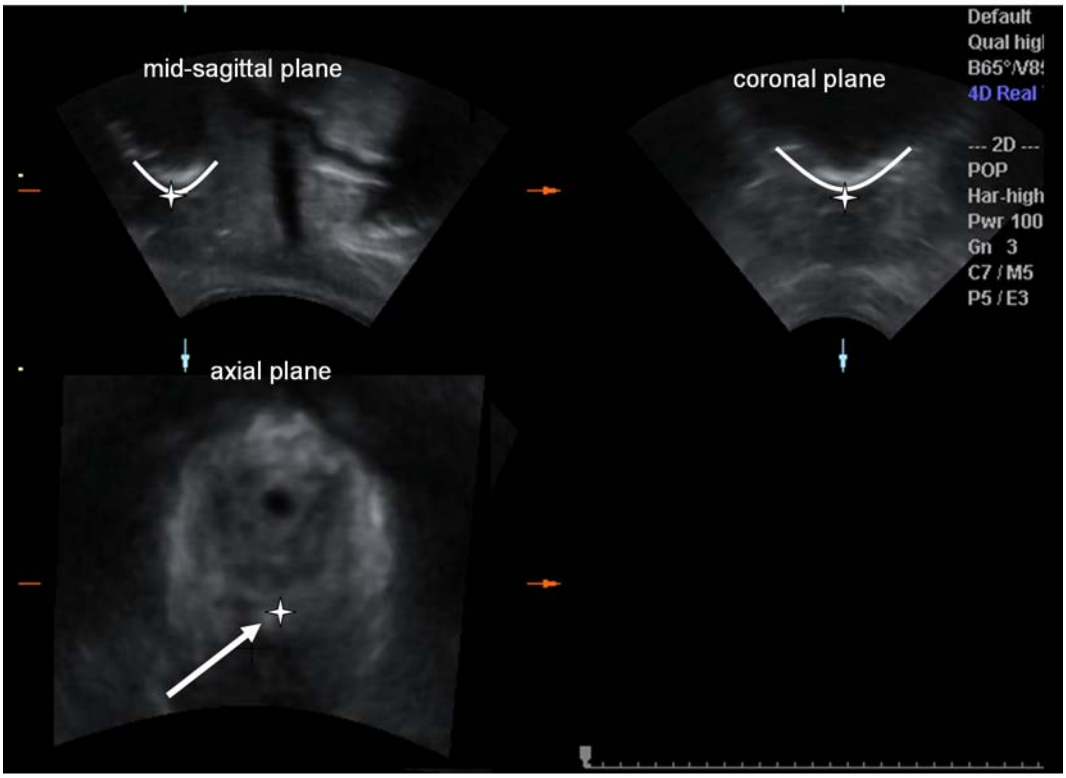
BN= Bladder Neck

Figure I



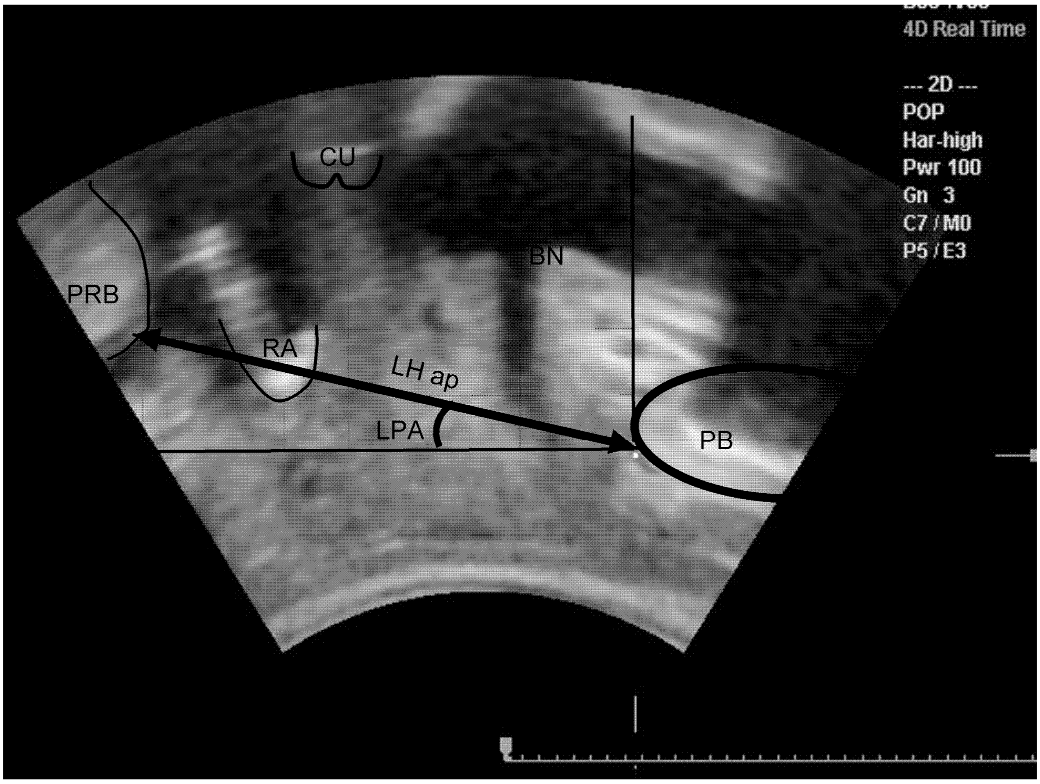
PS
inferior pubic ramus
inferior pubic ramus
LHap
LHrl
LHarea

Figure II



mid-sagittal plane
coronal plane
axial plane
Default
--- 2D ---
POP
Har-high
Pwr 100
Gn 3
C7 / M5
P5 / E3

Figure III


4D Real Time
--- 2D ---
POP
Har-high
Pwr 100
Gn 3
C7 / M0
P5 / E3
CU
BN
PRB
RA
LH ap
LPA
PB