Levator ani thickness variations in symptomatic and asymptomatic women using magnetic resonance-based 3-dimensional color mapping

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Objective: This study was undertaken to develop and test a 3-dimensional (3D) color thickness mapping technique on levator ani imaged with magnetic resonance imaging (MRI).

Methods: Supine MRI datasets from 30 women were studied: 10 asymptomatic, 10 with urodynamic stress incontinence, and 10 with pelvic organ prolapse. Levators were manually outlined, and thickness mapping applied. Three-dimensional models were colored topographically, reflecting levator thickness. Thickness and occurrences of absent levator substance (gaps) were compared across the 3 groups, using nonparametric statistical tests.

Results: Color thickness mapping was successful in all subjects. There were statistically significant differences in thickness and gap percentages among the 3 groups of women, with thicker, bulkier levators in asymptomatic women, compared with women with prolapse or urodynamic stress incontinence.

Conclusion: Color thickness mapping is feasible. It may be used to compare levators in symptomatic and asymptomatic women, to study relationships between levator thickness and pelvic floor dysfunction. This technique can be used in larger studies for hypothesis testing.

Magnetic resonance imaging (MRI) has greatly improved our ability to study the organs and tissues of the pelvis in women. Standard 2-dimensional MRI has been used to assess the anatomy of the female pelvic floor in cadavers and living women. 1-7

In seeking to better understand the specific anatomic defects that may correlate to female pelvic floor dysfunction, our group evaluated the morphology, volume, and integrity of the levator ani and the bladder neck, using reconstructed 3-dimensional (3D) MR-based models in living women. Fielding et al8 demonstrated the feasibility of the 3D 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 used MR-based 3D reconstruction techniques to evaluate a group of 30 women, divided...
into 3 groups. Ten women were asymptomatic (ASY), 10 had urodynamic stress incontinence (USI), and the final 10 had symptomatic pelvic organ prolapse (POP).\textsuperscript{9} That pilot data showed significant differences in levator volume, integrity, and shape across the range of ASY to USI to POP, suggestive of a continuum of disease from ASY to USI to POP. During that study, our observations of the 3D reconstructed images suggested that levator ani thickness may be a strong marker for pelvic muscle health, but we believed that our efforts for objectively quantifying this parameter were unsatisfactory. Therefore, we sought to develop a technique for describing levator muscle thickness that was visually intuitive, mathematically consistent, and feasible for research comparison across large groups of subjects. This article presents the results of our thickness mapping technique, applied to evaluate and compare the thicknesses of levators from the 30 subjects in our prior study.\textsuperscript{9}

**Material and methods**

This is a secondary analysis of a previously presented data set.\textsuperscript{9} In that study, we evaluated 3 groups of women, 10 ASY, 10 USI, and 10 POP, ranging in age from 38 to 78 years. Mean age in the ASY group was 51 years, with a range of 41 to 69 years. Subjects in the USI group were slightly younger, with a mean age of 48 years (range 38-56 years). The POP group was slightly older, with a mean age of 57 years (range 42-78 years). Of the 10 subjects in each group, there were 4, 6, and 6 postmenopausal women in the ASY, USI, and POP groups, respectively. Among postmenopausal subjects, hormone replacement was used by 1 in the ASY group, 2 in the USI group, and 1 in the POP group. If “estrogen-exposed” subjects are defined to include premenopausal and estrogen-using postmenopausal women, there were 7 estrogen-exposed women in the ASY group, 6 in the USI group, and 5 in the POP group. Further details of subject selection, MR scanning protocol, image segmentation, and 3D reconstruction techniques are further described in our previous article.\textsuperscript{9} Our group had previously developed a technique for characterizing and color-coding bladder wall thickness from computed tomographic (CT) images in an attempt to screen for bladder tumors.\textsuperscript{10,11} We modified this technique to measure and color code levator ani thickness.

**Preparation of the MR data for color thickness mapping**

Levator ani muscles on the source axial MR images are manually segmented. The “inner” and “outer” surfaces of the levator are identified on each slice of the segmented data. The inner surface is defined as that part of the levator that faces medially or superiorly in situ, and the outer surface is defined as the part that faces laterally or inferiorly. A 3D reconstruction is then made from the segmented data. This is clarified in Figure 1, where a reconstructed levator is shown with the inner and outer surfaces labeled.

**Color thickness mapping algorithm**

An algorithm is applied to each point (P\textsubscript{inner}) on the levator inner surface, measuring its distance from all points on the outer surface. The distance to the closest point on the outer surface is taken as the thickness of the levator at point P\textsubscript{inner}. After the thickness is determined, each point (or pixel) on the reconstructed image is colored to correspond to its thickness. The range of colors used goes in the order blue, green, yellow, orange, and red, where blue is the thinnest and red is the thickest. Each levator is then inspected, and its thickness at each point determined from its color. An example of
a color-mapped levator is given in Figure 2, along with a legend for mapping the colors back into distances in millimeters.

Data collection and statistical analysis

Each levator is then divided into 4 quadrants, left anterior (LA), left posterior (LP), right anterior (RA), and right posterior (RP). The left-right distinction is made with respect to a sagittal plane running through the mid-symphysis and mid-coccyx. The anterior-posterior distinction is made with respect to a plane parallel to the puborectalis, taken midway between the symphysis and the tip of the coccyx. Generally speaking, the anterior divisions correspond to the puborectalis portion, and the posterior divisions correspond to the ileococcygeus portions. The maximum thickness, minimum thickness, and presence or absence of gaps (ie, absent levator substance) is measured for each quadrant of each levator.

To determine the thickness and gap frequencies, each quadrant of each color-mapped levator is inspected onscreen. The maximum and minimum thickness in each quadrant is determined from the range of colors seen in the quadrant, and this information is recorded. The median thickness and range is calculated for each quadrant by study group.

The presence or absence of “gaps” in the levator substance of each quadrant of each levator is determined by inspection and is recorded as a “1” if a gap (ie, absence of levator substance) is present and a “0” if no gap is present in that quadrant. An example of a “gap” in levator substance is given in Figure 3, and labeled. Gap frequency was computed and recorded for each quadrant by group.

SPSS for Windows (version 10, SPSS Inc, Chicago, Ill) was used for data management and statistical analysis. Because the noncategorical measurements had statistically non-normal distributions, the nonparametric Kruskal-Wallis test and Mann-Whitney test were used to compare the 3 groups. Fisher exact test and Fisher extended exact test were performed to compare the groups with respect to the percentage with gaps in each quadrant. A .05 significance level was used for all statistical tests. No 1-sided statistical tests were performed.

Results

Medians, ranges, and statistical comparisons of maximum and minimum levator thickness for the test groups are presented in Table I for each quadrant of levator ani, across the groups. Statistical comparisons of gap frequencies for each quadrant among the 3 groups are presented in Table II. The right anterior levator was significantly thicker among ASY women when compared with women with USI or POP. The LA levator was significantly thicker in ASY women when compared with women with POP. Minimal levator thickness (ie, the thinnest part of levator ani) was greater in the RA portion in ASY women when compared with women with USI or POP. Minimal thickness was also greater in the LA portions of levator in ASY women compared with women with POP. In addition, there was a lower incidence of “gaps” in the levator substance on the LA levator in ASY women compared with women with USI or POP. All these differences were statistically significant.

Comment

These pilot study data demonstrate the usefulness of the color thickness mapping technique as a way to mathematically characterize and communicate information on levator muscle thickness in different portions of the muscle. In this experiment, the technique permitted us to easily visualize and quantify muscle thickness. On the basis of this experience, the technique appears to be suitable for reviewing and comparing large numbers of levators.

The results of this study suggest that the anterior portion of the levator (ie, puborectalis) is bulkier bilaterally in ASY women compared with those with...
POP, and bulkier on the right in ASY women compared with women with USI. On the left, significant increases in loss of levator substance are noted in the anterior portions of the levators in women with POP and USI, compared with ASY women. This finding is also suggestive of decreased bulk in the symptomatic groups. Possible explanations for these findings include muscle atrophy caused by denervation from childbirth injuries, or perhaps muscle wasting caused by the loss of insertion points for the puborectalis, also stemming possibly from childbirth injury, as has been suggested by the results of Delancey et al.\(^\text{12}\)

It is also possible that these may be normal variations in muscle parameters, as was seen by Tunn et al\(^\text{7}\) when they evaluated levator geometry in a group of nulliparous women.

Because striated muscle atrophies with age, and estrogen receptors have been detected in levator muscle stroma and fascia;\(^\text{13}\) it is reasonable to expect that levator muscle bulk, and thus thickness, is likely to decrease with age, and possibly also with estrogen status. Age and hormonal status therefore represent confounding factors in our analysis. There was considerable age overlap among the groups, but the USI group was the youngest, followed by the ASY and POP groups, respectively. On the basis of these age distributions, it is possible that age-related muscle atrophy could help to account for the differences in thickness and “gapping” between the ASY and POP (or USI and POP) groups, but not between the ASY and USI groups. Regarding hormonal status, there were 7 estrogen-exposed women in the ASY group, 6 in the USI group, and 5 in the POP group. It is possible that hormonal status might influence the comparison between the ASY and POP (or USI and POP) groups, but less so the comparison between ASY and USI groups. However, these relationships are best explored by a larger well-designed study.

In either case, a reduction in puborectalis bulk is noted in women with USI or POP, when compared with ASY women. The clinical significance of this finding remains to be clarified in larger studies.

In a multicenter study, Swift et al\(^\text{14}\) found stage II POP in 32% of women presenting to general gynecology clinics. Their results were not generalizable to the US population because of the racial and socioeconomic composition of the study population. Still, it is probably reasonable to expect a proportion of subjects with stage II POP among our ASY group. If POP is associated with a lower muscle bulk, then mean muscle thickness in our ASY group would be pulled lower by those ASY women with undiagnosed POP, and this would tend to narrow the differences among the study groups. If these “occult” POP subjects were excluded from the ASY group, the overall thickness and bulk of the levators in this group would be expected to increase, strengthening the differences among the groups. This point reinforces the need for objective subject characterization.

Regarding the gaps in the levator muscle substance, the well-known chemical shift phenomenon can, by artifact, “thin out” the muscle signal on MRI, depending on the encoding direction of the MR scan, and the spatial relationship of muscle to fatty tissue. For this

### Table I

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<thead>
<tr>
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<th>Maximal and minimal thickness parameters by levator quadrant in ASY vs USI and POP groups</th>
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<tbody>
<tr>
<td></td>
<td>Median Range</td>
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<tr>
<td>RA-max</td>
<td>10.01 8.6-11.35</td>
</tr>
<tr>
<td>RA-min</td>
<td>4.66 2.00-7.33</td>
</tr>
<tr>
<td>RP-max</td>
<td>8.00 2.00-11.33</td>
</tr>
<tr>
<td>RP-min</td>
<td>2.00 0.66-4.66</td>
</tr>
<tr>
<td>LA-max</td>
<td>11.35 10.01-11.35</td>
</tr>
<tr>
<td>LA-min</td>
<td>4.66 2.00-7.33</td>
</tr>
<tr>
<td>LP-max</td>
<td>7.33 4.66-11.35</td>
</tr>
<tr>
<td>LP-min</td>
<td>2.00 0.66-4.66</td>
</tr>
</tbody>
</table>

*RA-max, Maximal right anterior levator thickness; RA-min, minimal right anterior levator thickness; RP-max, min, right posterior levator maximal and minimal thickness; LA-max, min, left anterior maximal and minimal thickness; LP-max, min, left posterior levator maximal and minimal thickness; NS, not significant.*

### Table II

<table>
<thead>
<tr>
<th></th>
<th>Levator gap frequency by quadrant in ASY vs women with USI and POP</th>
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<tbody>
<tr>
<td></td>
<td>ASY %Gaps</td>
</tr>
<tr>
<td>RA</td>
<td>30</td>
</tr>
<tr>
<td>RP</td>
<td>80</td>
</tr>
<tr>
<td>LA</td>
<td>10</td>
</tr>
<tr>
<td>LP</td>
<td>90</td>
</tr>
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</table>
reason, one side (right) of the levator muscle tended to appear thinner on the MRI than the other side (left). Thickness comparisons between left and right sides were not attempted because of this artifact. The artifact-induced preferential thinning on the right should have led to more “gaps” on the right, in places where the muscle was truly thin to begin with. However, more gaps were seen on the left, where the muscle was thicker. This finding suggests that the “gaps” seen on the left represent a true finding, unrelated to artifact. These gaps may represent fibrosis or fatty infiltration of the muscle, and remain to be elucidated.

The important topic of interobserver and intraobserver measurement variability was addressed in the original manuscript, covering the manual segmentation used to calculate levator volume.9 As noted there, the interobserver bias was 1.17 mL, with limits of agreement at ±4.52 mL, and the intraobserver bias was −0.26 mL, and limits of agreement were ±3.4 mL. However, one could obtain identical volume measurements from 2 different segmentation geometries. Consequently, an appropriate reliability analysis needs to consider the spatial overlap of the segmentations as well as the actual numeric results (eg, volume or thickness). That type of analysis was not available when we did the current study, and is not included here. Since then, a suitable reliability technique has been developed by our colleagues at the Surgical Planning Laboratory,15 and we look forward to testing it on our datasets.

The current 3D thickness analysis is more accurate than a straight 2D analysis. This is true because a single slice thickness measurement only considers adjacent points within the plane of the slice, whereas the 3D analysis also considers adjacent points outside of the slice plane. Furthermore, variations in the MR slice acquisition angle can introduce artifacts that alter the thickness of the item under study.16 These artifacts are not present in the 3D thickness analysis. The 3D visual renderings allow an observer to quickly localize and compare thicknesses across large numbers of levators, and this capability is not readily available in slice-by-slice thickness analysis. In addition, a full mathematical description of the thickness at each point on the surface is retained as part of the geometric description of the color-mapped levator. Future algorithms can analyze and compare such descriptions across groups of interest.

Our study has some limitations, and we plan to remedy these in future work. First, our characterization of our subjects was limited to urodynamic testing and prolapse staging in the symptomatic groups only. In future studies we plan to include a validated symptom questionnaire, cough stress and urodynamic testing, and POPQ staging in all of our study subjects. Finally, the color-map analysis is limited by the speed of segmentation. With the use of the manual technique, segmentations can proceed at the rate of under 1 person-hour per dataset. This works out to about 2000 datasets per person-year, assuming 40-hour work week. We are currently evaluating methods for shortening the time required to process each dataset. Despite these limitations, our findings are potentially clinically relevant and we plan to continue this work in larger studies in the future.

Acknowledgments
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References
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