New imaging method for assessing pelvic floor biomechanics

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ABSTRACT

Objectives The investigation of female pelvic floor biomechanics is attracting attention due to its importance in pelvic floor dysfunction and childbirth. To date, there are no established means of assessing pelvic floor elasticity. We propose the use of translabial ultrasound to estimate strain, one element of pubovisceral muscle elasticity.

Methods Ultrasound datasets of 98 women seen at a tertiary urogynecology clinic were reviewed using proprietary software. Data were processed to estimate muscle fiber strain during Valsalva and contraction by measuring biatal circumference and deducting bony arc length. Clinical assessment included levator palpation during maximal contraction (modified Oxford grading scale) and at rest, with tone recorded on a new six-point scale. Analysis of imaging data was performed without knowledge of clinical data.

Results Mean age was 52.2 (range, 19–87) years and mean parity was 2.4 (range, 0–8). Mean (SD) biatal area during contraction, rest and Valsalva was 15.4 (3.8) cm², 18.9 (5.0) cm² and 27.3 (8.9) cm², respectively. There was a moderate association between strain during contraction and Oxford grade (r = 0.439, P < 0.0001), and a weak but significant association between strain during Valsalva and resting tone (r = −0.224, P = 0.033).

Conclusions Translabial ultrasound can be used to measure strain, a component of pubovisceral muscle elasticity, and we have validated the technique against clinical assessment. Pubovisceral strain during contraction correlates positively with Oxford grade. Pubovisceral strain during Valsalva correlates negatively with resting tone grade. This new non-invasive ultrasound technique may be of value for assessing patients with pelvic floor dysfunction. Copyright © 2008 ISUOG. Published by John Wiley & Sons, Ltd.

INTRODUCTION

The elastic properties of the pubovisceral muscle are likely to be important for pelvic organ support and probably affect progress in labor. Evidence from musculoskeletal medicine suggests that muscle elasticity is likely to play a role in the pathogenesis of major trauma to the insertion of the levator ani on the pelvic sidewall during childbirth. Such ‘avulsion injury’ has recently been shown to be a common consequence of vaginal childbirth, and seems to be associated with anterior and central compartment prolapse. On the other hand, contractility of this muscle probably also plays an important role in maintaining continence and preventing prolapse. Reliable measurement of pubovisceral muscle elasticity may help in risk stratification of women approaching parturition and in the investigation of women complaining of urinary incontinence and/or prolapse, and would be valuable for determining the relative efficacy of interventions.

Current clinical assessment of the pubovisceral muscle is by digital palpation for resting tone and contractility using the modified Oxford muscle grading scale. However, palpatory assessment of the muscle is subjective and of limited repeatability. Clearly, a reliable, non-invasive means of determining elasticity would provide researchers with an important new tool for assessing pelvic floor dysfunction.

In this study we outline a new, static-state translabial ultrasound method of measuring pubovisceral muscle strain during Valsalva and contraction, and determine the degree of agreement between independent graders when performing this new method. We also assess this measure...
as a surrogate for elasticity against digital palpation results.

METHODS

In this retrospective study, 98 consecutive patients referred to the Pelvic Floor Diagnosis and Treatment Unit with symptoms of lower urinary tract dysfunction and/or prolapse were investigated by urogynaecologists (C.S., H.P.D.) using physical examination and translabial ultrasound imaging. The data examined for this project were obtained in the context of a study of clinical aspects of pelvic floor dysfunction, which was approved by the Human Research Ethics Committee of Sydney West Area Health Service (05-029).

Digital palpation

All patients underwent physical examination, which included vaginal digital palpation of the inferior aspects of the levator ani muscle to determine the modified Oxford grade\(^5\) (Grade 0, nothing; 1, flicker; 2, weak squeeze; 3, moderate squeeze and lift; 4, good squeeze and lift; 5, strong squeeze and lift) and resting tone grade using a scale developed by us (0, muscle not palpable; 1, muscle palpable but very flaccid, wide hiatus, minimal resistance to distension; 2, hiatus wide but some resistance to distension; 3, hiatus fairly narrow, fair resistance to palpation but easily distended; 4, hiatus narrow, muscle can be distended but high resistance to distension, no pain; 5, hiatus very narrow, no distention, ‘woody’ feel, possibly with pain: ‘vaginismus’). We developed our resting tone grading method to parallel the Oxford grading of muscle contractility on the assumption that Young’s modulus (the elasticity of a material) is probably most closely associated with what is felt during palpation\(^7\). Young’s modulus (\(E\)) is defined as

\[
E = \frac{\sigma}{\varepsilon}
\]

where \(\sigma\) represents axial stress and \(\varepsilon\) axial strain (Equation 1).

Oxford grade and resting tone grade were assessed bilaterally and the minimum score was recorded.

Ultrasound imaging

Imaging was undertaken by two- and three-dimensional translabial pelvic floor ultrasound examination. A GE Kretz Voluson 730 Expert system (GE Medical Ultrasound, Sydney, NSW, Australia) was used with an 8–4-MHz volume transducer with an acquisition angle of 85°. Imaging was performed after bladder emptying with the patient supine. Hiatal biometry obtained by this method has been shown to be reproducible, both by the authors\(^8\) and others\(^9\). All assessments were conducted by C.S. and/or H.P.D., and were taken during contraction, at rest and during Valsalva. Stored volume datasets were processed using the software GE Kretz 4D View version 5.0 (GE Medical Ultrasound Kretz GmbH, Zipf, Austria).

Measurements and calculations

The plane of minimal hiatal dimensions was defined in the sagittal plane during contraction, rest and Valsalva (Figure 1). Measurements of hiatal circumference were taken using axial sectional images during contraction, rest and Valsalva (Figure 2). A further measurement of the bony arc (the non-elastic arc of the hiatal circumference) was taken during contraction when the insertion angle of the levator muscles into the pubic rami is most acute (Figure 2a). The muscular arc (the part of the hiatal circumference that contracts and stretches during contraction and Valsalva maneuver, respectively) is the difference between the hiatal circumference and the bony arc. Pubovisceral muscle strain (\(\varepsilon\)) was calculated relative to the resting state on contraction:

\[
\varepsilon_{\text{cont}} = \frac{C_{\text{cont}} - C_{\text{rest}}}{C_{\text{rest}} - l_b}
\]

where \(\varepsilon_{\text{cont}}\) represents the strain during contraction, \(C_{\text{cont}}\) the hiatal circumference during contraction, \(C_{\text{rest}}\) the hiatal circumference at rest and \(l_b\) the bony arc of hiatal circumference (Equation 2). Strain on Valsalva was calculated relative to the resting state as follows:

\[
\varepsilon_{\text{vals}} = \frac{C_{\text{vals}} - C_{\text{rest}}}{C_{\text{rest}} - l_b}
\]

where \(\varepsilon_{\text{vals}}\) represents the strain during Valsalva and \(C_{\text{vals}}\) the hiatal circumference during Valsalva (Equation 3).

Figure 1 Sagittal translabial ultrasound images depicting the plane of minimal hiatal dimensions (solid lines) during pelvic floor muscle contraction (a), rest (b) and Valsalva (c). This plane stretches from the pubic symphysis to the most ventral aspect of the puborectalis muscle posterior to the rectum.
Analysis of imaging data was performed without knowledge of clinical data.

Statistical analysis

Statistical analysis was performed after normality testing when necessary (histogram analysis and/or Kolmogorov–Smirnov testing), using Minitab version 13 (Minitab, State College, PA, USA). ANOVA and Spearman’s correlation were used to test for significance of the relationship between variables. $P < 0.05$ was considered statistically significant. Data are presented as mean (SD) or median (range). For test–retest analysis of ultrasound measurements, we used intraclass correlation (ICC; equivalent to Cohen’s kappa for continuous variables, absolute agreement definition). An ICC of less than 0.4 signifies poor agreement, 0.4–0.59 moderate agreement, 0.6–0.79 substantial agreement, whereas 0.8 or higher indicates excellent agreement. We also performed Bland–Altman analysis for repeatability, using Analyse-it version 2.0.3 (Analyse-it Software Ltd, Leeds, UK). The retest series was undertaken by two examiners producing single measurements on 20 randomly selected consecutive patients, blinded to each other’s results.

RESULTS

Ninety-eight women attended an outpatient urogynecology clinic for stress incontinence (69%), urge incontinence (71%) and/or symptoms of prolapse (41%). Demographics of the study group are summarized in Table 1. Thirteen women were excluded from the analysis of strain during Valsalva because of inability to perform a Valsalva maneuver that was not confounded by levator coactivation, leaving 85 datasets. Two women were excluded from the contraction strain analysis because of incomplete data, leaving 96 datasets.

Hiatal area and circumference had excellent intergrader reliability with consistently high ICC values (Table 2). ICCs were also excellent for corrected circumference. Mean (SD) strain during Valsalva was 22.7 (21.3)% with an ICC of 0.84, and mean strain on contraction was $-15.9$ (8.4)% with an ICC of 0.65. Strain on contraction is negative because of the relative shortening of the pubovisceral muscle in this state. Interobserver bias and limits of agreement according to the Bland–Altman method are presented in Table 3.

Figures 3 and 4 respectively show mean strain with 95% CI for each modified Oxford and resting tone grade. ANOVA showed a significant association between strain on contraction and Oxford grade ($P < 0.001$) with a moderate Spearman’s correlation ($r = 0.439, P < 0.0001$). ANOVA did not yield a significant association between strain during Valsalva and resting tone grade ($P = 0.059$), although there was a weak but significant correlation ($r = -0.224, P = 0.033$).
Table 2 Intraclass correlation (ICC) for repeatability of hiatal measurements and strain

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Contraction</th>
<th></th>
<th>Rest</th>
<th></th>
<th>Valsalva</th>
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<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>ICC</td>
<td>Mean (SD)</td>
<td>ICC</td>
<td>Mean (SD)</td>
<td>ICC</td>
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<tr>
<td>Number</td>
<td>96</td>
<td>20</td>
<td>98</td>
<td>20</td>
<td>85</td>
<td>20</td>
</tr>
<tr>
<td>Hiatal area (cm²)</td>
<td>15.4 (3.8)</td>
<td>0.88</td>
<td>18.9 (5.0)</td>
<td>0.95</td>
<td>27.3 (8.9)</td>
<td>0.96</td>
</tr>
<tr>
<td>Hiatal circumference (cm)</td>
<td>14.7 (1.9)</td>
<td>0.85</td>
<td>16.6 (2.2)</td>
<td>0.92</td>
<td>19.1 (3.3)</td>
<td>0.94</td>
</tr>
<tr>
<td>Bony arc (cm)</td>
<td>4.9 (0.7)</td>
<td>0.86</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Muscular arc (cm)</td>
<td>8.8 (4.0)</td>
<td>0.77</td>
<td>11.7 (2.1)</td>
<td>0.87</td>
<td>13.0 (5.6)</td>
<td>0.93</td>
</tr>
<tr>
<td>Strain (%)</td>
<td>−15.9 (8.4)</td>
<td>0.65</td>
<td>—</td>
<td>—</td>
<td>22.7 (21.3)</td>
<td>0.84</td>
</tr>
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</table>

DISCUSSION

This study investigates a new technique for assessing the biomechanics of the female pelvic floor using translabial ultrasound. Strain on contraction correlated significantly with modified Oxford grade, and strain on Valsalva correlated significantly with resting tone grade. The repeatability of this new measurement technique seems good (Tables 2 and 3), although it is recognized that the retest series was conducted on stored cineloops of volume datasets. Repeating the entire examination at another date may result in lower repeatability indices.

In order to understand the changes that occur in muscle as a result of physiology, pathology and therapeutic intervention it is necessary to measure mechanical properties of muscle in vivo. Elasticity, one of the main mechanical properties of any material, is likely to be of considerable value when assessing pelvic floor biomechanics because of the wide variety of functions this muscle fulfills throughout female life. Increased stiffness of this muscle may be desired for continence and avoidance of pelvic organ prolapse as well as for sexual function, but increased elasticity may be preferable at the time of childbirth in order to minimize trauma and facilitate vaginal delivery.

Elasticity of muscle can be measured either in the steady state (static elasticity) or during active muscle elongation (viscoelasticity). Static elasticity is the steady force required to produce unit displacement. This definition explicitly excludes rate of movement as a consideration. ‘Viscoelastic’ elasticity is a more accurate assessment of axial force during elongation as it incorporates the force induced by viscosity. Direct viscoelastic measurements are difficult in the pubovisceral muscle as it does not pass over a joint to allow cyclic elongation, which is

Table 3 Bland–Altman analysis for repeatability of hiatal measurements and strain

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Contraction</th>
<th>Rest</th>
<th>Valsalva</th>
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<tbody>
<tr>
<td></td>
<td>Interobserver bias</td>
<td>95% limits of agreement</td>
<td>Interobserver bias</td>
</tr>
<tr>
<td>Hiatal area (cm²)</td>
<td>−1.646</td>
<td>−5.1 to 1.9</td>
<td>−1.624</td>
</tr>
<tr>
<td>Hiatal circumference (cm)</td>
<td>−0.367</td>
<td>−1.4 to 0.6</td>
<td>−0.562</td>
</tr>
<tr>
<td>Bony arc (cm)</td>
<td>−0.224</td>
<td>−2.1 to 1.7</td>
<td>−0.195</td>
</tr>
<tr>
<td>Muscular arc (cm)</td>
<td>1.15</td>
<td>−26.3 to 28.6</td>
<td>—</td>
</tr>
<tr>
<td>Strain (%)</td>
<td>—</td>
<td>—</td>
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</tr>
</tbody>
</table>
necessary to measure the effect that viscosity and speed of elongation have in altering muscle tone, and because the instrumentation required to do this is expensive and invasive. However, one can examine a body segment for resistance to movement sufficiently slow that the speed of movement does not affect the result\textsuperscript{13}. In this study we measured strain of the pubovisceral muscle and compared this with clinical assessment of resting tone, which is known to approximate Young's modulus\textsuperscript{7}.

Resting muscle tone is the elastic and/or viscoelastic stiffness in the absence of contractile activity\textsuperscript{13}. It is a clinical tool used widely by musculoskeletal physicians and physiotherapists alike as a surrogate for assessment of muscle elasticity\textsuperscript{14}. To our knowledge, clinical assessment of pubovisceral muscle resting tone has been described only once previously in the literature as a general tool for identifying those likely to suffer urinary incontinence. In that study, Devreeze et al.\textsuperscript{3} used a series of 80 patients to distinguish only between normotonic and hypotonic muscle, which we consider insufficient to reflect the spectrum of clinical findings. We therefore developed a six-point resting tone scale paralleling the Oxford grading scale for muscle contractility, which is widely used in pelvic floor assessment; this resting tone scale is associated with anterior and posterior prolapse\textsuperscript{15}. It is generally accepted, however, that palpatory assessment of the pubovisceral muscle is of suboptimal repeatability. Hence there is a need for more reproducible methods of measuring elasticity, which we have attempted to provide in this study.

There are obvious limitations to the present study. We have made the assumption that pubovisceral muscle strain is approximately proportional to pubovisceral muscle elasticity. We feel that it is reasonable to use strain as a surrogate for elasticity in static measurements if the boundary conditions are known\textsuperscript{7}. The pelvic floor is a complex structure, both anatomically and functionally, and it is not possible to know all extraneous sources influencing axial pressures in the pubovisceral muscle. A more accurate measure of elasticity (Young's modulus, Equation 1) would also require direct pubovisceral muscle axial pressure measurements.

Constantinou et al. have recently developed a novel biosensor designed to measure the force and displacement of pelvic floor contraction in the anterior and posterior vagina\textsuperscript{16}. Another device, designed by Meyer et al., successfully measures the intravaginal and intrarectal pressures during exercise and/or labor\textsuperscript{17}. Data published on these direct measurement devices are promising, but disadvantages are the lack of commercial availability and the relative invasiveness of such instruments. There is currently no device described in the literature that is able to measure the elasticity of the pubovisceral muscle.

In conclusion, we have measured one component of pubovisceral muscle elasticity during Valsalva and contraction using a novel, non-invasive, highly repeatable ultrasound technique. Results were validated against findings obtained on digital palpation. The ultrasound parameter tested here may become an important research tool in the assessment of women with pelvic floor dysfunction, and for measuring the success of interventions to change muscle biomechanical properties.

REFERENCES