Repeatability of Female Midurethral Measurement Using High-Frequency 3-Dimensional Transvaginal Ultrasonography

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Objectives—Imaging assessment of the female urethra is critical for diagnosis and treatment of urinary incontinence. High-frequency 3-dimensional (3D) transvaginal ultrasonography (TVUS) is a novel technique for evaluating the female urethra. The aim of this study was to test the repeatability of 3D TVUS between examiners without prior experience with TVUS.

Methods—Fifty women underwent 3D TVUS. Two examiners without prior experience analyzed the urethral volumes and measured the urethral parameters. Two-dimensional (2D) parameters included urethral sphincter length and urethral sphincter thickness; 3D parameters included urethral sphincter volume, midurethral complex volume, and inner core volume. One of the examiners repeated the evaluations 1 month later. Subsequently, the measurements were compared.

Results—The mean age of the patients ± SD was 34.1 ± 8.1 (range, 23–55) years; the mean height, weight, and body mass index were 160.4 ± 5.1 (range, 150–173) cm, 61.8 ± 13.6 (range, 45–110) kg, and 23.98 ± 4.91 (range, 17.53–39.92) kg/m², respectively. The results of our study showed excellent to good intraobserver repeatability (intraclass correlation coefficient [ICC], 0.75–0.87) for the evaluations of all parameters but urethral sphincter length (moderate ICC, 0.53), whereas they showed good to moderate interobserver repeatability (ICC, 0.44–0.77) for all parameters. The repeatability of 3D volumes (ICC, 0.59–0.87) tended to be better than that of 2D parameters (ICC, 0.44–0.76).

Conclusions—The intraobserver and interobserver repeatability of high-frequency 3D TVUS measurements of the female urethra was excellent to moderate between examiners without previous experience. The repeatability of 3D measurements tended to be better than that of 2D parameters.

Key Words—female urethra; high frequency; pelvic floor; repeatability; 3-dimensional ultrasound; transvaginal ultrasonography; urethral sphincter; urology; volume

The normal anatomy and function of the female urethra are of vital importance for urinary continence. The function of the urethra has been assessed by urodynamic examinations, whereas the anatomy has been evaluated by imaging studies. Magnetic resonance imaging frequently has been used to evaluate urethral anatomy because of its superiority for differentiating soft tissues.
However, magnetic resonance imaging is expensive and inconvenient. With the rapid development of ultrasound techniques, the resolution of ultrasonography (US) has improved considerably. In addition, US is more readily available and less expensive. It has become one of the important imaging tools in the assessment of the urethral structures.

High-resolution 3-dimensional (3D) transvaginal ultrasonography (TVUS) is a novel technique for urethral assessment. It can show the fine structures surrounding the urethra with substantially improved resolution. However, before generalization of TVUS as a new technique, its reliability should be verified. There have been a limited number of the relevant studies in this field. The aim of this study was to investigate the intraobserver and interobserver repeatability of 2-dimensional (2D) and 3D measurements of the female mid urethra using TVUS between examiners without prior experience.

Materials and Methods

This study was conducted at the Beijing Obstetrics and Gynecology Hospital, Capital Medical University. The study protocol was approved by the Institutional Ethical Committee. Fifty premenopausal patients voluntarily participated in this study and provided signed informed consent. Detailed histories and demographic data from the patients were collected, including age, height, weight, body mass index, parity status, delivery mode, and menstrual history. All of the patients were Chinese. Patients with urinary incontinence, pelvic organ prolapse, urinary tract infections, systemic diseases involving urinary tracts, a history of pelvic floor or lower urinary tract surgery, and gynecologic US findings of a pelvic mass larger than 5 cm in maximum diameter were excluded.

Two examiners (Y.X. and S.Y.) had performed gynecologic US for 8 to 10 years but had no prior experience with female urethral imaging using TVUS. Both examiners were responsible for the urethral volume acquisition and the following measurements. Considering the deficiency of prior experience with TVUS, during the beginning period of this study, an application specialist from BK Ultrasound (Shanghai, China) assisted the operators with adjustment of machine settings and use of the transducer during examinations.

All of the patients underwent TVUS after routine transvaginal scans. Transvaginal US was performed with a linear 360° rotational high-frequency transducer (4–12 MHz, type 8838; BK Medical, Herlev, Denmark). Different from a conventional end-firing transvaginal transducer, the 8838 transducer was side firing, with a long linear array lining on the side of the transducer, which could directly image the surrounding structures of vagina. The patients lay in a dorsal lithotomy position after voiding. The transducer was placed into the vagina in a neutral position, to avoid exerting excessive pressure on the urethra. The volume acquisition angle was set at 120° to make sure that the acquired volume contained the whole urethra, even when the urethra was displaced laterally. The initial mid sagittal plane covered the full length of the urethra, from the bladder neck to the external orifice, and the disk of the symphysis pubis. The urethral sphincter should be clearly seen on the initial plane. A 3D volume of the urethra was acquired during patient rest and stored.

The urethral volume from each patient was acquired once by either of the examiners. A subsequent measurement was done in a single volume data set for each patient. Afterward, 2 examiners (Y.X. and S.Y.) measured the 2D and 3D parameters of the urethra offline with BK 3D Viewer 7.0 software for analysis of the interobserver repeatability. During the measurement, both examiners were blinded to all data. One month later, Y.X. repeated the measurements in all volumes, blinded to the results of the former assessment, to test intraobserver repeatability.

The BK 3D Viewer 7.0 software could display the volume in orthogonal and cubic modes. In the orthogonal mode, sagittal, coronal, and axial sections of the urethra were shown at the same time. In the cubic mode, the operator could manipulate the cube and cut the volume in any direction to get any random section. The measurements could be performed only in the cubic mode. The advantage of this software is that the operator only needs to delineate the margin of the targeted organ or tissue on successive planes to get volume values when measuring volume parameters.

All 2D and 3D parameters were measured on the volume data set. Two-dimensional parameters were evaluated on the midsagittal section of urethra (Figure 1), including the following:

1. Urethral sphincter length—the straight distance between the cranial and caudal margins of the urethral sphincter on the ventral part of urethra (Figure 1B).
2. Urethral sphincter thickness—the straight distance between the inner and outer margins of the thickest ventral portion of the urethral sphincter, vertical to the urethral sphincter length (Figure 1B).

On the reconstructed axial sections, the midurethral complex was mainly composed of the outer urethral sphincter, inner smooth muscle layers, submucosa, and mucosa of the urethra. The urethral sphincter appeared as a hypoechoic structure, omega or ring shaped, with absence or thinning of the dorsal portion. The inner core was hyperechoic and consisted of smooth muscles, submucosa, and mucosa of the urethra. The 3 components were hard to differentiate clearly from each other on axial planes. The 3D parameters were measured on successive axial sections in the cubic mode, including the following:

1. Urethral sphincter volume—obtained by manipulating the cube along its longitudinal axis and navigating gradually from the bladder neck to the distal urethra. When the cranial portion of urethral sphincter just appeared as a thin omega or ring, the volume measurement was started. The outer and inner margins of the urethral sphincter were continuously delineated on the first section; tracing of the outline of the urethral sphincter was repeated on successive serial sections at a 2-mm interslice interval, until the omega- or ring-shaped urethral sphincter disappeared or the compressor urethra appeared; and the volume was then calculated automatically (Figure 2).

2. Midurethral complex volume—obtained after tracing the outer margin of the urethral sphincter on the same serial axial sections as the urethral sphincter volume measurement.

3. Inner core volume—subtraction of the urethral sphincter volume from the midurethral complex volume.

SPSS version 17.0 software (IBM Corporation, Armonk, NY) was used for the statistical analysis. The intraclass correlation coefficient (ICC) was calculated to test the repeatability of the measurement of each parameter. Intraclass correlation coefficient values of less than 0.20 were considered poor; 0.21 to 0.40, fair; 0.41 to 0.60, moderate; 0.61 to 0.80, good; and 0.81 to 1.00, very good or excellent.

Results

The mean age of the patients ± SD was 34.1 ± 8.1 (range, 23–55) years; the mean height, weight, and body mass index were 160.44 ± 5.12 (range, 150–173) cm, 61.80 ± 13.64 (range, 45–110) kg, and 23.98 ± 4.91 (range, 17.53–39.92) kg/m², respectively. Twenty-nine patients were nulliparous, whereas 21 patients were multiparous (including 7 cesarean and 14 vaginal deliveries).

Table 1 shows comparisons of the measurement of each parameter by the same examiner at different time points and by the different examiners with the mean values, standard deviations, and intraclass correlation coefficients. The results of our study showed good to excellent intraobserver repeatability (ICC, 0.75–0.87) for the evaluations of all parameters except the urethral sphincter length (moderate ICC, 0.53), whereas they showed moderate to good interobserver repeatability (ICC, 0.44–0.77) for all parameters. The repeatability of

Figure 1. Midurethral structures displayed on a midsagittal section of a volume and measurement of 2D urethral parameters. A, Delineation of the urethral sphincter (US) margin. B, Urethral sphincter length and thickness measurements. BL indicates bladder; BN, bladder neck; EO, external orifice of urethra; IC, inner core; USL, urethral sphincter length; and UST, urethral sphincter thickness.
3D volumes (ICC, 0.59–0.87) tended to be better than that of 2D parameters (ICC, 0.44–0.76).

**Discussion**

The urethra is about 3.5 to 4.5 cm long. It is composed of 3 parts, including the intramural part, mid urethra, and distal part. The mid urethra, accounting for 40% of the urethral length, is critical in maintaining continence.1

Urethral closure pressure in women is known to develop mainly by contraction of the striated and smooth muscles of the mid urethra.9 Thus, imaging studies have focused on the display of the structures of the mid urethra, especially the urethral sphincter.7,10–12

The novel technique of high-frequency 3D TVUS is an ideal imaging tool for urethral assessment. It has several superiorities. First, it enables high-resolution scanning by insertion of the transducer into the vagina just

![Figure 2. Urethral sphincter (US) manifested as an omega shape on reconstructed axial planes. Its volume was calculated automatically after drawing along the outline of the urethral sphincter on serial axial planes. A, Cranial portion of the urethral sphincter. B and C, Middle portions of the urethral sphincter. D, Caudal portion of the urethral sphincter. IC indicates inner core.](image)

| Table 1. Repeatability of the Urethral Measurements by 3D TVUS |
|---------------------------------------------------------------|
| **Parameter** | **Examiner 1 (1st)** | **Examiner 2 (2nd)** | **Intraobserver ICC** | **Interobserver ICC** |
|---------------|----------------------|----------------------|----------------------|----------------------|
| 2D            |                      |                      |                      |                      |
| Urethral sphincter length, mm | 16.42 ± 1.92 | 16.20 ± 2.36 | 16.53 ± 2.06 | 0.53 | 0.44 |
| Urethral sphincter thickness, mm | 1.91 ± 0.30 | 1.96 ± 0.44 | 1.85 ± 0.28 | 0.76 | 0.63 |
| 3D            |                      |                      |                      |                      |
| Urethral sphincter volume cm³ | 0.52 ± 0.12 | 0.55 ± 0.13 | 0.55 ± 0.13 | 0.80 | 0.71 |
| Midurethral complex volume, cm³ | 1.48 ± 0.33 | 1.41 ± 0.34 | 1.49 ± 0.33 | 0.87 | 0.77 |
| Inner core volume, cm³ | 0.96 ± 0.27 | 0.86 ± 0.28 | 0.94 ± 0.22 | 0.75 | 0.59 |
The repeatability of our urethral measurements was excellent to moderate (ICC range, 0.44–0.87), showing excellent to good intraobserver repeatability for most parameters and good to moderate interobserver repeatability. The results seem encouraging, considering the fact that both examiners had no prior experience with evaluations of the urethra by TVUS. The study by experienced examiners who used a different BK transvaginal transducer7 showed better repeatability (ICC range, 0.611–0.942). In addition to proficiency, different volume calculations might have been one of the factors that caused the discrepancy. In that study, a formula was used to calculate the volume after measuring the length, width, and thickness of the urethral sphincter, whereas
in our study, we traced the margin of the urethral sphincter on 8 to 9 successive sections on average. In our study, the 3D volume measurements were most reliable, with ICC values that showed better results for 3D volume than 2D parameters. We believe that 3D imaging is superior in displaying the entire contour, and the volume measurement of a structure could more correctly reflect the size of the structure, which could improve the reliability. The lowest intraobserver and interobserver ICC values were found for the urethral sphincter length by 2D measurement. One of the possible reasons for the relatively lower repeatability was the difficulty in defining the upper and lower margins of the urethral sphincter on the sagittal plane. The repeatability of urethral sphincter thickness measurement in this study showed better results than that of the urethral sphincter length. That finding might have been caused by the fact that the outer and inner margins were relatively easy to define. The urethral sphincter was nearly fusiform shaped, thicker in the middle part, and thinner in the upper and lower portions. The thinnest upper and lower borders were hard to determine exactly, which might have caused the measurement discrepancies. In comparison, when measuring the volume of the urethral sphincter, the upper and lower margins were relatively easy to define because either margin appeared as a thin hypoechoic ring or an omega-shaped structure, which can be identified much more distinctly than a pointed end on a sagittal plane. The difficulty in discerning the borders of the urethral sphincter on 2D sections may be overcome by using the 3D orthogonal display mode (Figure 3). Navigating the sections along 3 axes and showing the urethral sphincter on the coronal, sagittal, and axial planes at the same time could be helpful for better recognizing the entire contour and the border of the urethral sphincter. The other advantage of 3D US in our study was that it could assist examiners in better recognizing the compressor urethra on the reconstructed planes in the orthogonal mode (Figure 3). The urethral sphincter was caudally contiguous with the compressor urethra. Identification of the compressor urethra distally was helpful for discerning the lower margin of the urethral sphincter and improving volume measurement accuracy. The compressor urethra is 1 of the 3 components of the striated urethral sphincter muscle of the urethra (including the urethral sphincter, compressor urethra, and urethrovaginal sphincter). The compressor urethra and urethrovaginal sphincter have been reported to be located in the distal part of urethra.\(^3\)\(^9\)\(^\text{13}\) In 90% of the cases in our study, we could differentiate the compressor urethra. Two extensions of the compressor urethra ran posteriorly and laterally. In our study, better repeatability was shown for midurethral complex volume measurement than urethral sphincter volume measurement. Measuring the midurethral complex volume only needed to definition of the outer margin of the urethral sphincter, whereas urethral sphincter volume measurement required definition of both the outer and inner margins of the urethral sphincter. This factor might explain the better repeatability of midurethral complex volume measurement.

Transvaginal US has a potential limitation. When the transducer is inserted vaginally, the urethral contour might be changed by compression from the transducer. However, with the advantage of its high resolution, by clearly imaging the fine urethral structures, the technique enables examiners to better understand the detailed anatomy of the urethra and conduct reasonable measurements. In our study, with little experience with transvaginal urethral scans, the examiners were able to perform the urethral evaluations with satisfactory intraobserver and interobserver repeatability.

In conclusion, the intraobserver and interobserver repeatability of high-frequency 3D TVUS measurements of the female mid urethra was excellent to moderate. The repeatability of 3D volume measurements tended to be better than that of 2D parameters. This technique appears to be suitable for wide use in female urethral measurements.

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