Two- and 3-dimensional MRI comparison of levator ani structure, volume, and integrity in women with stress incontinence and prolapse

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OBJECTIVE: The aim of this study was to identify imaging markers for genuine stress incontinence and pelvic organ prolapse by using magnetic resonance imaging and reconstructed 3-dimensional models.

STUDY DESIGN: Thirty women were studied, 10 with prolapse, 10 with genuine stress incontinence, and 10 asymptomatic volunteers. Axial and sagittal T1 and T2 weighted pelvic magnetic resonance scans were obtained with the patient in the supine position. Source images were measured to determine levator hiatus height, bladder neck to pubococcygeal line, levator plate angle, and perineal descent at rest and maximum Valsalva. Manual segmentation and surface modeling was applied to build 3-dimensional models of the organs. The 3-dimensional models were measured to determine levator muscle volume, shape and hiatus width, distance between symphysis and levator sling muscle, posterior urethrovesical angle, bladder neck descent, and levator plate angle.

RESULTS: The 3 groups of subjects were comparable in age, parity, and body mass index. In the control, genuine stress incontinence, and prolapse groups, the menopausal rate was 40%, 60%, and 55% (P = .7).

In the same order, significant mean 2-dimensional measures were: resting bladder neck descent of 24, 17, and 3 mm (P < .005), straining levator plate angle of −4.3, −11.5, and −31 degrees (P = .01), straining levator hiatus height of 48.5, 51.1, and 65.3 mm (P < .005), and straining perineal descent of 17.2, 22.5, 27.2 mm (P = .02). Similarly ordered mean 3-dimensional parameters showed levator volumes of 32.2, 23.3, and 18.4 cm³ (P < .005); hiatus widths of 25.7, 34.7, and 40.3 mm (P < .005); left levator sling muscle gaps of 15.6, 20.3, and 23.8 mm (P = .03), right levator sling muscle gaps of 15.6, 22.5, and 30.8 mm, (P = .003), and levator shape (90%, 40%, and 20% dome shaped; P < .005).

CONCLUSION: Both 2-dimensional magnetic resonance images and 3-dimensional models yield findings that differ among asymptomatic subjects compared with those with genuine stress incontinence and prolapse. Our 3-dimensional data demonstrate a statistically significant continuum in levator volume, shape, and integrity across groups of asymptomatic, genuine stress incontinence, and prolapse subjects. (Am J Obstet Gynecol 2001;185:11-19.)

Key words: 3-Dimensional modeling, pelvic floor, prolapse, urinary incontinence, levator ani, magnetic resonance imaging, levator sling gap
the result of failure to identify the causative lesion in the pelvic floor before operation. The causative lesion could be a site-specific fascial defect or an anatomic disruption of the levator ani muscles.

Conventional 2-dimensional (2-D) magnetic resonance imaging (MRI) has been used to assess the anatomy of the female pelvic floor. Strohbehn et al. reported excellent correlation between cadaveric dissection and MRI findings. In living women, MRI has been used to correlate imaging findings with the presence of clinical pelvic floor dysfunction. Huddleston et al. reported 3 alterations in vaginal shape that were associated with pelvic floor prolapse. Kirshner-Hermanns et al. reported increased T1 signal intensity as evidence of muscle atrophy in 66% of their subjects with stress incontinence. When we investigated the value of MRI of the pelvis with the patient in the sitting position, we found a trend toward levator muscle laxity and thinning in women with stress urinary incontinence. The disadvantage of 2-D MRI stems from its inability to easily disclose the 3-dimensional (3-D) relationships, which may be at the root of the defects that lead to clinical pelvic floor pathology.

To better understand the specific anatomic defects that may be at issue, we evaluated the morphology, volume, and integrity of the levator ani and the bladder neck by using 3-D MR-based models in living women. Our previous work demonstrated the feasibility of the 3-D technique and yielded early estimates of the normal range of levator volume (39-57 mL) in a group of 10 asymptomatic women aged 22 to 33 years. Our subsequent study evaluated a group of 5 individuals with a wide range of age, parity, prolapse, and continence status. That limited data showed levator ani volume to be lowest in the woman with prolapse, higher in the woman with GSI, and highest in the asymptomatic women, suggesting that levator weakness was a component of pelvic floor dysfunction. From those data, we also identified a marker, the levator symphysis gap, which appeared to correlate with GSI and prolapse. The levator symphysis gap (LSG) is defined as the distance from the anterior most aspect of the levator sling muscle to the closest point on the symphysis pubis. The measurement is taken on the left and on the right and is a measure of the closeness of attachment of the levator sling to the lateral aspect of the symphysis. In our small study, the levator symphysis gap was greatest in women with prolapse, smallest in asymptomatic women, and intermediate in women with GSI. This suggested that detachment of the levator sling arms may be related to GSI and prolapse and that pelvic floor dysfunction may occur on a continuum, with GSI being the first manifestation followed by prolapse as the levators became weaker and sling detachment worsens. That small study could not exclude parity or age as confounding factors. Therefore, we conducted the current study to determine whether MR-based 2-D and 3-D imaging markers could be used to contrast patients with GSI and prolapse in comparison with asymptomatic women in the control group.

**Material and methods**

We evaluated 3 groups of women ranging in age from 38 to 78 years. All subjects were referred from local urogynecology and gynecology practices. The first group consisted of 10 women who presented with complaints unrelated to GSI or prolapse (eg, annual routine examination, vaginal discharge, and dysuria). They all denied vaginal fullness or loss of urine with cough or straining. The second group consisted of 10 women who presented with complaints of urine loss with straining or coughing. These individuals were diagnosed with urodymanically proven GSI, in the absence of anterior wall, posterior wall, or uterine descent (ie, equivalent to stage 0 according to the Pelvic Organ Prolapse Quantification system). For a subject to meet the criteria for GSI, multichannel urodynamic testing was required to demonstrate urine loss on valsalva in the absence of a detrusor contraction and an absence of urine leakage at rest. The third group consisted of 10 women who presented with complaints of vaginal fullness or tissue protruding from the vagina. These individuals received a diagnosis of anterior vaginal wall or uterine prolapse if vaginal wall or uterine tissue was visible beyond the introitus with the patient in the dorsal lithotomy position. This is equivalent to stage III or greater in the Pelvic Organ Prolapse Quantification system, involving points Aa, Ba, C, and D. This prolapse grading system was chosen because it was familiar to a wide range of referring physicians. The interpretation in terms of the Pelvic Organ Prolapse Quantification system is presented here for the sake of comparison only and was not part of the original examination.

Inclusion criteria consisted of willingness and ability to tolerate an MRI scan and ability to give informed consent. Exclusion criteria were prior pelvic or vaginal operation (with the exception of cesarean delivery, tubal ligations, episiotomy and laparoscopy), ferromagnetic implants, pregnancy, and gynecologic cancer or history of pelvic irradiation. The study was approved by our institutional review board and informed consent was obtained from each patient at enrollment. Demographic data were recorded, including parity, menopausal status, age, height, weight, and hormone replacement status.

All individuals voided before entering the scanner. Conventional supine MRI studies were performed as follows. T2-weighted axial source images were obtained by using a 1.5T magnet (General Electric Medical Systems, Milwaukee, Wis) and a torso phased array coil wrapped around the pelvis. The following imaging parameters...
were used: TR = 4200 ms, TE(eff) = 108 ms, 128 phase encodes, 24-cm field of view, 3-mm slice thickness, no gap. Midsagittal images were also obtained at rest and maximal Valsalva by using an ultrafast T2-weighted pulse sequence with the following parameters: repetition time = 10,000 ms, echo to time 1/echo to time 2 = 90 ms, echo train length = 8, one acquisition, 10-mm section thickness, 24-cm field of view, and 256 phase encoding steps. These parameters allowed for rest and strain image acquisition in 2 seconds. Total scanning time was approximately 10 minutes per subject.

After the MRI acquisitions were completed, a senior radiologist reviewed the source images and measured the following parameters: distance from bladder neck to pubococygeal line (PCL), levator plate angle, levator sling arm thickness and signal intensity, levator hiatus width (left-to-right distance), and length (anterior-posterior distance), and perineal descent (ie, distance from anal sphincter to pubococygeal). Example axial and sagittal MR images are given in (Fig 1). MRI data were then electronically transferred to a Sun UltraSparc-30 graphics computer workstation (Sun Microsystems, Mountain View, Calif). The axial image data were segmented into anatomically significant components, including bladder, urethra, vagina, levator ani, symphysis, and coccyx, and then labeled by using a combination of semiautomated and manual editing.17 A gynecologist experienced in pelvic radiologic anatomy performed the manual seg-

Fig 1. Source image parameters. A, Axial plane: Arrow points to levator sling. B, Sagittal plane at rest: Big arrow points to bladder, small arrow points to symphysis. C, Sagittal plane at strain; arrows same as B.
mentation, which required approximately 2 hours per subject. Three-dimensional surface models were generated by using a pipeline consisting of dividing cubes, triangle reduction, triangle smoothing, and a surface-rendering method. The computer processing time for 3-D model generation was less than 10 minutes per subject. Examples of 3-D reconstructions are given (Fig 2, A [dorsal lithotomy view] and B [left sagittal view]). To obtain data for interobserver and intraobserver repeatability calculations, a second experienced gynecologist repeated the manual segmentation and data collection on 5 subjects from each group, each on 2 separate occasions (separated by more than 2 weeks in time). This second gynecologist had comparable training to the first but was unaware of the results of the segmentations performed by the first.

The 3-D models were then analyzed to obtain a set of measurement parameters (Fig 2, C) found useful in our prior work. The pubococcyegeal line was the path from the inferior symphysis to the tip of the coccyx. The H-line was the midsagittal distance from the inferior symphysis to the curve of the levator ani (in effect, the anterior-posterior dimension of the levator hiatus). The M-line was the distance from the anal sphincter to the pubococcygeal (in effect, a measure of the descent of the anal sphincter). The levator plate angle was formed by the posterior-most aspect of the ileococcygeus with respect to the pubococcygeal, measured in the midline. The levator symphysis gap (Fig 2, D) was measured as the distance from the most anterior aspect of each arm of the levator sling to the nearest aspect of the symphysis. The shape of the ileococcygeus muscle was divided in 2 groups (upwardly biconvex [dome-shaped] and downwardly concave [U-shaped]) and determined by visual inspection as follows: Attention was turned to an axial view of the muscle at the median raphe, midway between the posterior-most aspect of the ileococcygeus muscle and the posterior-most aspect of each arm of the levator velophus (in effect, the anterior-posterior dimension of the levator hiatus). The M-line was the distance from the anal sphincter to the pubococcygeal (in effect, a measure of the descent of the anal sphincter). The levator plate angle was formed by the posterior-most aspect of the ileococcygeus with respect to the pubococcygeal, measured in the midline. The levator symphysis gap (Fig 2, D) was measured as the distance from the most anterior aspect of each arm of the levator sling to the nearest aspect of the symphysis. The shape of the ileococcygeus muscle was divided in 2 groups (upwardly biconvex [dome-shaped] and downwardly concave [U-shaped]) and determined by visual inspection as follows: Attention was turned to an axial view of the muscle at the median raphe, midway between the symphysis and the tip of the coccyx. If the muscle turned cephalad then lateral, it was considered upwardly biconvex (dome-shaped; Fig 2, E [left images]). If the muscle moved lateral and then cephalad (or failed to turn cephalad), it was considered downwardly concave (U-shaped; Fig 2, E [right images]). The final results were viewed on a workstation with graphics acceleration, and specialized measurement software was used to compute the linear and volume measurements of the on-screen renderings.

The following statistical methods were used: Univariate summary statistics were calculated for each 2-D and 3-D imaging feature, stratified on the basis of subject group. For each categorical variable, the analysis of contingency tables and the Fisher exact test of independent were used. For each continuous variable, a 2-way analysis of variance and F distribution test of equal underlying means were used. Finally, a multivariate logistic regression analysis was conducted to select the variables on the basis of their predictive values for the subject groups. Only the P values from statistically significant results were reported.

Interater, intrarater, and method-related agreements were assessed on 5 subjects from each group by applying the statistical approach described by Bland and Altman. In essence, the agreement of 2 sets of measurements of a sample of a target population were assessed by relating the measurement difference in each subject to the average of the 2 measurements. The bias was defined as the average of the differences throughout the sample. Limits of agreement were the bias ± 2 SD of the differences. The 95% confidence intervals were computed as described in the reference.

Results

The subjects tolerated the MRI scans well. Good quality source images were obtained, and we were able to easily identify the structures of interest. Segmentation of the structures, and conversion to 3-D, was performed without difficulty. Computation of volume, linear, and angular measures was accomplished interactively, and recorded on a standard form. Data storage for 30 individuals required approximately 20 megabytes per subject, or 600 megabytes in total, which fits on a single CD-ROM disk.

Mean age (± SD [range]) was 51 years (± 9.7 years [41-69]) and 48 years (± 7.3 years [39-56]) in the control and GSI groups and slightly higher 57 years (± 11.5 years [39-56]) in the prolapse group. Vaginal parity (median [range]) was (1 [0-4]) in the control group, (2 [0-4]) in the GSI group, and (2 [0-6]) in the prolapse group. Body mass index (mean ± SD [range]) was similar in the 3 groups at (28 ± 4.2 [22-35]), (26 ± 4.1 [21-33]), and (31 ± 6.3 [25-42]) kg/m² in the control, GSI, and prolapse groups, respectively. There were no statistically significant differences in any of these parameters. Menopausal status showed some variation among the groups, but without statistical significance. The control group showed 40% postmenopausal subjects, while the postmenopausal rate was 60% in the GSI group and 55% in the prolapse group. Twenty-five percent of the healthy postmenopausal subjects were on hormone replacement therapy compared with 50% in the GSI group and 60% in the prolapse group; but these differences were not statistically significant.

2-D results

Axial images. Mean signal intensity in the levator sling increased slightly from the control group to the GSI and prolapse groups at 51, 54, and 67 Hounsfield units, respectively, but did not achieve statistical significance. Obturator externus mean signal intensity was uniform at 45, 48, and 49 Hounsfield units across the 3 groups. Mean levator sling arm thickness failed to demonstrate significant differences across the 3 groups, with left sling arm mean widths of 5.7, 5.6, and 6.2 mm in the control, GSI, and prolapse groups, respectively. The right arm mean widths were nonsignificant at 3.7, 4.3, and 4.9 mm in the same group order. Levator hiatus mean width showed an

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Fig 2. 3-D reconstructed images. A, Showing a lithotomy view of reconstructed 3-D model (note the subject was scanned in dorsal supine position). Color legend: white, pelvic bones; grey, symphysis and coccyx; yellow, bladder/urethra; pink-tan, vagina; red-brown, levator ani; purple-brown, obturator internus; blue, recto-sigmoid. B, Left sagittal view, with left pelvic bones and obturator-internus muscle removed. C, Left sagittal view, illustrating measurement parameters: Pubococcygeal line, solid black line; M-line (ML), white line with double arrows; bladder neck to Pubococcygeal line, black line with double arrows. The levator plate angle is the angle formed by the levator plate (L) and the Pubococcygeal line. The posterior urethrovesical angle (PUVA) is bounded by the posterior bladder wall and the urethra. Its vertex is marked (V). D, Lithotomy view with levator symphysis gap (LSG); left, black line with double arrows; right, white line with double arrows. The H-line (HL) parameter is shown with plain solid black line. E, Levator shape lithotomy view (lower images) and sagittal view (upper images). Left images, Upwardly biconvex (dome-shaped) muscle; right images, downwardly biconcave (U-shaped) muscle.
**Table I. Rest and strain source image parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group 1 (asymptomatic) n=10</th>
<th>Group 2 (GSI) n=10</th>
<th>Group 3 (prolapse) n=10</th>
<th>Statistical significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPCL-R</td>
<td>Mean ± SD</td>
<td>Median</td>
<td>Range</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>BPCL-S</td>
<td>24 ± 4.8 23.7</td>
<td>16-32</td>
<td>10.17 ± 5.2 17.5</td>
<td>8.1-26</td>
</tr>
<tr>
<td>LPA-R</td>
<td>10.24 ± 9.1 9.7</td>
<td>(-4)-24</td>
<td>(-11.2) ± 28.2 (-7.6)</td>
<td>(-83)-18.6</td>
</tr>
<tr>
<td>LPA-S</td>
<td>9.5 ± 16.6 2.5</td>
<td>(-17)-38</td>
<td>10.13 ± 11.9 12.5</td>
<td>0.3-4</td>
</tr>
<tr>
<td>HLR</td>
<td>46.2 ± 8.9 48.2</td>
<td>30-62</td>
<td>48.3 ± 7.7 46.6</td>
<td>37-542.1</td>
</tr>
<tr>
<td>HL-S</td>
<td>48.5 ± 8.3 49.4</td>
<td>33-341.4</td>
<td>51.1 ± 7.2 52</td>
<td>36-541.0</td>
</tr>
<tr>
<td>HL-Del</td>
<td>5.0 ± 4.3 4.1</td>
<td>0.6-13.2</td>
<td>7.9 ± 6.2 6.9</td>
<td>0.6-22.0</td>
</tr>
<tr>
<td>ML-R</td>
<td>14.7 ± 7.0 13.2</td>
<td>3-26</td>
<td>17.6 ± 5.8 16.9</td>
<td>6.7-25.6</td>
</tr>
<tr>
<td>ML-S</td>
<td>17.2 ± 6.2 15.9</td>
<td>9.8-25.1</td>
<td>22.5 ± 6.2 21.6</td>
<td>13-22.52</td>
</tr>
</tbody>
</table>

**Table II. Continuous resting variables from 3-D constructions**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group 1 (asymptomatic) n=10</th>
<th>Group 2 (GSI) n=10</th>
<th>Group 3 (prolapse) n=10</th>
<th>Statistical significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>BVOL</td>
<td>Mean ± SD</td>
<td>Median</td>
<td>Range</td>
<td>Mean ± SD</td>
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<tr>
<td>LH-W</td>
<td>75.5 ± 50 52.3</td>
<td>23-150.5</td>
<td>49.0 ± 36.8 42.6</td>
<td>13-83</td>
</tr>
<tr>
<td>LVOL</td>
<td>25.7 ± 5.7 25.4</td>
<td>16-35.4</td>
<td>34.7 ± 5.4 36.7</td>
<td>24.5-40.6</td>
</tr>
<tr>
<td>B-PCL</td>
<td>19.7 ± 4.3 20.9</td>
<td>15-24.51</td>
<td>12.9 ± 5.5 13.8</td>
<td>0.1-193</td>
</tr>
<tr>
<td>LSG-L</td>
<td>16.4 ± 4.8 14.6</td>
<td>9-23.6</td>
<td>20.3 ± 6.1 20.1</td>
<td>9.4-30.4</td>
</tr>
<tr>
<td>LSG-R</td>
<td>15.6 ± 4.2 16.2</td>
<td>8-22.8</td>
<td>22.5 ± 7.0 22.5</td>
<td>12.4-88.0</td>
</tr>
<tr>
<td>HL</td>
<td>54.7 ± 4.7 55.2</td>
<td>45-68.1</td>
<td>56.7 ± 5.8 57.2</td>
<td>48.5-64.3</td>
</tr>
</tbody>
</table>

**Repeatability.** The interobserver bias for levator volume was 1.17 cm³ and the limits of agreement was ± 4.52 cm³. The intraobserver bias was −26 cm³ and the limits of agreement was ± 3.4 cm³.

**Comment**

Our MR-based 2-D MRI and 3-D markers demonstrate differences between asymptomatic subjects and those with GSI and prolapse. The 2-D results demonstrate a statistically significant continuum in resting bladder neck descent, straining levator plate angle, levator hiatus height, and perineal descent across control, GSI, and prolapse pathology. This points to weakened levators in GSI and prolapse groups compared with the asymptomatic matched control group. The 3-D-derived parameters show a clear and statistically significant continuum in levator volume degradation, loss of sling integrity, and laxity in the order of asymptomatic, GSI, and vault prolapse. Evidence of this continuum is strengthened by visual comparison of the reconstructed levator ani across the 3 subject groups (Fig 3), which demonstrates the bulkiest levators and highest rate of intact slings among the subjects without symptoms, the frailest levators with the lowest rate of intact slings in the prolapse group, and intermediate findings in the GSI group. This combination of results suggests that levator atrophy and loss of structural integrity are major cofactors in female pelvic floor dysfunction.
Fig 3. Color images of reconstructed levator ani muscles from 3 subject groups: A, Asymptomatic group; B, GSI group; C, prolapse group.
By way of comparison, it is interesting to note that mean levator volume in our asymptomatic group was 32.2 mL and the mean age was 51 years. This is in contrast to a mean levator volume of 46.6 mL in our previous study of 10 asymptomatic subjects where the mean age was 27 years. The underlying mean volumes from the 2 studies are statistically significantly different by the 2-tailed 2-sample \( t \) test with 18 degrees of freedom, yielding a \( P \) value of < .005. In light of that previous study, the current data points to an age-related decline in levator volume, which is probably independent of pelvic floor functional status.

The current study also demonstrates that MR-based 3-D reconstruction is a feasible technique to evaluate the symptomatic female pelvic floor. The relatively high resolution and noninvasive nature allows for the visualization of vital pelvic structures, and the lack of anatomic distortion allows for the study of these structures in their natural physiologic state.

The right arm of the levator sling was consistently narrower than the left arm on the 2-D images. This is likely because of a chemical shift artifact at the fat-muscle interface at the medial aspect of the right sling arm.

The disagreement between 2-D and 3-D measurement results is likely the result of variations in the MR slice angle and tilt with respect to the long axis of the subject being scanned. These variations in slice angle can lead to systematic errors in the measurements on the 2-D images, thereby confounding the 2-D analysis. This artifact can probably be best understood by considering the example is given of a cylinder, which is cut perpendicular to its long axis. The cut surface reveals a circle with diameter \( d_1 \). If the same cylinder is cut at an oblique angle, the cut surface yields an ellipse with a larger width \( d_2 \) when compared with the first cut. From trigonometric analysis, the cut-plane distances are related by the equation:

\[
d_1 = d_2 \times \cos(\text{slice-tilt angle})
\]

Specifically, for a 45-degree change in the slice tilt angle, the distance \( d_2 \) will be 41% larger than \( d_1 \). A 30-degree change in slice angle would yield a 15% difference in the measures. This means that any given linear measurement can vary by up to 15% to 40% based only on alterations in the position of the subject in relation to the scanner. This is likely to confound the analysis. The 3-D reconstruction neutralizes this artifact by allowing the user to perform the measurements in arbitrary planes that are not constrained by the source acquisition angles and which are best suited for the specific measurement. Another way to neutralize this artifact would be to standardize the planes of the 2-D slice acquisitions with respect to the long axis of the subject. This source axis standardization was not done in our study and would probably be difficult to achieve across subjects, but it could theoretically ensure consistency across multiple acquisitions and subjects.

A limitation of our study stems from the lack of surgical or clinical confirmation of our imaging findings. Surgical confirmation could be properly achieved only by extensive pelvic floor dissection, which would be inappropriate in living subjects. In an ongoing study, we are comparing MR-based findings with those obtained intraoperatively. We are attempting to find ways to correlate our MR findings with suitable clinical markers. Also, given that our subjects were scanned while they were in the supine positions, it is reasonable to presume that a scan in the upright position would better reflect the anatomic effect of gravity on the levators and pelvic organs. In our earlier work, however, we were unable to demonstrate significant variation in pelvic floor laxity in the sitting compared with the supine position.

Thus, we do not opt to use the Bonferroni adjustment in this preliminary report. We will, however, be interested in developing the relevant statistical methods for this problem, but this is beyond the scope of this report.

This was a pilot study to gain an understanding of the ranges of the parameters under evaluation. As such, it was difficult to accurately gauge the expected variations to perform a priori power calculations. After evaluation of our findings, we performed power calculations on 2 of the nonsignificant 2-D parameters. These were the H-line and the left levator sling width. For the H-line parameter, the study had 24% power to detect a 10% (5 mm) differ-
ence between the asymptomatic group and the prolapse group, and 71% power to detect a 20% (10 mm) difference between the same groups. In the same manner, the left levator sling width had a 17% power to detect a 20% (about 1 mm) increase from the asymptomatic to the prolapse group, and 55% power to detect a 40% (2 mm) increase. We plan to make use of the information gained from this study to guide power calculations in order to optimize future study designs.

Among the subjects with GSI, there was great variation in the levator sling gap. We hypothesize that the larger values of LSG represent defects (tears) in the levator sling attachments to the parasymphysis, whereas smaller values of LSG represent intact levator sling arm attachments. If this finding is extrapolated to the general population of GSI patients, a portion of them can be expected to have intact levator sling arms bilaterally, while others will have tears in one or both sling arms.

The levator is a striated muscle. It is possible that those patients with GSI with bilaterally intact levator sling arms may be able to increase their levator sling tone by way of pelvic floor exercises, thereby enhancing closure at the midurethra and aiding continence. On the other hand, those with torn sling arms would probably not be able to increase their sling tone with exercises. This latter group of subjects would likely be unable to improve their continence status with pelvic muscle exercises. This could explain why some patients with GSI benefit from pelvic muscle exercises and others do not see improvement with such therapy. Furthermore, it has been suggested that estrogen may have tonic effects on collagen in the lower urinary tract, possibly increasing levator sling tone and reversing GSI. However, the work by Fantl et al suggests that estrogen replacement may cure GSI in only a fraction of patients. It is possible that estrogen replacement would cure those patients with GSI with intact levator sling arms, but fail to do so in those with torn levator slings.

We hypothesize, therefore, that unilateral or bilateral levator sling arm defects present a barrier to nonsurgical cure of GSI. If this can be proven, the technique of MR-based 2-D and 3-D analysis of levator sling integrity could be a valuable step in triaging patients with GSI in the future. Patients with intact slings would have a high chance of success with pelvic muscle toning therapy (or estrogen replacement), and those with tears would likely require surgical therapy to reverse their incontinence. We are conducting an ongoing study to test this hypothesis.

REFERENCES