Ultrasound Obstet Gynecol 2009; **33**: 465–471

Validation of new ultrasound parameters for quantifying pelvic floor muscle contraction

S.-H. YANG*, W.-C. HUANG†‡§, S.-Y. YANG§, E. YANG¶ and J.-M. YANG‡**

*Schools of *Nutrition and Health Sciences and ‡Medicine, Taipei Medical University, †Department of Obstetrics and Gynecology, Cathay General Hospital, §School of Medicine, Fu Jen Catholic University and **Division of Urogynecology, Department of Obstetrics and Gynecology, Mackay Memorial Hospital, Taipei, Taiwan and ¶Jacobs School of Engineering, Department of Bioengineering, UCSD, La Jolla, CA, USA*

KEYWORDS: intravaginal digital palpation; levator hiatal parameter; pelvic floor muscle contraction; polar coordinate system; stress urinary incontinence

ABSTRACT

Objective *To determine the reliability and validity of new ultrasound parameters, measured in the polar coordinate system, for quantifying pelvic floor muscle action.*

Methods *This was a prospective study, from January 2005 to December 2007, in 209 women with urodynamic stress incontinence, to validate new ultrasound parameters for quantifying pelvic floor muscle contraction. The examination of each patient included intravaginal digital palpation of voluntary pelvic floor muscle contractility and an ultrasound assessment of the positions of the bladder neck and anorectal junction at rest and during pelvic floor muscle contraction. The position of the bladder neck was expressed by bladder neck angle and bladder neck distance from the lower border of the pubic symphysis, and the position of the anorectal junction was expressed by the levator hiatal angle and sagittal hiatal diameter. The vector lengths of the motion of the bladder neck and anorectal junction during pelvic floor muscle contraction were calculated from the positions at rest and during pelvic floor muscle contraction by mathematical formulae.*

Results *There was good inter- and intraobserver reliability of measurement of ultrasound parameters on stored volumes. During pelvic floor muscle contraction, elevated bladder neck distance and shortened sagittal hiatal diameter were valid parameters representing stronger pelvic floor muscle contractility, with shortened sagittal hiatal diameter having the best correlation (*$r = -0.348$*,* $P < 0.001$*).*

Conclusion *The methods used in this study appear to be reliable for quantifying pelvic floor muscle action. The bladder neck distance with respect to the lower border of the pubic symphysis and the sagittal hiatal diameter were both valid parameters reflecting PFM contractility.*

INTRODUCTION

Functional assessment of the pelvic floor muscle (PFM) plays a crucial role in the conservative management of incontinent women, the status of PFM contractility determining whether active or passive PFM exercises should be the first step in treatment[1]. In addition, weak PFM contractility and a wide genital hiatus are predictive of surgical failure in those who have undergone concomitant reconstructive pelvic surgery[2].

PFM function can be evaluated by inspection, intravaginal digital palpation, electromyography, perineometry and imaging studies, including ultrasound and magnetic resonance imaging[3]. Digital palpation and perineometry have been regarded as the gold standards for the assessment of PFM contractility[4]. However, it is well known that subjective bias with low repeatability limits intravaginal digital palpation[5], while interference from intra-abdominal pressures limits perineometry[6]. Ultrasound has been reported as a reliable tool for quantifying PFM contractility, with the advantages of being non-invasive and easy to perform, and allowing application of biofeedback[7–9].

Degree of cranioventral movement or inward-upward displacement of pelvic structures displayed on ultrasound, whether through transperineal, translabial or transabdominal approaches, may be used to represent PFM

Correspondence to: Dr J.-M. Yang, Division of Urogynecology, Department of Obstetrics and Gynecology, Mackay Memorial Hospital, 92, Chung-Shan North Road, Section 2, Taipei, 104, Taiwan, R.O.C (e-mail: yangjm0211@hotmail.com)

Accepted: 28 October 2008

function[7–12]. Of the tested ultrasound parameters, elevation of the bladder neck has been found to have the best agreement with intravaginal digital palpation and perineometry[12]. Nevertheless, one would expect any method relying on a change in the geometry of the proximal urethra and bladder neck to be limited in those who have a pelvic organ prolapse interfering with bladder neck motion or who have undergone a surgical procedure aimed at immobilizing the bladder neck, such as a colposuspension or sling operations[6].

The aim of this study was to determine the reliability and validity of new ultrasound parameters for quantifying PFM contractility in subjects with objective evidence of stress urinary incontinence, based on the hypothesis that shortening of the sagittal hiatal diameter (SHD) is a superior measure of PFM contractility.

PATIENTS AND METHODS

From January 2005 to December 2007, women who presented at one of our urogynecology clinics with bothersome symptoms and urodynamic evidence of stress urinary incontinence were invited prospectively to enroll in a survey to validate the new ultrasound parameters, measured in the polar coordinate system, to quantify PFM contractility. Women who had a medical history of diabetes, cerebrovascular disease or overt neurological diseases, or who had previously undergone pelvic floor re-education programs, were excluded. The survey, performed by W.C.H. or J.M.Y., both experienced urogynecologists, included a site-specific analysis of pelvic organ prolapse, intravaginal digital palpation of voluntary PFM contractility and an ultrasound assessment of pelvic floor structures, both at rest and during PFM contraction. The project had been approved by the institutional review boards and informed consent was obtained from all participants. Methods, definitions and units conform to the standards recommended by the International Continence Society (ICS)[3,13], except where specifically noted.

Site-specific analysis of pelvic organ prolapse

First, to detect any pelvic support defects, a pelvic examination was conducted using a split speculum, with patients in the dorsal lithotomy position and straining maximally. The severity of pelvic organ prolapse was assessed using the ICS Pelvic Organ Prolapse Quantification (POP-Q) system and was graded from Stage 0 (no prolapse) to Stage IV[13].

Intravaginal digital palpation

The women were then asked to perform a maximal PFM contraction, with instructions to 'please draw in and lift the PFM, and hold the contraction while breathing normally'. A correct voluntary PFM contraction was confirmed by observation of a puckering and in-drawing of the vaginal introitus, anal sphincter and perineal body. During digital vaginal palpation, the strength of voluntary PFM contraction was assessed using a modified Oxford grading system[14] (0, no contraction detected; 1, flicker; 2, weak contraction; 3, normal (or moderate) contraction with slight finger lift effect (i.e. examining fingers inserted inside the vagina lifted slightly by the PFM contraction) and no resistance; 4, strong contraction with a finger lift effect and slight resistance; 5, very strong contraction with a finger lift effect and strong resistance).

Ultrasound examination

With the patient lying supine, we performed real-time ultrasound examination, via an introital approach[15,16], of the pelvic floor structures using a Voluson 730 (GE Medical Systems, Zipf, Austria) or, when the Voluson was unavailable ($n = 22$) a Toshiba SSA-260A (Toshiba Medical Systems, Tokyo, Japan) ultrasound machine, equipped with a 5.0–9.0-MHz endovaginal probe. The resting images were obtained first, then the patient was asked to contract maximally, and once this was visualized on the ultrasound screen, the images were frozen and the subject could relax again (Figure 1). Mean values were measured for three resting–contraction paired tests. The position of the bladder neck was expressed as two parameters in polar coordinates: the bladder neck angle (BNA, the angle between the bladder neck–symphyseal line and the midline of the pubic symphysis), and the bladder neck distance (BND, the distance between the bladder neck and the lower border of the pubic symphysis) (Figure 2a). The position of the anorectal junction was also expressed as two parameters in polar coordinates: the levator hiatal angle (LHA) was defined as the angle between the anorectal junction–symphyseal line and the midline of the pubic symphysis and the SHD (sagittal hiatal diameter) was defined as the distance between the anorectal junction and the lower border of the pubic symphysis (Figure 2b)[16]. The vector lengths of the motion of bladder neck and anorectal junction during PFM contraction were calculated from the positions at rest (r) and during PFM contraction (sq) by mathematic formulae:

vector length of bladder neck motion during

$$\text{PFM contraction} = \surd(\text{rBND}^2 + \text{sqBND}^2 - (2 \times \text{rBND} \times \text{sqBND} \times \cos(\text{rBNA} - \text{sqBNA})));$$

vector length of motion of anorectal junction during

$$\text{PFM contraction} = \surd(\text{rSHD}^2 + \text{sqSHD}^2 - (2 \times \text{rSHD} \times \text{sqSHD} \times \cos(\text{rLHA} - \text{sqLHA}))).$$

Volume datasets of the pelvic floor images at rest and during PFM contraction were acquired by three-dimensional ultrasound with the Voluson 730 ultrasound machine in those who could contract the PFM with

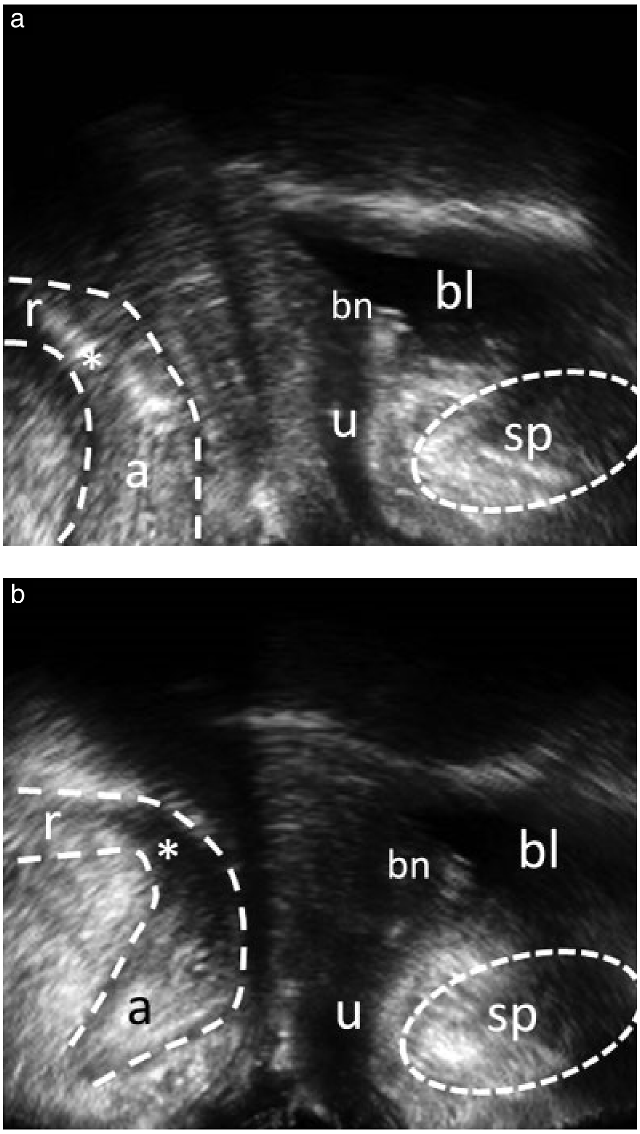

Figure 1 Ultrasound images of the pelvic floor at rest (a) and during pelvic floor muscle contraction (b). *, anorectal junction; a, anal canal; bl, bladder; bn, bladder neck; r, rectum; sp, pubic symphysis; u, urethra.

a duration of at least 3 s, for analysis of intra- and interobserver reliability.

Statistical analysis

Data are presented as mean ± SD or median (interquartile range). The 3D volume datasets of 20 subjects were randomly retrieved for analysis of inter- and intraobserver reliability. For interobserver reliability, the investigators and planes of imaging were both randomized to avoid order effects. The testers were blind to each other's results. For intraobserver reliability, ultrasonographic measurements on stored volumes were repeated, by the same observer on two occasions 1 or 2 weeks apart. The reliability of ultrasound measurements was determined by intraclass correlation coefficients and their 95% CIs as well as limits of agreement by Bland–Altman analysis[17]. The Pearson correlation test was used to determine the associations of ultrasound parameters with explainable variables. All analyses were carried out using SPSS 15.0 software (SPSS, Inc., Chicago, IL, USA), and a *P*-value <0.05 was considered statistically significant.

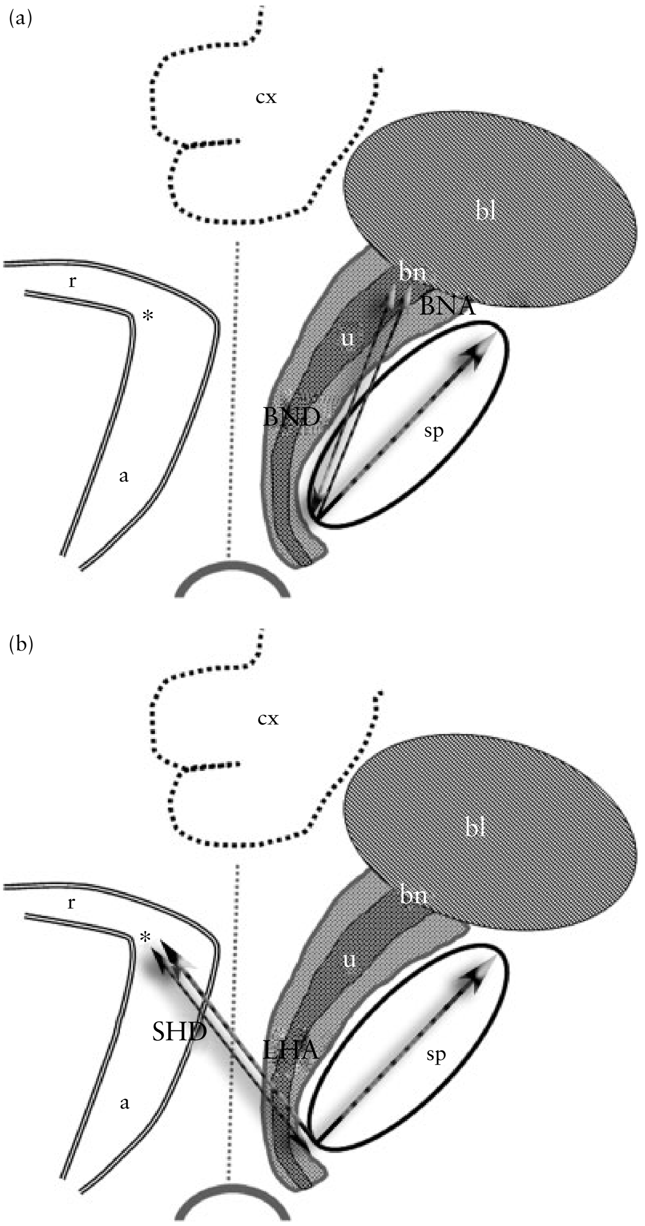

Figure 2 Measurement of the positions of the bladder neck (a) and the anorectal junction (b) in the polar coordinate system. The position of the bladder neck is expressed by the bladder neck angle (BNA) and bladder neck distance (BND). The position of the anorectal junction (*) is expressed by the levator hiatal angle (LHA) and sagittal hiatal diameter (SHD). *, anorectal junction; a, anal canal; bl, bladder; bn, bladder neck; cx, cervix; r, rectum; sp, pubic symphysis; u, urethra.

RESULTS

During the 3-year study period, 644 women who had bothersome urinary incontinence symptoms presented at the clinics. Of these, objective evidence of stress urinary incontinence (i.e. urodynamic stress incontinence) was

Table 1 Demographic and clinical data in the study group ($n = 209$)

Variable	*Value*
Demographics	
Age (years)	50.8 ± 11.9
Parity	3 (1–5)
Menopause	101 (48.3)
Body mass index (kg/m^2)	24.4 ± 3.9
Pelvic examination	
Pelvic organ prolapse by POP-Q system	
Aa (cm)	−0.6 ± 1.5
Ba (cm)	−1.3 ± 1.8
Ap (cm)	−2.1 ± 1.1
Bp (cm)	−2.3 ± 0.7
C (cm)	−4.2 ± 3.3
PFM contractility by MOG system	
Grade 0	6 (3)
Grade 1	14 (7)
Grade 2	67 (32)
Grade 3	74 (35)
Grade 4	45 (22)
Grade 5	3 (1)
Ultrasound	
Bladder neck angle at rest (°)	93 ± 24
Bladder neck distance at rest (mm)*	22.3 ± 4.8
Bladder neck angle during PFM contraction (°)	71 ± 15
Bladder neck distance during PFM contraction (mm)*	24.5 ± 5.2
Vector length of bladder neck motion during PFM contraction (mm)	3.0 ± 1.5
Levator hiatal angle at rest (°)	156 ± 78
Sagittal hiatal diameter at rest (mm)	47.8 ± 7.6
Levator hiatal angle during PFM contraction (°)	137 ± 14
Sagittal hiatal diameter during PFM contraction (mm)	41.6 ± 5.0
Vector length of anorectal junction motion during PFM contraction (mm)	15.9 ± 9.2

Values are presented as mean ± SD, median (interquartile range) or *n* (%). *Bladder neck distance is distance between bladder neck and lower border of pubic symphysis. MOG, modified Oxford grading; PFM, pelvic floor muscle; POP-Q, pelvic organ prolapse quantification system.

identified in 223 (35%), including 21 (9%) who had coexisting detrusor overactivity. Of these 223 subjects with urodynamic stress incontinence, 209 denied having any neurological diseases or previous experience with pelvic floor re-education programs. These 209 subjects were enrolled in the study; Table 1 summarizes their demographic and clinical data. Of the 209 study women, six (3%) were unable to contract their PFM during three attempts under detailed instruction and 12 (6%) performed a Valsalva maneuver instead on the first attempt but turned out to be able to contract their PFM on subsequent attempts. 3D volume datasets of the PMF at rest were obtained in all 187 women assessed with the Voluson ultrasound machine, but 3D volume datasets during PFM contraction (of at least 3 s duration) were available in only 55 women.

Table 2 Reliability of ultrasound parameters during pelvic floor muscle (PFM) contraction

Parameter	*ICC (95% CI)* *Interobserver*	*Intraobserver*
sqBNA	0.859 (0.799–0.883)	0.849 (0.775–0.879)
sqBND	0.858 (0.797–0.883)	0.859 (0.799–0.884)
sqLHA	0.827 (0.726–0.871)	0.825 (0.721–0.870)
sqSHD	0.891 (0.777–0.896)	0.886 (0.769–0.895)

ICC, intraclass correlation coefficient; sqBNA, bladder neck angle during PFM contraction; sqBND, bladder neck distance during PFM contraction; sqLHA, levator hiatal angle during PFM contraction; sqSHD, sagittal hiatal diameter during PFM contraction.

Reliability

The average intraclass correlation coefficients for interobserver reliability ranged between 0.827 and 0.891 (95% CI, 0.726–0.896), while intraobserver reliability ranged between 0.825 and 0.886 (95% CI, 0.721–0.895) (Table 2). Bland–Altman plots displaying the intraobserver bias and limits of agreement for each ultrasound parameter are presented in Figure 3.

Validity

During PFM contraction, there was a weak to modest association between LHA and BNA and between SHD and BND. Yet, the BND and SHD during PFM contraction were the only two parameters significantly correlated with PFM contraction strength ($r = 0.190$, $P = 0.013$ and $r = -0.348$, $P < 0.001$, respectively) (Table 3). The vector lengths of the motion of the bladder neck and anorectal junction during PFM contraction did not correlate with intravaginal digital palpation strength.

DISCUSSION

The methods used in this study of a sample of women with urodynamic stress incontinence, to quantify PFM contractility by measuring the positions of the bladder neck and anorectal junction in the polar coordinate system during PFM contraction, demonstrated good inter- and intraobserver reliability. Of the tested ultrasound parameters, the shortened SHD during PFM contraction had the best correlation with PFM contraction strength.

Normal PFM function is defined as the ability to perform a normal or strong voluntary contraction and to present an involuntary contraction preceding or during increased intra-abdominal pressure, resulting in a circular closing of the levator hiatus and a cranioventral or inward-upward movement of the perineum and pelvic floor structures[18]. As the gold standard for assessment of PFM action, intravaginal digital palpation evaluates not only squeeze pressure but also lift. Moreover, and most importantly, intravaginal digital palpation can palpate the components of pelvic floor dysfunction, such as muscle defects,

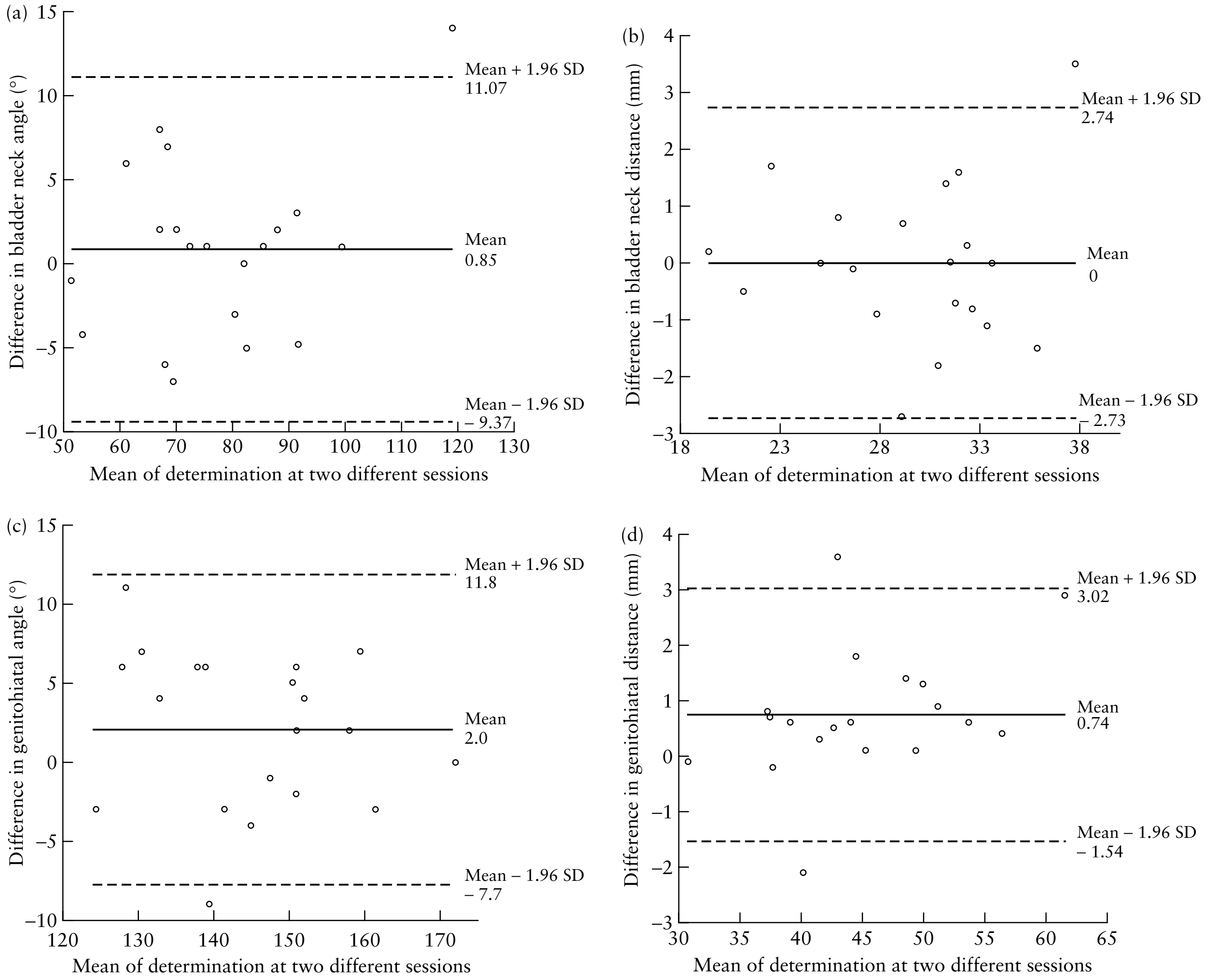

Figure 3 Bland–Altman plot: intraobserver bias and limits of agreement for bladder neck angle (a), bladder neck distance (b), levator hiatal angle (c), and sagittal hiatal diameter (d) during pelvic floor muscle contraction.

Table 3 Validation of ultrasound parameters during pelvic floor muscle (PFM) contraction along with PFM contractility

Parameter	r	P
sqBNA vs. PFM contractility*	−0.035	0.647
sqBND vs. PFM contractility	0.190	0.013
sqLHA vs. PFM contractility	−0.046	0.555
sqSHD vs. PFM contractility	−0.348	< 0.001
vectorBN vs. PFM contractility	0.121	0.125
vectorAR vs. PFM contractility	0.046	0.559

*Determined by modified Oxford grading system. sqBNA, bladder neck angle during PFM contraction; sqBND, bladder neck distance during PFM contraction; sqLHA, levator hiatal angle during PFM contraction; sqSHD, sagittal hiatal diameter during PFM contraction; vectorAR, the vector length of anorectal junction motion during PFM contraction; vectorBN, the vector length of bladder neck motion during PFM contraction.

tone or pain[19,20]. However, the inherent limitations of digital palpation, such as subjective bias and the narrow measuring scale, make scientific quantification a difficult task[5].

By determining morphological changes in the geometry of pelvic floor structures, ultrasound appears to be a promising tool for providing reliably quantitative and qualitative analyses of PFM contractility[7–12,21]. However, the correlation of ultrasound parameters with digital palpation strength varies markedly in the reports using different approaches. Transperineal ultrasound demonstrated modest correlations of ultrasound parameters (e.g. changes in urethral axis, urethral inclination and maximum displacement of the bladder neck) with intravaginal digital palpation strength during voluntary PFM contraction, with the maximum displacement of the bladder neck having best agreement[12]. Through the transabdominal approach, Sherburn *et al.*[22] found no association between the posterior bladder wall motion, either in a transverse or sagittal plane, and digital palpation strength. Using the introital approach, our present study also supported this finding. Nevertheless, Thompson *et al.*[8] demonstrated modest correlation of bladder base motion with PFM strength on transabdominal ultrasound. Morphologically, the displacement of the posterior bladder wall, bladder base or levator plate manifested on transabdominal ultrasound[8,21–23] has been found to correspond to the movement of the anorectal junction displayed on introital ultrasound.

In contrast to the complex processes involved in determining the vector length of pelvic floor structures to reflect PFM contractility[8,12,21,22], we found merely measuring SHD or BND during PFM contraction to be easier. Nevertheless, both shortened SHD and elevated BND, the two parameters significantly correlated with PFM contraction strength, had only weak to modest correlation with intravaginal digital palpation grading. Our findings differ from those of other studies, which reported higher correlations of ultrasound indices with Oxford grading[8,12]. Inherent limitations of our ultrasound methodology, suboptimal coaching for PFM contraction, or both, may account for this difference.

The PFM (or levator ani muscle) is composed of two portions, the lateral supportive iliococcygeus and the central sphincteric puborectalis and pubococcygeus (or pubovisceral muscles)[24]. As a dome-shaped muscle, voluntary PFM contraction is thought to occur in three planes: mediolateral occlusion, posteroanterior draw and cephalad displacement[22]. Cranioventral movement or inward-upward displacement of the bladder neck[12], posterior bladder wall[22], levator plate[23] or anorectal junction have been found to reflect only the lift and anterior draw, and not the squeeze, of PFM action[22]. The squeeze generated by PFM has been attributed to the contraction of the puborectalis muscle, a U-shaped muscle surrounding the levator hiatus centrally[25]. The ultrasound index of SHD during PFM contraction, representing the shortest distance between the pubic symphysis and anorectal junction, is morphologically equivalent to the route traversed by the sphincteric puborectalis muscle when it is maximally contracted[24]. This might explain the best correlation of SHD during PFM contraction with digital palpation strength when compared with the other parameters in this study. However, the fact that this correlation was modest suggested that the squeezing of the PFM, which also involves complex biophysiology, especially the action of mediolateral occlusion, was ignored by ultrasound. To date, there is neither published nor clinical evidence which suggests that there is a single tool available to fully assess PFM action.

There are several limitations of this study. First, the repeatability of our ultrasound parameters was analyzed on static volumes, obtained with a Voluson 730 ultrasound machine. Therefore, only a fraction of the total variability was assessed. Second, the relationships between our ultrasound parameters and Oxford grading were poor. Methodological limits, suboptimal coaching, and the complex biophysiology involved in PFM action may explain the low correlations. Despite these limitations, our study has demonstrated that the ultrasound indices we used are of good reliability and, most interestingly, a reduction in the anteroposterior diameter of the levator hiatus correlated best with Oxford grading. Thus, in clinical situations in which the bladder neck motion is limited or restricted by external compression or pelvic surgery, determining SHD could be a superior option for assessing PFM contractility.

In conclusion, the methods used in this study appear to be reliable for quantitative analysis of PFM action. Elevated BND with respect to the lower border of the pubic symphysis and shortened SHD were both valid parameters reflecting stronger PFM contractility.

ACKNOWLEDGMENT

This study was supported by grants from the National Science Council (research grant nos. NSC 97-2314-B-195-012-MY3 and NSC 97-2314-B-281-003-MY2), Mackay Memorial Hospital (research grant no. 9812), and Cathay General Hospital (research grant no. CT9659).

REFERENCES

1. Laycock J. Interferential therapy. In *Pelvic Floor Re-education*, Schussler B, Laycock J, Norton P, Stanton S (eds). Springer-Verlag: London, 1994; 168–169.
2. Vakili B, Zheng YT, Loesch H, Echols KT, Franco N, Chesson RR. Levator contraction strength and genital hiatus as risk factors for recurrent pelvic organ prolapse. *Am J Obstet Gynecol* 2005; **192**: 1592–1598.
3. Messelink B, Benson T, Berghmans B, Bø K, Corcos J, Fowler C, Laycock J, Huat-Chye Lim P, van Lunsen R, Lycklama a Nijeholt G, Pemberton J, Wang A, Watier A, van Kerrebroeck P. Standardization of terminology of pelvic floor muscle function and dysfunction: report from the Pelvic Floor Clinical Assessment Group of the International Continence Society. *Neurourol Urodyn* 2005; **24**: 374–380.
4. Isherwood PJ, Rane A. Comparative assessment of pelvic floor strength using a perineometer and digital examination. *BJOG* 2000; **107**: 1007–1011.
5. Bø K, Finckenhagen HB. Vaginal palpation of pelvic floor muscle strength: inter-test reproducibility and comparison between palpation and vaginal squeeze pressure. *Acta Obstet Gynecol Scand* 2001; **80**: 883–887.
6. Peschers UM, Gingelmaier A, Jundt K, Leib B, Dimpfl T. Evaluation of pelvic floor muscle strength using four different techniques. *Int Urogynecol J Pelvic Floor Dysfunct* 2001; **12**: 27–30.
7. Braekken IH, Majida M, Ellstrøm-Engh M, Dietz HP, Umek W, Bø K. Test–retest and intra-observer repeatability of two-, three- and four-dimensional perineal ultrasound of pelvic floor muscle anatomy and function. *Int Urogynecol J Pelvic Floor Dysfunct* 2008; **19**: 227–235.
8. Thompson JA, O'Sullivan PB, Briffa K, Neumann P, Court S. Assessment of pelvic floor movement using transabdominal and transperineal ultrasound. *Int Urogynecol J Pelvic Floor Dysfunct* 2005; **16**: 285–292.
9. Dietz HP, Wilson PD, Clarke B. The use of perineal ultrasound to quantify levator activity and teach pelvic floor muscle exercise. *Int Urogynecol J Pelvic Floor Dysfunct* 2001; **12**: 166–169.
10. Dietz HP, Steensma AB, Vancaillie TG. Levator function in nulliparous women. *Int Urogynecol J Pelvic Floor Dysfunct* 2003; **14**: 24–26.
11. Thompson JA, O'Sullivan PB, Briffa NK, Neumann P. Assessment of voluntary pelvic floor muscle contraction in continent and incontinent women using transperineal ultrasound, manual muscle testing and vaginal squeeze pressure measurements. *Int Urogynecol J Pelvic Floor Dysfunct* 2006; **17**: 624–630.
12. Dietz HP, Jarvis SK, Vancaillie TG. The assessment of levator muscle strength: a validation of three ultrasound techniques. *Int Urogynecol J Pelvic Floor Dysfunct* 2002; **13**: 156–159.

13. Bump RC, Mattiasson A, Bø K, Brubaker LP, DeLancey JO, Klarskov P, Shull BL, Smith AR. The standardization of terminology of female pelvic organ prolapse and pelvic floor dysfunction. *Am J Obstet Gynecol* 1996; **175**: 10–17.
14. Laycock J. Clinical evaluation of the pelvic floor. In *Pelvic Floor Re-education*, Schussler B, Laycock J, Norton P, Stanton S (eds). Springer-Verlag: London, 1994; 42–48.
15. Yang JM, Huang WC. Discrimination of bladder disorders in female lower urinary tract symptoms on ultrasonographic cystourethrography. *J Ultrasound Med* 2002; **21**: 1249–1255.
16. Huang WC, Yang SH, Yang JM. Anatomical and functional significance of urogenital hiatus in primary urodynamic stress incontinence. *Ultrasound Obstet Gynecol* 2006; **27**: 71–77.
17. Bland JM, Altman DG. Statistical methods for assessing agreement between measurement. *Biochimica Clinica* 1987; **11**: 399–404.
18. Talasz H, Himmer-Perschak G, Marth E, Fischer-Colbrie J, Hoefner E, Lechleitner M. Evaluation of pelvic floor muscle function in a random group of adult women in Austria. *Int Urogynecol J Pelvic Floor Dysfunct* 2008; **19**: 131–135.
19. Dietz HP, Shek KL. The quantification of levator muscle resting tone by digital assessment. *Int Urogynecol J Pelvic Floor Dysfunct* 2008; **19**: 1489–1493.
20. Dietz HP, Shek C. Levator avulsion and grading of pelvic floor muscle strength. *Int Urogynecol J Pelvic Floor Dysfunct* 2008; **19**: 633–636.
21. Thompson JA, O'Sullivan PB, Briffa NK, Neumann P. Comparison of transperineal and transabdominal ultrasound in the assessment of voluntary pelvic floor muscle contractions and functional maneuvers in continent and incontinent women. *Int Urogynecol J Pelvic Floor Dysfunct* 2007; **18**: 779–786.
22. Sherburn M, Murphy CA, Carroll S, Allen TJ, Galea MP. Investigation of transabdominal real-time ultrasound to visualize the muscles of the pelvic floor. *Aust J Physiother* 2005; **51**: 167–170.
23. Thompson JA, O'Sullivan PB. Levator plate movement during voluntary pelvic floor muscle contraction in subjects with incontinence and prolapse: a cross-sectional study and review. *Int Urogynecol J Pelvic Floor Dysfunct* 2003; **14**: 84–88.
24. Kearney R, Sawhney R, DeLancey JO. Levator ani muscle anatomy evaluated by origin-insertion pairs. *Obstet Gynecol* 2004; **104**: 168–173.
25. Constantinou CE, Hvistendahl G, Ryhammer A, Nagel LL, Djurhuus JC. Determining the displacement of the pelvic floor and pelvic organs during voluntary contractions using magnetic resonance imaging in younger and older women. *BJU Int* 2002; **90**: 408–414.