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The Axial Location of Structural Regions in the Urethra: A Magnetic Resonance Study in Nulliparous Women

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Abstract

OBJECTIVE—To define and quantify the appearance and location of distinct regions of the bladder neck and urethra by using axial magnetic resonance images from healthy, continent, nulliparous women.

METHODS—Seventy-eight asymptomatic, healthy, nulliparous women (mean age 29.2 ± 5.4 years) volunteered for this study. All women were proven continent on urodynamic examination. Axial proton density magnetic resonance images of the pelvic floor were analyzed at 5-mm intervals. A geometric origin was established at the internal urethral meatus. The presence or absence of each of six structural regions—the bladder base, bladder neck, striated urethral sphincter, compressor urethrae and urethrovaginal sphincter, perineal membrane, and distal urethra—was then noted in each more distal image. The proportion of women in whom a structural region was seen at each 5-mm interval was recorded.

RESULTS—The striated urogenital sphincter was observed at 5–25 mm distal to the bladder base. It was observed 10 and 15 mm below the bladder base in 91% (95% confidence interval [CI] 85%, 98%) and 99% (95% CI 97%, 100%), respectively, of all women. The perineal membrane, marking the distal end of the muscular urethra, was located 20–35 mm distal to the bladder base. The length of the muscular region of the urethra ranged from 20 to 35 mm (mean 24 mm, 95% CI 24, 25 mm).

CONCLUSION—Magnetic resonance images allow the normal appearance and location of urethral and bladder neck structures to be quantified in healthy, continent, nulliparous women.

To identify the anatomic changes that might be associated with impaired urethral function, it is important first to describe the normal variation in urethral morphology in healthy, continent individuals.

Histologic studies have been used to describe this variation in vitro^{1–5}; however, interpretation of the results is complicated by the unknown continence status of the donors. When ultrasound,^{6–8} computed tomography,⁹ and magnetic resonance¹⁰ are used to study urethral morphology in vivo, along with urodynamic studies of the same individuals, they offer the possibility of correlating structure–function relationships in a way that is not usually possible with in-vitro studies.

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Among these diagnostic imaging modalities, magnetic resonance offers the best soft tissue resolution, and it has been used successfully to examine urethral anatomy.^{11–15} However, these studies included women with either pathologic conditions of the pelvic floor or symptoms of pelvic floor dysfunction, thus the normal appearance of the urethra in healthy continent women remains unknown.

The purpose of this study, therefore, was to define and quantify the appearance of distinct regions of the bladder neck and urethra on axial magnetic resonance images from healthy, continent, nulliparous women.

MATERIALS AND METHODS

The study was approved by the University of Michigan Medical School Institutional Review Board. Between November 1997 and April 2001, we recruited 78 nulliparous, continent women through advertisement (mean [$\pm$ standard deviation] age 29.2 ± 5.4 years; 93% Caucasian, 3% African American, 4% other). No woman in this group had a history of term pregnancy or pelvic floor surgery. All were healthy and continent on history and urodynamic examination; their mean urethral closure pressure was 88 ± 24 cm H₂O (range 40–142). Their mean body mass index was 24 ± 4 kg/m² (range 18–40). For the purpose of the study, we defined continent as no history of “leakage of urine beyond control” confirmed by a negative full bladder stress test.

After signing an informed consent document, women underwent a filling-cystometrogram and a full bladder standing cough test. All women then had a multiplanar, two-dimensional, fast spin proton density magnetic resonance scan (echo time 15 milliseconds; repetition time 4000 milliseconds) in the supine position. The scan was performed on a 1.5-Tesla superconducting magnet (Signa; General Electric Medical Systems, Milwaukee, WI). The slice thickness was 4 mm, with a slice gap of 1 mm, yielding an image spacing of 5 mm. A 160×160 mm field of view and an imaging matrix of 256×256 were used. Although axial, sagittal, and coronal views were taken, the study focused on the axial views. Figure 1 explains the orientation of the scan planes.

In assessing the quality of each magnetic resonance scan, we considered the following artifacts: motion, partial volume averaging, truncation, and chemical shift.¹⁶ The quality was judged as adequate if main structures in the pelvis (bladder, urethra, vagina) could be identified and differentiated. The quality was judged as inadequate if urethral and pelvic floor structures could not be differentiated. Three scans had to be excluded owing to motion artifacts, leaving 75 magnetic resonance imaging scans for the study evaluation.

The definitions of the urethral and bladder neck structure appearances were based on prior studies of urethral anatomy.^{2,4,5,6,13} There are three distinct parts to the striated urogenital sphincter: the striated urethral sphincter, the compressor urethrae muscle, and the urethrovaginal sphincter muscle.¹ In its proximal part, the urethra includes the bladder base, the bladder neck, and the urethral sphincter. More distally, the compressor urethrae and urethrovaginal sphincter terminate outside the urethral wall, and the urethra fuses with surrounding tissues in the perineal membrane. Distal to the perineal membrane, the urethra is devoid of striated muscle (Figure 1).

To facilitate measurement of the location of structures along the length of the urethra, a geometric reference point, “O,” was defined at the bladder base, specifically at the point of the internal urethral meatus. The axial locations of all subsequent images were defined in terms of their distance, in millimeters, distal to the origin, “O.” For example, we used 10 mm to indicate the scanned tissue in the second image below the bladder base. The appearance of each image

was noted along with its location relative to “O.” The perineal membrane demarcated the distal end of the muscular urethra.

The length of the muscular urethra, the locations of the proximal and distal ends of the urethral sphincter, and the distance between the bladder base and the urethral sphincter were measured. The length of the muscular urethra was defined as the distance from the bladder base to, and including, the perineal membrane.

We determined interobserver reliability by having 20 scans independently analyzed by two different investigators (WU and RK). We report the percent agreement rate on the classification of structural regions.

The proportion of women in whom a specific morphologic appearance of urethral structures was seen at each 5 mm distal to the bladder base is reported as percentages. Means, standard deviations, minimum, maximum, and confidence intervals [CIs] are given.

RESULTS

Six regions of urethral anatomy and bladder neck structures were discernible: bladder base, bladder neck, striated urethral sphincter, compressor urethrae muscle and urethrovaginal sphincter muscle, perineal membrane, and distal urethra. Figure 2 shows three examples of each of the identified structures (distal urethra not shown). Figure 3 shows two entire individual urethrae. In the following description, structures that appeared with high signal intensity on proton density scans will be described as “bright,” whereas those structures that appeared with low signal intensity will be described as “dark.”

The bladder base region was identified where the urethral lumen emerged from the bladder. It usually appeared as an inverted omega (Ω), with the detrusor muscle dorsal to the beginning of the urethral lumen. A complete tube was not yet visible at this level.

In the bladder neck region, the urethral lumen was surrounded by the muscle of the bladder. An outer dark layer of detrusor was often visible around a lighter ring of trigonal smooth musculature. The urethral lumen appeared bright. Frequently, the surrounding submucosa appeared as a thin dark ring. Surrounding the submucosa, the urethral smooth muscle was a broad, bright ring, which could be differentiated from the smooth muscle of the detrusor.

In the region distal to the bladder neck but proximal to the perineal membrane, the striated urethral sphincter forms the outer layer of the urethra as a dark ring. Consistently, the ring appeared symmetric with little to no decrease in size along the dorsal aspect where the sphincter conjoins with the vagina. The sphincter encircled a bright ring, namely the smooth muscle layer. The circular and longitudinal smooth muscles could not be differentiated. Inside the smooth muscle ring lay a second dark ring, the submucosa. Outside the urethral sphincter, fat was found in the Space of Retzius on its ventral aspect, vessels on its lateral aspects, and the muscular layer of the ventral vaginal wall dorsally.

The region distal to the urethral sphincter contained the other two parts of the striated urogenital sphincter: the compressor urethrae and the urethrovaginal sphincter muscles. These muscles diverged from the urethral wall, and were distinct structures but they were not consistently visible.

In the perineal membrane region, at the caudal end of the compressor urethrae and urethrovaginal sphincter muscles, the urethra fused with the perineal membrane and the surrounding structures. The urethra was no longer a separate structure in this region. The distal

portions of the compressor urethrae and urethrovaginal sphincter muscles could still be seen in this region as they passed toward their peripheral origins.

The distal urethra (not shown in Figure 2) was identified caudal to the perineal membrane. Here the urethra passed between the bulbs of the vestibule. This layer is fibrous and devoid of striated muscle; it only contains the terminations of the longitudinal muscle.

Figure 4 shows the proportions of the 75 urethras' morphologic appearances at given levels below the bladder base. The bladder neck extended to 15 mm below the bladder base. Because the scans had a finite interval of 5 mm, it was possible that an anatomic region was too short to be seen in any image. As a result, the urethral sphincter followed the bladder base at 5 mm in 16% of all women. The urogenital sphincter could be found 5–25 mm below the bladder base. The proximal part of the urogenital sphincter contained the urethral sphincter, and the distal part contained the compressor urethrae and urethrovaginal sphincter muscles. The compressor urethrae and urethrovaginal sphincter muscles were seen at 15 mm in 4% (95% CI 0%, 8%), at 20 mm in 15% (95% CI 7%, 23%), and at 25 mm in 4% (95% CI 0%, 9%). These percentages are not separately shown in Figure 4. The perineal membrane region was found 20, 25, 30, and 35 mm below the bladder base in 28% (95% CI 18%, 38%), 57% (95% CI 45%, 69%), 13% (95% CI 4%, 22%), and 1% (95% CI 0%, 5%) of all women, respectively.

The distance between the bladder base and the proximal end of the striated urethral sphincter was 5 mm in 17.3% (95% CI 8.7%, 25.9%), 10 mm in 73.3% (95% CI 63.3%, 83.3%), and 15 mm in 9.3% (95% CI 2.7%, 15.9%).

Urethral length, defined as the distance from bladder base to perineal membrane, was 20 mm in 29% of all women (95% CI 19%, 39%), 25 mm in 57% (95% CI 46%, 68%), 30 mm in 13% (95% CI 5%, 21%), and 35 mm in 1% (95% CI 0%, 3%) (mean 24 mm, 95% CI 24, 25 mm).

The interobserver reliability between two of the authors (WHU and RK) was 83%, expressed as agreement on the recognition of structural regions.

DISCUSSION

This study quantifies the appearance and location of structural regions along the length of the bladder neck and urethra on magnetic resonance images in continent, nulliparous women. It defines normal anatomy, as seen on magnetic resonance images, which can help in future research to determine whether age and/or vaginal delivery alter the visible appearance of the urethra. It is also a precursor to investigations that could describe the structural abnormalities that might be associated with urinary incontinence.

In the first published work on magnetic resonance imaging of the female urethra, Hricak et al¹² described how the appearance of urethral anatomy varied, depending on the location along its axis. In the middle third of the urethra the authors found a “target like” appearance in 80% of women and in 100% of those less than 40 years old. In the distal third, they found the “target like” appearance in only 30% of the urethras. Our results are consistent in that we found increasing numbers of poorly defined sphincter muscle in the distal part of the muscular region of the urethra. Because magnetic resonance imaging techniques and resolution have improved, we might have been able to see poorly defined urethral sphincter that Hricak et al could not see.

The locations of urethral structures have been evaluated in vitro before. A histologic study found the maximum thickness of the striated urethral sphincter at 50–70% of the total length of the muscular urethra.⁵ In another study, urethral length was measured from the bladder neck to the external meatus, and the striated urethral sphincter lay between the 18th and 64th

percentile of that length.² Our results are consistent in that we found urogenital sphincter 5–25 mm below the bladder base in urethrae, which measured 20–35 mm in length.

A number of earlier studies have examined the axial configuration of the striated sphincter muscle. For example, using diagnostic ultrasound in both continent and incontinent women, Athanasiou et al⁷ described an “omega” (Ω) shape of the urethral sphincter with a thinner or missing dorsal part. Perucchini et al⁵ described a progressive loss of muscle fibers in the dorsal part of the urethral sphincter with increasing age. In the present urethrae, we consistently observed a symmetric ring of sphincter muscle. This differs from earlier observations and might be explained by the fact that we examined young, nulliparous women, whereas earlier studies sampled mainly older, parous women. Examinations of additional urethrae using magnetic resonance imaging should allow a better understanding of what is normal morphology and which changes are age- or parity-related.

Other magnetic resonance studies of the female urethra have focused on pathology, as reviewed by Ryu et al¹⁷ and Siegelman et al.¹⁸ Various coil techniques have been used, including intravaginal¹⁴ and intraurethral coils.¹⁵ Although smaller coils can be applied closer to the area of interest and do provide better image resolution, both intravaginal and intraurethral coils inherently distort urethral anatomy. To limit distortion, we chose not to use such coils.

The presented method has a number of limitations. In this study, women were in the supine position during scanning. At present, we believe that the supine position is preferred. It minimizes variation in urethral axis and allows women to remain motionless during the 4 to 5 minutes that one high resolution scan lasts. Upright scans with women seated on a commode have been done,¹⁹ but this introduces its own distortions, putting women in a posture for evacuation. We would prefer to scan women in the standing position, but this has limitations at present. Technical advances in magnetic resonance imaging are needed to produce images of sufficient detail in standing women.

The choice of a 4-mm slice thickness meant that the minimum resolution with which the location of any given structure could be measured was 4 mm. This choice was a compromise between the higher spatial but poorer image resolution associated with thinner slices, and lower spatial but higher image resolution associated with thicker slices.

The estimates of axial location are most accurate for women with average urethral lengths but will be less accurate for women with short or long urethrae.

Finally, there is possible subjective bias in reading the magnetic resonance scans. In this study, all scans were examined by the first author (WHU) and then reviewed together with the senior author (JD). The interobserver agreement among two authors (WHU and RK) on the classification of urethral structural appearance was 83% and as such comparable with other imaging studies.

At present, magnetic resonance technology cannot provide detailed images of individual muscle fibers, even when intravaginal or intraurethral coils are used. As a consequence, the visualization of fiber direction remains a domain of histology and cadaver dissection. Quantification techniques are also limited because some urethrae have a slight curve around the pubic symphysis, so that axial images are not uniformly perpendicular to the urethral axis. This is a normal phenomenon,¹ but a straight urethral axis would be preferable when quantifying urethral structures. It is likely to be more of a problem in women with pelvic support defects, and in our population it proved to be a minor limitation.

In an earlier study, we described a system for analyzing the location of several pelvic floor structures, using bony landmarks.²⁰ It became evident during that study that considerably more

detail could be seen in the urethra than the reported presence of the urethra and bladder neck. The present study expands on the earlier study by quantifying the location of all elements of the urethra that are currently visible on magnetic resonance imaging. We expect that improved scanning techniques will allow even more detailed structural analysis in the future.

Knowledge of the normal appearance of the female urethra is important for further magnetic resonance studies of the continence mechanism. Magnetic resonance measurements will allow studies to compare healthy with incontinent, young with old, and nulliparous with parous women. In addition, it will be possible to correlate functional measurements, such as urethral closure pressure and the occurrence of intrinsic sphincter deficiency with the structural appearance of the urethra.

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Figure 1.

Diagram of bladder neck and urethral anatomy. Lines correspond to the orientation of axial scans. Letters A–E indicate levels at which the following structures typically appear on axial magnetic resonance scans: A, bladder base; B, bladder neck; C, striated urethral sphincter; D, compressor urethrae and urethrovaginal sphincter muscles; E, perineal membrane. PS = symphysis; V = vagina; SUS = striated urethral sphincter; CU = compressor urethrae muscle; UVS = urethrovaginal sphincter; BS = bulbospongiosus muscle. © DeLancey, 2003. Umek. Normal Urethra on MRI. *Obstet Gynecol* 2003.

Figure 2.

Variations of normal urethral anatomy. Each column shows three examples of typical urethral anatomy, each from a different woman. Rows do not represent individual urethrae. SUS = region of the striated urethral sphincter; CU/UVS = region of the compressor urethrae and urethrovaginal sphincter muscles; PM = region of the perineal membrane; B = bladder; V = vagina; PS = pubic symphysis. *Arcuate pubic ligament below the symphysis pubis. © DeLancey, 2003.

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Figure 3.

Examples of two individual urethrae of different lengths. Each row represents a single urethra from bladder base to perineal membrane. Both are aligned at the bladder base (first picture on the left). Numbers are the distance distal to the bladder base, in millimeters. The perineal membrane (last picture on the right) marks the end of the muscular urethra. B = bladder; V = vagina; * Arcuate pubic ligament under the symphysis pubis. © DeLancey, 2003. Umek. Normal Urethra on MRI. Obstet Gynecol 2003.

Figure 4.

Percentage distribution (ordinate) of urethral appearances at each given level along the urethral axis (abscissa). Each column represents the percentage of all women who showed the particular urethral appearance at the given distance from the bladder base (left column). For example, 91 in the third column from left means that 91% of the 75 women showed a striated urethral sphincter appearance of the urethra at 10 mm below the bladder base. Columns at 25, 30, and 35 mm do not sum to 100% because some urethrae already ended at 20 mm. SUS = striated urethral sphincter; CU/UVS, compressor urethrae and urethrovaginal sphincter muscles. © DeLancey, 2003.

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