## ACWPH CONFERENCE 2009

# Margie Polden Memorial Lecture: From research lab back to clinical practice

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**Abstract**
The aim of this study was to define new quantitative parameters of dynamic pelvic floor muscle (PFM) function using two-dimensional transperineal ultrasound imaging in combination with image processing methods (IPMs). Ultrasound and digital vaginal data were obtained from a volunteer convenience sample of 32 women who were recruited from the general community of the San Francisco Bay Area, CA, USA. Twenty-three subjects were continent and nine suffered from stress urinary incontinence (SUI). Several research questions were addressed using transperineal ultrasound combined with IPMs. The process allowed the dynamic evaluation of pelvic floor displacement throughout an entire manoeuvre, in contrast to the limited quantification possible when using static images taken from the rest position to the end of the manoeuvre. Caution regarding the generalizability of the results is warranted because of the small number of women with SUI who were involved in the study and the significant differences in parity between the groups. However, this non-invasive tool for physiological measurement represents a new way of assessing the PFMs. It is envisaged that the present research will provide a foundation for future studies involving larger, parity-matched populations, and therefore, that it will eventually contribute to improvements in the rehabilitation of women with SUI and other pelvic floor disorders.

*Keywords:* clinical practice, continence, image processing methods, pelvic floor muscles, ultrasound imaging.

## Introduction

There is increasing evidence that the pelvic floor muscles (PFMs) perform multiple functions, such as: continence and pelvic organ support (DeLancey 1990; Howard *et al.* 2000); sexual function (Baytur *et al.* 2005); respiration (Hodges *et al.* 2007); and spinal stability and containment of intra-abdominal pressure (IAP) (Hemborg *et al.* 1985; Pool-Goudzwaard *et al.* 2004; Smith *et al.* 2008). The physiological mechanisms by which the PFMs perform these roles are not clearly understood, primarily because of a lack of suitable instrumentation. The female pelvic floor remains an under-studied region of the body, particularly from a biomechanical perspective (Ashton-Miller & DeLancey 2007).

Pelvic floor dysfunction encompasses both urinary and faecal incontinence, pelvic organ prolapse, and pelvic pain (Martins *et al.* 2007). It is a significant problem for women and has been described as 'the hidden epidemic' by DeLancey (2005). Estimates from the USA indicate that that between 21% and 26% of American women have at least one pelvic floor disorder, with the greatest percentage experiencing urinary incontinence (Nygaard *et al.* 2008). Pelvic floor dysfunction affects between 300 000 and 400 000 women in the USA so severely that they require surgery, and 30% of those will need more than one operation (Olsen *et al.* 1997; Boyles *et al.* 2003). No equivalent prevalence data on pelvic floor dysfunction are currently available in the UK.

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To date, PFM dysfunction and its relationship with stress urinary incontinence (SUI) has been the most extensively studied pelvic floor pathology, particularly from the perspective of conservative rehabilitation (Dumoulin & Hay-Smith 2008). Several randomized controlled trials have demonstrated that PFM strength training in women with SUI is more effective than no treatment or treatment involving other modalities; cure rates varying between 44% and 67% have been reported (Henalla *et al.* 1988; Miller *et al.* 1998; Mørkved *et al.* 2002; Dumoulin *et al.* 2004). Nevertheless, although strength training is effective, the strength of a PFM contraction does not always correlate with an individual's level of functional continence (Kessler & Constantinou 1986; Theofrastous *et al.* 2002; Morin *et al.* 2004). It is unclear why rehabilitation is effective in some women and not in others because little research has focused on the mechanisms of therapeutic change in order to identify the critical components of training. Although there are exceptions (Miller *et al.* 2001, 2008; Dumoulin *et al.* 2004), most conservative treatment and assessment options remain focused upon strength training, and these rarely, if ever, consider other properties of PFM function, such as the timing and direction of contractions, endurance, the ability of the PFMs to relax, overactivity of the PFMs, pelvic organ support, and coordination with muscles of the abdominopelvic cylinder. Given the multipurpose role of the pelvic floor, the motor control challenge for the PFMs must be immense and the efficiency of these muscles will not only rely upon the anatomical integrity of the pelvic floor, but will also depend on the central nervous system (CNS) response to satisfy the hierarchical demands of function. The CNS must interpret the afferent input and generate a coordinated response so that the activity of the muscles occurs at the right time, with the appropriate level of force.

A combination of neuropathic changes, and muscle, fascial or connective tissue damage is most likely responsible for the development of pelvic floor disorders, but the precise mechanisms remain controversial (Shafik *et al.* 2005; Ashton-Miller & DeLancey 2007; Papa Petros 2007; Smith *et al.* 2007). It would seem logical that knowing the exact nature of each woman's condition and directing treatment to the specific dysfunction would improve treatment success. Since it is likely that the PFMs are also affected in conditions other than SUI, it was hoped that two-dimensional perineal ultrasound combined with image processing methods (IPMs) could provide a novel way of measuring PFM function. This would then contribute to the existing knowledge base about PFM function and provide a foundation for future PFM research.

## Subjects and methods

A convenience sample of 33 female volunteers was recruited according to a protocol approved by the Stanford University Institutional Review Board from the general community of the San Francisco Bay Area, CA, USA. The women were recruited through networking, and fliers posted at schools, hospital, sports associations and Stanford University. Informed written consent was obtained from all subjects prior to the commencement of the investigation. They completed a demographic questionnaire, the validated short form of the Incontinence Impact Questionnaire (IIQ-7) and the short form of the Urogenital Distress Inventory (UDI-6).

The investigators were blinded to the continence status of the volunteers. After evaluation, the women were divided into two groups on the basis of their histories and self-reported symptoms: (1) asymptomatic subjects, i.e. those who reported no incontinence; and (2) subjects with SUI, i.e. those whose continence severity could be ranked on a 12-point scale (Sandvik *et al.* 2000). The exclusion criteria included: women who had undergone previous genitourinary surgery; those who described symptoms associated with overactive bladder (OAB) or were currently using pharmacotherapy for OAB; those who were currently pregnant; and those who had a neurological or psychiatric disease, a major medical condition, significant prolapse, or a urinary tract or vaginal infection. One volunteer was excluded because she had symptoms of OAB.

To ensure adequate bladder volume for ultrasound imaging, a standardized pragmatic approach was taken. The volunteers were asked to void one hour before testing, then drink 450 mL of water and to refrain from voiding until after the test sequences. Volunteers performed a cough, Valsalva, 'The Knack' (i.e. a PFM contraction prior to and during activities that increase IAP), a voluntary PFM and a transversus abdominis (TrA) contraction with an ultrasonic transducer placed on the perineum in a mid-sagittal orientation. To satisfy local infection control procedures, the transducer was


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**Table 1.** Mean ± standard deviation (and range) of the age, parity and Body Mass Index (BMI) of the subjects, and their ranking on the Continence Severity Scale (CSS)

| Variable | Subject group | | *P*-value |
|---|---|---|---|
| | Continent ($n=23$) | Stress urinary incontinence ($n=9$) | |
| Age (years) | 40.8 ± 13.8 (25–84) | 46.8 ± 12.9 (34–71) | $P=0.24$* |
| Parity | 0.5 ± 0.9 (0–3) | 1.4 ± 0.8 (0–2) | $P=0.01$ |
| BMI | 22.0 ± 2.0 | 23.9 ± 2.6 | $P=0.09$* |
| CSS | Continent | Slightly = 5; moderately = 4 | – |

*Not significant.

washed in hot water and disinfectant, covered in ultrasound gel, and then covered by an un-powdered examination glove that was coated with more ultrasound gel before being placed on the perineum in a mid-sagittal direction. The transducer was orientated so that the clearest images of the bladder, urethra, rectum and symphysis pubis (SP) were viewed.

Video recordings of imaging signals were recorded on a personal computer for offline analysis. The captured audio-visual image ultrasound files were evaluated using reliable novel image processing methodology described elsewhere (Peng *et al.* 2006a, 2007; Jones *et al.* 2008).

## Results and discussion

The general demographic of the two groups available for ultrasound evaluation is described in Table 1. One woman was excluded because of symptoms of OAB.

The severity scale devised by Sandvick *et al.* (2000) was used to determine that five of the incontinent group were slightly incontinent (i.e. a few drops of urine a maximum of a few times a month) and four were moderately incontinent (i.e. a few drops or splashes of urine a maximum of a few times a week). No subject was rated as severely incontinent. Overall, the bothersomeness of the condition was slight, as determined by analysis of the UDI-6 and IIQ-7 questionnaires. Five subjects indicated that they were slightly bothered by their incontinence, three were moderately bothered and one was greatly bothered by her incontinence.

There was a significant difference in parity between groups, and epidemiological evidence suggests that there is a correlation between parity status and incontinence (Foldspang *et al.* 1992). Nevertheless, sister pair and identical twin studies have also reported that vaginal delivery is not associated with urinary incontinence, concluding that an underlying familial predisposition toward the development of urinary incontinence may be present (Buchsbaum *et al.* 2005; Buchsbaum & Duecy 2008).

It was beyond the scope of the present study to look at the effect of parity on either sample group, and therefore, caution regarding the generalizability of the results is warranted; however, these results may provide the foundation for future studies with larger, parity-matched populations.

### *Cough*

During a cough, the PFMs of the continent women actively shortened, as indicated by the reduction in the distance between the anorectal angle (ARA) and the SP, and the initial direction of the displacement, velocity and acceleration of the ARA (Lovegrove Jones *et al.* 2009c). This either implies that there is an anticipatory PFM contraction in continent women or that the PFMs respond quickly to prevent any dorsal displacement caused by the rise in IAP during a cough. In women with SUI, the muscle was lengthened, as indicated by the increase in the distance between the ARA and SP. During a cough, the urethra in both groups was displaced in a dorsocaudal direction, although the urethra was displaced by half the distance and with a smaller velocity in asymptomatic volunteers. This not only implies that the continent group had a stiffer pelvic floor to support the urethra, but that the fascial attachments of the urethra were also stronger.

### *The Knack*

Transperineal ultrasound in combination with IPMs is specific enough to be able to distinguish between The Knack and the cough, and reveals whether or not there is a coordinated and effective PFM contraction that is sufficiently able to support the urethra during a cough (Lovegrove Jones *et al.* 2009a). In both groups of subjects,

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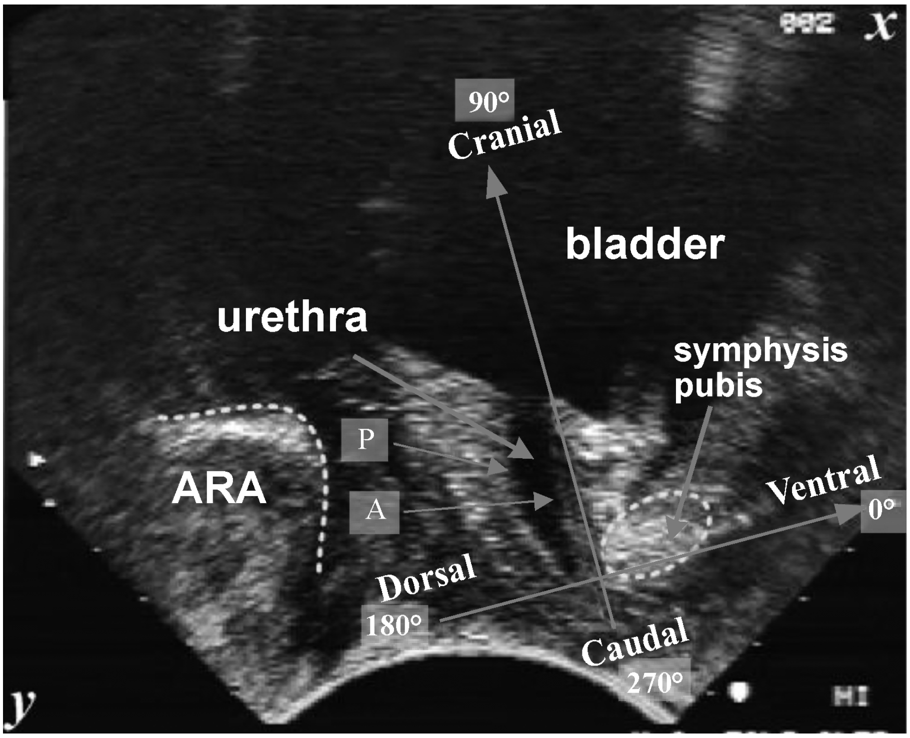


**Figure 1.** Ultrasound scan showing a typical transperineal view. The coordinate system has been placed on the symphysis pubis, and is parallel and vertical to the urethra: (P) posterior edge of the urethra; (A) anterior edge of urethra; and (ARA) anorectal angle. Reprinted with the permission of the publisher from Lovegrove Jones *et al.* (2009c).

The Knack had three basic stages (Lovegrove Jones *et al.* 2009b):

(1) During the active PFM contraction, there was an initial cranioventral displacement of both the ARA and urethra.
(2) During the cough component, there was a dorsocaudal displacement of the urethra and the ARA of women with SUI, and a predominately caudal displacement of the ARA in continent women.
(3) On return to the resting position, the urethra of both groups returned to the original starting position. However, the ARA of women with SUI tended to rest in a slightly more dorsocaudal position and the ARA of continent women was slightly more dorsocranial than in their original start position.

Significant differences occurred with regard to the behaviour of both the urethra and ARA of the continent women and those with SUI during The Knack. In the initial PFM component of The Knack, the ARA of the continent group had significantly more ventral displacement than that of the group with SUI, and unlike the ARA of the group with SUI, the continent group were able to maintain most of their ventral displacement throughout the cough part of the manoeuvre.

There was also over twice as much displacement of the urethra in the women with SUI compared to the continent group. In addition, there was significantly more initial ventral displacement of the posterior edge of the urethra in the continent women than in those with SUI.

Craniocaudally, the overall displacement pattern was more comparable, but there were significant differences in magnitude of displacement of both the ARA and urethra. During the cough stage of The Knack, both groups lost much of the cranial displacement created by the initial PFM component, although the ARA of the group with SUI descended more than twice the distance of that of the continent group.

### *Transversus abdominis*

In both groups of women, it was found that there was co-activation of the PFMs with a TrA manoeuvre, as indicated by the cranioventral displacement of the ARA (Jones *et al.* 2006). However, there was significantly less ARA displacement in the group with SUI compared with the continent group, particularly in the ventral direction. The co-contraction was sustained for longer in the continent group and the ARA finished at a higher position than at the starting point. The displacement of the urethra during a TrA contraction between groups was very


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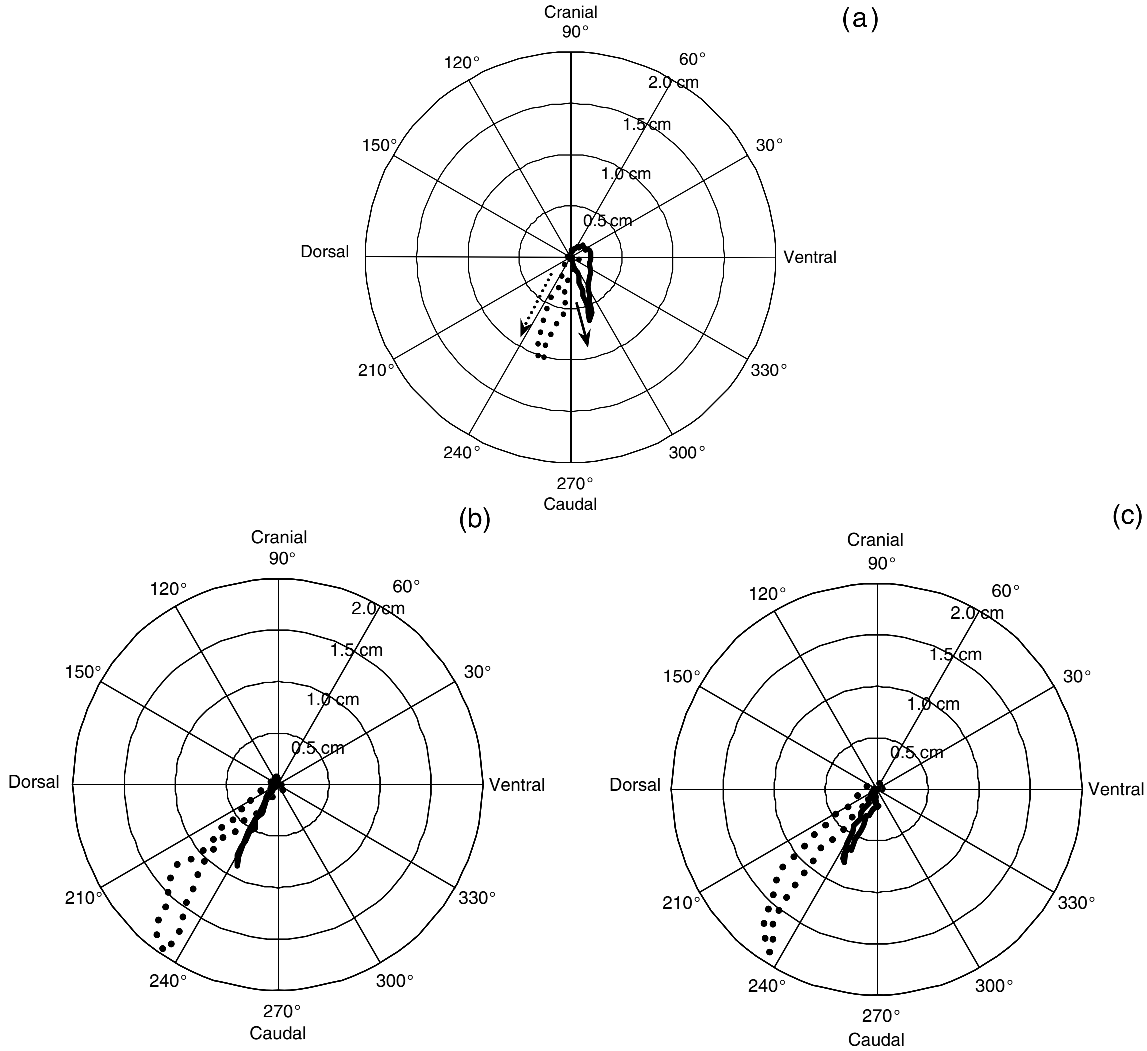


**Figure 2.** Comparison of the mean displacements (cm) and directions (degrees) of (a) the anorectal angle, and (b) the anterior and (c) posterior edges of the urethra during a cough in supine women. Some of the subjects were continent ($n=23$; solid lines) and others had stress urinary incontinence (SUI) ($n=9$; dotted lines). The arrows in (a) represent the initial direction of movement. Notice also the co-linear path of the urethra of the continent women compared with the more convoluted trajectory of the urethra in the group with SUI. Reprinted with the permission of the publisher from Lovegrove Jones *et al.* (2009c).

similar, although, in general, there was slightly greater displacement of the urethra in the group with SUI, but this only reached statistical significance in the cranial displacement of the anterior edge.

### *Voluntary pelvic floor muscle contraction*

In response to a maximum perceived voluntary contraction, the ARA and urethra of both groups were displaced in a cranioventral direction (Peng *et al.* 2006b). In supine, from a zero reference point, the amount of overall displacement was slightly bigger in the continent group, but this did not reach statistical significance in any direction. However, the direction or angle of displacement of the posterior edge of the urethra was different between groups, with the more acute displacement occurring in the continent women. Conversely, in standing, there were significant differences in the amount of displacement from a zero reference point of both the urethra and ARA between continent women and those with SUI.

Not accounting for starting position, the continent women had significantly greater displacements in standing compared to the supine position, which is in agreement with other studies using TA ultrasound to measure the displacement of the bladder base (Frawley *et al.* 2006; Kelly *et al.* 2007). However, Kelly *et al.* (2007) mistakenly concluded that the greater displacement in standing represented a greater ability of healthy adults to elevate the pelvic floor in standing compared to supine. The present study clarifies that the greater displacement in the standing position does not reflect an

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anatomically higher final resting position of either the ARA or urethra, but is representative of the ARA and urethra starting from a lower position as a result of the effects of gravity on the pelvic viscera. Accounting for the relative starting position of the PFM structures, the present study is in agreement with an earlier study involving transperineal ultrasound by Dietz *et al.* (2001), which indicated that there were better contractions in supine for both groups (Bump *et al.* 1991; Dietz *et al.* 2001; Thompson & O'Sullivan 2003).

### *Valsalva*

There were statistically significant greater displacements of the ARA and both edges of the urethra in the group with SUI compared to those who were continent: the urethra in the women with SUI was displaced at least 0.5 cm more than in those who were continent (Shishido *et al.* 2006). Significant differences were found consistently in the dorsal displacement of both the ARA and the urethra: there was negligible dorsoventral displacement of the ARA in the continent group compared to over 0.5 cm of dorsal displacement in the group with SUI; consequently, the angle of ARA displacement was very different between the groups. In both supine and standing, the urogenic structures of the women with SUI all behaved in a similar fashion, moving dorsocaudally away from the SP in the direction expected from a passive stretch under the influence of forces associated with raised IAP. However, there was a slight shortening of the distance between the ARA and the SP in the continent women, and negligible dorsoventral displacement of the ARA in supine, which suggests that, as in a cough, either there was a pre-planned activation of the PFMs or that the restoring forces of the PFMs responded quickly to prevent any dorsal displacement. In standing, the direction and amount of ARA displacement was similar between both groups. These were both displaced in the same direction as the urethra, although, because of the more ventral starting position of the ARA in the continent women, the pelvic floor of the women with SUI was elongated more.

## Conclusion: main impact of study findings

Transperineal ultrasound in combination with IPMs has enabled the dynamic evaluation of pelvic floor displacement throughout an entire manoeuvre, in contrast to the limited quantification possible when using static images taken from the rest position to the end of the manoeuvre. In this way, IPMs have determined unique quantitative data regarding the automatic displacement, velocity and acceleration of the ARA and the urethra during a variety of manoeuvres, and indicated that the displacement of the pelvic floor structures during automatic events demonstrates greater differences between groups than voluntary PFM contractions. The IPMs were also specific enough to differentiate between a cough and The Knack, a manoeuvre that is commonly used in the rehabilitation of women with SUI.

The IPMs were shown to be valid, specific and sensitive measurement tools that are able to discriminate between continent women and those with SUI (Jones *et al.* 2008). Considering that the group with SUI were only mildly to moderately incontinent and still produced very different patterns of movement to the asymptomatic group, this suggests that transperineal ultrasound imaging combined with IPMs may make a valuable contribution to achieving a greater understanding of normal pelvic floor mechanisms. It could also provide a foundation for future studies involving larger, parity-matched populations and potentially improve the rehabilitation of women with SUI and other pelvic floor disorders.

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*Dr Ruth Lovegrove Jones combines the disciplines of international research, writing and education with her role as a clinician. She has worked in private practice for the past 20 years, establishing a multidisciplinary clinic for pain management, sports medicine and pelvic floor rehabilitation. Ruth was recently awarded a doctorate from the University of Southampton, Southampton, UK. She was supervised by Professor Maria Stokes and Professor Victor Humphries, and worked collaboratively with Professor Christos Constantinou and Dr Qiyu Peng at Stanford University, Stanford, CA, USA. This team of physiotherapists, physicists and engineers evaluated the dynamic function of the pelvic floor muscles in women using two-dimensional ultrasound and novel image processing methods. Ruth was honoured to have the opportunity to present the tenth Margie Polden Memorial Lecture at Conference 2009. She thanks all the women's health physiotherapists who came before her, making her own journey so much easier, particularly Maeve Whelan, Jo Laycock, Jeanette Haslam and Judith Lee, who have all been a constant source of inspiration and guidance.*


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