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ORIGINAL ARTICLE

Assessment of female pelvic floor support to the urethra using 3D transperineal ultrasound

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Abstract

Introduction and hypothesis To explore the feasibility of three-dimensional (3D) transperineal tomographic ultrasound in evaluating pelvic floor support of the urethra in women.

Methods Three-dimensional transperineal ultrasound volume data sets of 50 women with stress urinary incontinence (SUI) and 25 women without SUI were obtained for analysis. Pelvic floor support of the urethra was evaluated by studying the relationship between the urethra and vagina in vaginal cross section and quantified by estimating the urethral depression (UD) rate. The extent of paravaginal support at level II was also evaluated in tomographic ultrasound imaging (TUI) mode in all participants. Two-sample *t*-test and Mann-Whitney U test were used for statistical analysis.

Results The extent of paravaginal support at level II showed no difference between the two groups. Posterior depression of the urethra into the anterior vaginal wall was increased in SUI ($P < 0.05$). When the UD rate value was 0.53 (CI 85%) combined with three continuous "abnormal slices," the maximum Youden Index value (sensitivity 0.82, specificity 0.88) was obtained to screen dysfunctional support of the urethra.

Conclusions The pelvic floor support of the urethra can be evaluated indirectly by studying the relationship between the urethra and anterior vaginal wall in the vaginal cross section by TUI. The obvious posterior depression of the urethra into the anterior vaginal wall could be indirect evidence of a defect in the support of the urethra.

Keywords Ultrasound · Pelvic floor · Stress urinary incontinence · Paravaginal support · Urethral support

Introduction

Stress urinary incontinence (SUI) is a troublesome problem for women. The prevalence ranges from 4 to 46% worldwide [1–4], depending on age, race, severity and healthcare. The primary risk factors include age, pregnancy, vaginal delivery and obesity [5].

Urinary continence is a complex process relying on normal anatomy and function of the continence control system with the urethral support system and sphincteric closure systems primarily contributing to continence. The major components of the urethral supportive structure are the levator ani muscles, arcus tendineus fasciae pelvis, pubourethral ligaments and endopelvic fascia [6]. Weakened support of the urethral continence system is the cause of SUI [7]. In both the "hammock hypothesis" [8] and "integral theory" [9], the pelvic support surrounding the vagina is suggested to be important to normal continence control because of its close anatomical relationship with the urethra and vagina. However, the exact pathophysiology and etiology of SUI are still poorly understood.

Imaging methods are useful tools in evaluating the anatomy of the pelvic floor and have been widely used in the study of SUI. Magnetic resonance imaging (MRI) and ultrasound are most frequently used as they are noninvasive and nonradiative. Abnormal descent of the bladder neck was

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confirmed by MRI and transperineal ultrasound [10–12], and it was speculated to result from impairment of the pelvic support of the urethra. The shape of the vagina in cross section was considered a reflection of the endopelvic fascia, which was shown by MRI and tomographic ultrasound image (TUI) modes [13–17]. Abnormal vaginal configuration (loss of the normal H-shape vaginal contour) was found on axial MRI and TUI in women with SUI, but the morphologic appearance of injured or damaged connective tissue is not comprehensively understood [18, 19].

In this study, we tried to find a feasible method to evaluate the support of the urethra by studying the morphology of the anterior vaginal wall using 3D transperineal tomographic ultrasound in women with SUI. Quantitative parameters were also used to estimate the efficiency of the evaluation.

Materials and methods

This study is a retrospective analysis of data obtained between January 2014 and June 2018. Fifty women with SUI were included in the SUI group and twenty-five women without SUI in the normal control group. All the participants had filled in a questionnaire about their physical condition and the symptoms of pelvic floor and urinary incontinence. The inclusion criteria for the control group were women without any urinary incontinence and pelvic organ prolapse beyond the hymen. The inclusion criteria for the SUI group were women with grade II or higher SUI according to the Ingelman-Sundberg scale [20] (grade I, urinary incontinence while coughing or sneezing; grade II, urinary incontinence while running or picking up objects from the floor; grade III, incontinence while walking or climbing stairs). The exclusion criteria for the SUI group were voiding symptoms, vaginal bulge beyond the hymen on examination, urethral abnormality, recurrent urinary tract infection and other classification of urinary incontinence (such as urgency incontinence, postural incontinence, continuous incontinence, etc.) [21]. Other exclusion criteria for both groups were pelvic tumor with diameter $\geq$ 3.0 cm (such as uterine myoma, ovarian tumor and fallopian tube tumor), history of pelvic trauma and surgery. All procedures performed in the study involving human participants were in accordance with the 1964 Helsinki Declaration and its later amendments. This study was approved by the Ethics Committee of Shanghai Jiao Tong University Affiliated Sixth People's Hospital, and informed consent was obtained from all individual participants included in the study.

A 3D transperineal pelvic floor ultrasound examination was performed on all participants using GE Voluson E8 (GE Medical System, Zipf, Australia) with an RAB4-8-D 3D volume probe after voiding in the supine position. The 3D volume images were obtained at rest for offline analysis. Imaging processing was performed using GE 4D View software by one experienced doctor, who was blinded to all clinical information. A continuous cross-sectional plane (C-plane) image was obtained using tomographic ultrasound imaging (TUI) at 2-mm slice intervals in the mid-sagittal plane perpendicular to the long axis of the vagina from the top of the vagina to the hymeneal ring, as previously described [20]. The volume contrast imaging (VCI) technique was applied to improve the quality of the image by enhancing the contrast and improving the depiction of margins.

The slices of level II paravaginal support (images with a box-shaped vaginal cross-sectional morphology [22]) were counted in all participants, and for each participant, the urethral depression rate (UD%) in each slice at level II was recorded to quantify the extent of urethral depression into the vagina. UD% was obtained as follows:

$$UD\% = d/D \times 100\%$$

"D" was the diameter of the extremely hypoechoic part of the urethra.

"d" represented the depth of the extremely hypoechoic area of the urethra below the level of the vaginal anterior fornices (Fig. 1).

To study the efficiency of the UD rate in screening SUI, the UD rates in all slices at level II of the control group were set as a normal sample, and then the 95, 90, 85 and 80% confidence intervals (CI) were computed. When the UD% was out of the CI, the slice was considered an "abnormal slice" whether it was in the control group or SUI group. The number of continuous "abnormal slices" was counted for each individual according to the different CI, respectively, in both normal women and those with SUI.

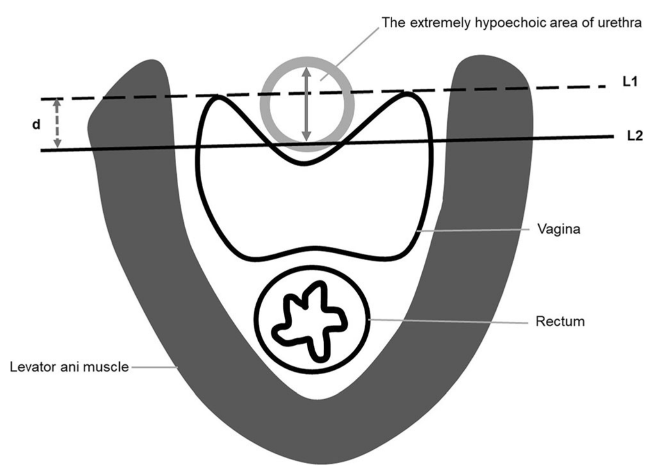

Fig. 1 Measurement of the UD rate. L1 (dotted line): level of the vaginal anterior fornices. L2 (solid line): a parallel line of L1 through the most dorsal points of the extremely hypoechoic area of the urethra. "d" is the distance of L1 and L2 (dotted double-headed arrow). "D" is the distance of the most ventral side and the most dorsal side of the extremely hypoechoic area of the urethra (solid double-headed arrow). When L2 was at the dorsal side of L1, the UD rate was positive, otherwise negative

Table 1 Comparison of the extent of paravaginal support at level II between the nulliparous and SUI groups

	Extent of paravaginal support at level II (slice no.)							*P* value
	7	8	9	10	11	12	13	
Nulliparous group	1(4%)	1(4%)	9(36%)	7(28%)	1(4%)	5(20%)	1(4%)	0.072
SUI group	1(2%)	10(20%)	18(36%)	14(28%)	5(10%)	2(4%)	0(0%)	

Statistical analysis was performed using SPSS 19.0 for Windows (SPSS Chicago, IL, USA). Median values were compared by Mann-Whitney U test, and continuous variables were assessed using the two-sample *t*-test. $P < 0.05$ was considered statistically significant. The Youden Index was adopted to assess the diagnosis efficiency.

Results

All 3D transperineal volume images of 50 women with SUI and 25 control group women were valid for offline analysis. The average age was 48.3 years (range 19–74 years) in the control group and 50.6 years (range 29–80 years) in women with SUI.

(1) **The extent of paravaginal support at level II in TUI**

The extent of paravaginal support at level II was evaluated by counting the slice number of images with box-shaped vaginal cross-sectional morphology in each participant. In the normal control group, the median was 10 (range 7–13), and it was 9 (range 7–12) in the SUI group. The difference was not statistically significant ($P > 0.05$, Table 1).

(2) **The manifestations of the relationship of the urethra to the vagina at level II**

The cross-sectional morphology of the vagina at level II was box shaped with a bilateral broadside part tenting toward the os pubis, leaving a concavity of the anterior vaginal wall. The urethra was adjacent to the ventral side of the concavity. The urethra was at a sustained position relative to the anterior vaginal wall in the normal control group, leaving an impression that the urethra was "floating" on the anterior vaginal wall. In the SUI group, the urethra had an obvious posterior depression into the anterior vaginal wall, and the urethra seemed to 'sink' into the anterior vaginal wall (Fig. 2).

(3) **The difference in the urethral depression rate (UD%) in normal women and women with SUI**

To quantify the extent of urethral depression into the vagina, we calculated the UD rate in all slices at level II and compared the differences between the SUI and control group. The maximum UD rate in each individual participant was 59 ± 21% in the control group and 81 ± 23% in the SUI group. The differences were statistically significant ($P < 0.05$). The average UD rate of each individual participant was 28 ± 15% in the control group and 52 ± 18% in the SUI group, with a statistically significant difference ($P < 0.05$). For all the slices at level II in the control group, the average UD rate was 28 ± 25% (range − 67 ~ 111%), and for all the slices of level II in the SUI group, the average UD rate was 53 ± 28% (range – 50 ~ 149%) in the SUI group. The differences were statistically significant ($P < 0.05$).

(4) **The value of the urethral depression rate (UD%) in screening SUI**

The sensitivity, specificity and Youden Index calculated in screening SUI among all the subjects when the value of continuous "abnormal slices" was 1, 2, 3 and 4, respectively, are shown in Table 2. The maximum Youden Index was obtained when the UD rate was 53% (CI 85%) combined with the continuous abnormal slice value of 3. The sensitivity and specificity were 0.82 and 0.88, respectively.

Discussion

SUI is a common condition in women. Despite the efforts that have been made in studying the pathophysiology and etiology, there is still much to be understood about the anatomic changes that accompany the condition. While many anatomic factors contribute to continence, including the anterior vagina, endopelvic fascia, arcus tendineus fasciae pelvis and levator ani muscles [6], there are several theories regarding the interplay of these muscles, tendons and ligaments in achieving continence. In the "hammock hypothesis," the endopelvic fascia, stretching the vaginal wall to the arcus tendineus fascia pelvis and suspending the vagina between the pubic bone and the ischial spine, provides a "hammock" for the bladder neck and urethra to prevent urinary incontinence even when the abdominal pressure is abnormally increased. It was proposed that the defects of paravaginal support at level II would result in the loss of support to the urethra from the "hammock" and urinary incontinence would occur [23].

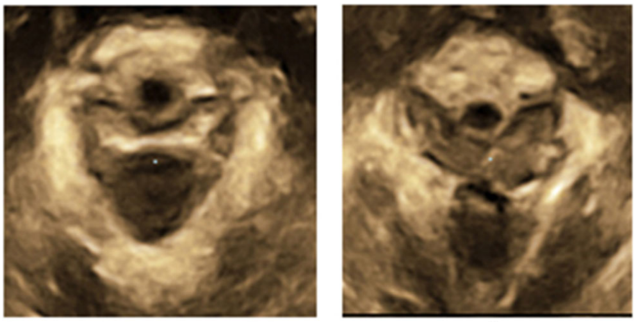

Fig. 2 The relationship between the urethra and vagina in vaginal cross section at level II in normal women and those with SUI. The urethra seemed to "float" on the anterior vaginal wall in women without SUI (**a**). The urethra seemed to "sink" into the anterior vaginal wall in women with SUI (**b**)

In the theory of the "garden hose," Delancey explained the mechanism of how the urethra fights against increasing abdominal pressure. If the hose is lying on noncompliant ground, stepping on it will lead to a deformation and flattening of the hose cross-sectional area, closure of the lumen, resulting in the cessation of water flow. If instead the hose is resting on very compliant ground, stepping on the hose will tend to cause it to indent the trampoline under it; then, the hose and trampoline move downward together and water will flow unabated in the hose [24]. In the continence mechanism, the urethra is just like the "hose" and the "hammock" is the "ground." As the hose indents the soft "ground" under it, the "hammock" of women with SUI cannot provide adequate support to the urethra, and it will descend posteriorly with the lumen unclosed under the increasing abdominal pressure, resulting in SUI.

Imaging studies have been helpful in the study of SUI, and MRI and ultrasound have become the most common methods in recent years. In two-dimensional ultrasound, bladder neck hypermobility is the most common finding in women with SUI, which is believed to be a result of impairment of the pelvic support of the urethra. However, proof of this hypothesis is currently inadequate [10–12]. Levator ani muscle defects have been observed by both MRI and TUI, but their relationship with SUI has not been substantiated [25–28]. Abnormal vaginal configuration (loss of the normal H-shaped vaginal contour) in vaginal cross section was found on axial MRI in women with SUI, which was speculated to be associated with defects of the endopelvic fascia, ligaments and levator ani muscle [13–15]. With development of 3D ultrasound techniques such as TUI mode, it is also convenient to display the vaginal cross-sectional morphology by ultrasound [22, 29].

Our study observed the relationship of the urethra and vagina in vaginal cross-section at level II using 3D ultrasound techniques with TUI mode, and obvious differences were shown between women with SUI and the control group. Posterior depression of the urethra into the anterior vaginal wall increased obviously in the SUI group compared with that in the control group. In the SUI group, the urethra appears to "sink" into the anterior vaginal wall, while in the control group, the urethra appears to "float" on the vagina.

Anatomically, the vagina serves as a frame for the endopelvic fascia to attach to, providing a "hammock" [8] for the urethra to lie on, and the pull strength and orientation of the surrounding connective tissue shape the vagina to a fixed morphology. Once the paravaginal defects occur, traction directions of the vaginal wall change, and the vaginal morphology differs correspondingly. Therefore, a dysfunctional "hammock" in SUI which descends posteriorly would present as an increasing depression of the vagina. In our study, we noted that there was increasing concavity in the anterior wall of women with SUI, which is an expected change as it reflects a pelvic support defect in paravaginal support level II. Furthermore, the increased posterior depression of the urethra into the anterior vaginal wall is considered the soft "ground" under the "hose," and we speculated that it representats a urethral support defect in TUI. However, further study is needed to provide sufficient evidence of the cause and pathomechanism of the change.

In addition, the extent of level II was roughly evaluated by the number of slices of the vagina which was box shaped in cross section in our study. The result showed no statistically significant difference between the SUI and control group, suggesting women with SUI have similar support at this level. This finding may imply that the quality of suburethral support rather than the extent of support at level II is more responsible for continence in SUI.

To quantify and objectify the extent of urethral depression into the anterior vaginal wall in TUI, we tried using parameters such as the depth of the anterior vaginal wall depression,

Table 2 Efficiency of the UD rate in screening SUI

CI (UD rate)	CI = 95%(UD% = 64%)				CI = 90%(UD% = 59%)				CI = 85%(UD% = 53%)				CI = 80%(UD% = 47%)			
Continuous abnormal slices	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Sensitivity	0.82	0.66	0.52	0.28	0.86	0.68	0.56	0.38	0.94	0.86	0.82	0.46	0.96	0.92	0.86	0.70
Specificity	0.72	0.96	1	1	0.48	0.80	0.96	1	0.40	0.68	0.88	1	0.36	0.64	0.72	0.92
Youden Index	0.54	0.62	0.52	0.28	0.34	0.48	0.52	0.38	0.34	0.54	0.70	0.46	0.32	0.56	0.58	0.62

urethral depression depth and UD rate. The UD rate was selected for its ability to evaluate the relationship between the urethra and vagina without interference of individual differences in the diameter of the extremely hypoechoic part of the urethra. By analyzing the continuous "abnormal slices" which were defined according to the 80, 85, 90 and 95% CI of the UD rate in the control group, we attempted to predict the probability of SUI. As a result, the best screening efficiency was achieved when the UD rate was 53% (85% CI) and three continuous abnormal slices were identified. Using this metric, a sensitivity of 0.82 and specificity of 0.88 were demonstrated. Using one "abnormal slice," the Youden Index demonstrated high sensitivity, but low specificity, suggesting that it was common for a woman to have a single abnormal slice, even in women without SUI. The characteristic of continuous abnormal slices might provide more reliable evidence of a defect in the pelvic support of the urethra, and the UD rate of 53% combined with three continuous abnormal slices might be a proper parameter for screening abnormal support.

Our study has some limitations, so the results should be interpreted carefully. As the sample size was small, we consider this a preliminary study, so the accuracy and efficiency should be confirmed in further investigations. Furthermore, SUI is a pathological process occurring when abdominal pressure increases, so future studies should incorporate the impact of Valsalva on the measurements. In this study, we only focused on the different ultrasound appearances of women with uncomplicated SUI; therefore, the impact of parity, delivery mode, etc., should be evaluated in the future. Remarkably, continuous "abnormal slices" are only used to screen inadequate urethral support, and diagnosis of SUI is based on symptoms and clinical evaluation. Another potential limitation of our study may be the selection bias as data sets were obtained in patients with uncomplicated SUI. Hence, our conclusions are limited to the population with this condition.

In conclusion, pelvic support of the urethra can be indirectly observed by TUI by studying the relationship between the urethra and vagina in vaginal cross section at level II. The increased posterior depression of the urethra into the anterior vaginal wall could be regarded as indirect evidence of a support defect of the urethra in SUI. The UD rate of 53% combined with three continuous abnormal slices has potential to be a useful screening parameter for abnormal support of the urethra and may have uses in assisting clinical evaluation of SUI.

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Compliance with ethical standards

Conflicts of interest None.

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