MR-Based Three-Dimensional Modeling of the Normal Pelvic Floor in Women: Quantification of Muscle Mass

OBJECTIVE. Our objective was to use a combination of axial MR source images and three-dimensional (3D) models to describe the anatomy of the normal pelvic floor in young nulliparous women and to measure the volume of the levator ani.

SUBJECTS AND METHODS. Ten healthy nulliparous female volunteers (average age, 27 years) underwent T2-weighted MR imaging of the pelvis. Three-dimensional color-coded models of the pelvic bones and organs and the three major components of the levator ani—puborectalis, iliococcygeus, and coccygeus—were created. Source images were used to measure muscle width and signal intensity and to identify ligamentous structures. Using 3D models, we measured the volume of the levator ani, the angle of the levator plate, the posterior urethrovesical angle, and the distance of the bladder neck from the symphysis pubis and the pubococcygeal line.

RESULTS. In all volunteers, the signal intensity of the puborectalis exceeded that of the obturator externus. The average volume of the levator ani was 46.6 ml, the average width of the levator hiatus was 41.7 mm, and the average posterior urethrovesical angle was 143.5°. Vaginal shape in the volunteers followed no recognizable pattern.

CONCLUSION. Muscle morphology, signal intensity, and volume is relatively uniform among healthy young women.

Subjects and Methods

We recruited 10 young (age range, 22–33 years; mean age, 27 years), nulliparous continent female volunteers from the hospital community. One woman had undergone resection of an ovarian cyst. Because this surgery was performed approximately 10 years before the MR examination and because the surgery involved an abdominal wall incision, it seemed unlikely that the pelvic floor anatomy would have been altered. The remaining women denied previous pelvic surgery. All women underwent MR imaging of the pelvis using a 1.5-T magnet (Signa 1.5; General Electric Medical Systems, Milwaukee, WI) and a pelvic phased array or torso coil wrapped around the pelvis. After discussion of possible risks and benefits, informed consent was obtained from all the women before imaging. Institutional review board approval is not required at our institution for MR imaging using standard pulse sequences. Standard two-dimensional T2-weighted images were obtained in the axial plane with the following imaging parameters: TR/TE_{eff} 4200/108; phase encodes, 128; field of view, 24 cm; slice thickness, 3-mm interleaved; acquisitions, two. Because of a diminished signal-to-noise ratio, it was not possible to use a slice thickness smaller than 3 mm. Therefore, the entire
sequence was repeated to adjust the slice locations to obtain interleaved contiguous images 1.5 mm thick. In most volunteers, scan time was 9 min. Depending on body size, we obtained between 60 and 100 images.

After the MR imaging was completed, the images were electronically transferred to a workstation (Sun Microsystems, Mountain View, CA) for production of 3D models. On average, 70 axial images were used to form each model. The data were first segmented into anatomically significant components including bones, bladder, urethra, vagina, uterus, rectum, obturator internus, and the three major components of the levator ani (puborectalis, iliococcygeus, and coccygeus) using manual editing (Fig. 1). It was not possible to identify and segment the pubovaginalis or puboanalis muscles individually; therefore, they were included in the puborectalis muscle. The iliococcygeus could be identified on axial images in all but a few patients in whom examination of both axial and reconstructed coronal images was required. Each model required 10 hr to complete segmentation.

From these images, 3D renderings of the pelvic viscera and supporting muscles and bones were reconstructed with the marching-cubes algorithm and a surface-rendering method [8] (Fig. 2). We used a surface-rendering method rather than a volume-rendering method because the latter offered no advantage in the identification of target structures and required significantly more time. Our method of slice-by-slice outlining of polygons did not use a numeric threshold value that may alter measurements. The final results were viewed on a workstation with graphics acceleration and 3D slicer software (developed in house) allowing visualization and measurement of source images and models simultaneously (Fig. 3).

Two radiologists reviewed each case in consensus. Source images were used to determine width of the levator hiatus, width and signal intensity of the puborectalis, signal intensity of the obturator externus, vaginal shape (H shape, flattened, or asymmetric), and presence or absence of the lateral pubovesical ligaments. All measurements were made at the level of the transverse urethral ligament, a thin low-signal band located just anterior to the mid portion of the urethra. The width of the puborectalis muscle was measured at its midpoint in the axial plane to the right and left of the vagina. The angle of the levator plate, distance from the bladder neck to the symphysis and the pubococcygeal line, posterior urethrovesical angle, and volume of the levator ani were measured using 3D models. All measurements were treated as continuous data. The relationships between body mass index and the remaining variables were assessed with correlation coefficients and simple linear regression analyses.

Results

High-quality source images were obtained and models generated in all 10 volunteers (Table 1). The mean body mass index, calculated with the formula of weight (kg) / height (m)$^2$,
was 21.2 kg/m². The mean width of the levator hiatus, measured at the level of the transverse urethral ligament, was 41.7 ± 4.7 mm. The right side of the puborectalis was consistently thinner than the left, with a mean thickness of 2.2 ± 0.5 mm versus 4.4 ± 0.7 mm. The average signal intensity of the puborectalis muscle was 45.1 ± 11.2 compared with 30.0 ± 5.5 for the obturator externus muscle. The volume of the combined coccygeus, puborectalis, and iliococcygeus was 46.6 ± 5.9 ml (range, 39.4–57.7 ml).

Five women had H-shaped vaginas, four vaginas were flat, and one was asymmetric. The lateral pubovesical ligaments extending from the urethra to the arcus tendineus fasciae (site of fusion of supporting fascia to bony undersurface of the pelvis) were visible in all 10 volunteers. The mean distance from the bladder neck to the pubococcygeal line was 21.7 ± 4.2 mm; the mean distance from the bladder neck to the symphysis was 21.5 ± 5.3 mm. In six volunteers, the levator plate was parallel to the pubococcygeal line. In the remaining four volunteers, the levator plate formed an angle with the pubococcygeal line ranging from –5° to 18°, (mean, 8.5°). The mean posterior urethrovesical angle was 143.5° ± 10°.

Because a high body mass index is associated with stress incontinence and presumed diminished pelvic floor muscle width and volume, we searched for an association between the two. Statistical analysis with linear regression revealed a moderate and negative

### TABLE 1

<table>
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<tr>
<th>Healthy Volunteers</th>
<th>Body Mass Index (kg/m²)</th>
<th>Lev SI</th>
<th>Obt Ext SI</th>
<th>Width (mm)</th>
<th>Bladder Neck (mm) to PCL</th>
<th>Angle Lev R Plate</th>
<th>PUAb</th>
<th>Volume Levator Ani (ml)</th>
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<td></td>
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<td>Lev Hiatus</td>
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Note.—Lev SI = signal intensity of puborectalis, Obt Ext SI = signal intensity of obturator externus muscle, lev hiatus = levator hiatus, LevR = right aspect of puborectalis, LevL = left aspect of puborectalis, PCL = pubococcygeal line.

aAngle of levator plate with pubococcygeal line.

bAngle of urethral insertion at bladder neck.
correlation ($r = -0.69$) between width of the right aspect of the puborectalis and body mass index. No significant correlation between body mass index and volume of the levator ani ($r = 0.12$) was found.

**Discussion**

The 3D anatomy of the healthy female pelvic floor derived from MR images shows consistent signal intensity. Morphology of the levator ani shows small standard deviations. The morphology of the levator ani depicted in our 3D models of living women is in agreement with previous studies that used cadavers [2, 3]. The increased signal intensity of the puborectalis muscle compared with that of the obturator externus may indicate more fat in the puborectalis, the muscle supporting the rectum, vagina, and bladder neck. Increased T1 signal intensity of the puborectalis muscle was associated with stress incontinence [9].

As reported by Fielding et al. [6, 7], the average width of the levator hiatus at the level of the transverse urethral ligament, approximately 4 cm, is constant in the healthy female population. A widened levator hiatus that correlates with the clinical genitai hiatus at our measured level was reported in association with pelvic organ prolapse [10]. Tunn et al. [11] used MR imaging, including a body coil and dual-echo T2-weighted imaging, to assess the anatomy of the female pelvic floor in 20 healthy women who were 17–63 years old. Those researchers reported the puborectalis muscle to be 5.2 mm thick to the right of the vagina, and 7.6 mm thick to the left at the level of the mid urethra. In our population of women, we found the puborectalis to be narrower at a similar level, probably because we achieved higher resolution images by using a multicoil array and because our population was more homogeneous in age and pregnancy history. We also found asymmetry of width of the puborectalis, with the right aspect consistently thinner than the left. Tunn et al. showed that at least part of this difference was caused by the chemical shift artifact. Review of our images, however, revealed little artifact. No correlation between body mass index and volume of the levator ani was found; however, limiting the power of this observation, the range of body mass index was quite narrow.

The lateral pubovesical ligaments that support the proximal urethra and bladder neck and recently described as the pararethral ligaments by Tan et al. [12] were identified in all 10 women. The variable shape of the vagina in the volunteers was reported in previous studies to be associated with continent and incontinent women [6, 7]. Other researchers reported a flattened or asymmetric vagina on axial images to be associated with loss of vaginal support and a paravesical tear [13, 14]. It seems likely that the vagina varies in shape in the healthy population.

An expected occurrence in continent women was finding the levator plate nearly parallel to the pubococcygeal line. Other researchers reported a caudal inclination of the levator plate associated with cystocele and uterine and vaginal vault prolapse [10, 15]. The location of the bladder neck close to the symphysis and above the pubococcygeal line is also an expected finding in healthy women [16]. The average posterior urethrovaginal angle was larger than that derived from voiding cystourethographic studies because our measurements taken from the posterior surface of the urethra rather than the lumen generated a more obtuse angle [17]. In previous studies, some authors correlated a widened posterior urethral angle (>115°) with the presence of stress urinary incontinence, although this correlation remains an area of contention [18, 19].

A limitation of our study is the lack of correlation of imaging findings with physical examination. A young continent nulliparous woman may have some congenital laxity of the pelvic floor support structures or even a paravesical tear. It did not seem reasonable to subject healthy volunteers to a detailed gynecologic examination. Also, because our results correlate well with those derived from cadavers with normal anatomy, it seems unlikely that our volunteers had any significant anatomic abnormality. A second limitation of our study is the small sample size, which limits statistical power.

In the future, urinary incontinence and pelvic organ prolapse may be treated in a more sophisticated and efficacious manner. Therapies have not been optimized and many different surgical procedures and nonsurgical therapies have been reported for the treatment of these conditions. Women with intact pelvic floor support structures would respond well to behavior modification techniques and estrogen replacement therapy, whereas those with disruption of the levator ani would benefit from surgery. Rapidly improving computer hardware and software tools may soon make 3D imaging faster and more cost-effective. If such imaging becomes a reality, it could provide information such as muscle morphology, bulk, and signal intensity to guide appropriate treatment. Our measurements derived from the anatomy of healthy young women provide a baseline to which symptomatic women can be compared.

**References**