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Visualized Urethral Mobility Profile During Urine Leakage in Supine and Standing Positions

Visualisiertes Mobilitätsprofil der Harnröhre bei Harnverlust in Rückenlage und im Stehen

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ABSTRACT

Objectives To describe the urethral course and position during urine leakage based on the visualized urethral mobility profile (UMP) and to explore the differences between supine and standing positions.

Method This was a prospective study of 100 women with SUI and 100 control women who underwent a cough stress test (CST) with transperineal ultrasound (TPUS) in supine and standing positions. In the mid-sagittal plane, the UMP software automatically placed six equidistant points from the bladder neck (point 1) to the external urethral meatus (point 6). It determined the x and y coordinates of the points relative to the symphysis pubis. The distance between the points and symphysis pubis (dist. 1 to 6) was calculated using the formula SQRT (x2 + y2). The visualized UMP was created by reproducing the six points on a bitmap.

Results Valid UMP data of 78 control women and 90 women with SUI were analyzed. In the two positions, distances 1 to 6 were significantly greater in the SUI group than the continent group (all $p < 0.05$). During Valsalva, the distance between the mid-urethra (dist. 3 and 4) and the symphysis was significantly increased (all $p < 0.001$) in the SUI group. The visualized UMP showed a similar upper-urethral course in the two groups. The gap between the mid-urethra (points 3 and 4) and symphysis was wider in the SUI group.

Conclusion The visualized UMP in supine and standing positions showed no difference in the bladder neck and upper urethral stability between incontinent and continent women, but mid-urethral stability was weaker in SUI.

ZUSAMMENFASSUNG

Ziel Beschreibung des Verlaufs und der Position der Harnröhre während des Harnverlusts anhand des visualisierten urethralen Mobilitätsprofils (UMP) und Untersuchung der Unterschiede zwischen Rückenlage und stehender Position.

Methode Es handelte sich um eine prospektive Studie mit 100 Frauen mit Stress-Harninkontinenz (SUI) und 100 Kontrollfrauen, die sich einem Husten-Stress-Test (HST) mit transperinealem Ultraschall (TPUS) in Rückenlage und im Stehen unterzogen. In der mittleren Sagittalebene platzierte die UMP-Software automatisch 6 äquidistante Punkte vom Blasenhals (Punkt 1) bis zum Meatus urethrae externus (Punkt 6). Sie bestimmte die x- und y-Koordinaten der Punkte relativ zur Symphysis pubica. Die Distanz zwischen den Punkten und der Symphysis pubica (Dist. 1 bis 6) wurde mit der Formel SQRT ($x^2 + y^2$) berechnet. Das visualisierte UMP wurde durch die Wiedergabe der 6 Punkte auf einer Bitmap erstellt.

Ergebnisse Die validen UMP-Daten von 78 Kontrollfrauen und 90 Frauen mit SUI wurden analysiert. In den beiden Positionen waren die Distanzen 1 bis 6 in der SUI-Gruppe signifikant größer als in der Gruppe mit Kontinenz (alle $p < 0{,}05$). Während des Valsalva-Manövers war der Abstand zwischen der mittleren Urethra (Dist. 3 und 4) und der Symphysis in der

SUI-Gruppe signifikant vergrößert (alle $p < 0{,}001$). Das visualisierte UMP zeigte in beiden Gruppen einen ähnlichen Verlauf der oberen Harnröhre. Die Distanz zwischen der mittleren Harnröhre (Punkte 3 und 4) und der Symphysis war in der SUI-Gruppe größer.

Schlussfolgerung Das visualisierte UMP in Rückenlage und im Stehen zeigte keinen Unterschied hinsichtlich der Stabilität des Blasenhalses und der oberen Harnröhre zwischen inkontinenten und kontinenten Frauen, aber bei SUI war die Stabilität der mittleren Harnröhre geringer.

Introduction

Female stress urinary incontinence (SUI) is an involuntary urinary leakage that results from increased abdominal pressure during a sneeze, cough, and exercise. This condition has a high incidence of 20 % and seriously affects women's life quality [1, 2]. Urethral hypermobility is one of the main underlying mechanisms of SUI. Significant developments in visualization techniques and interpretation of images allowed us to study the lower genitourinary tract structures and assess the real-time anatomic changes during the Valsalva maneuver [3, 4, 5]. Bladder neck configuration and urethral mobility have been described by many parameters such as the bladder neck position and descent, urethral rotation angle, retrovesical angle, and urethral kinking angle during the Valsalva maneuver. However, the anatomic change in stress urinary incontinence is still controversial [6, 7, 8, 9, 10].

Imaging urogenital anatomic changes under real conditions of urinary leakage provides reliable evidence for SUI investigation [3]. Previous studies showed transperineal ultrasound could record real-time urine leakage and describe the anatomic changes in SUI. There were differences regarding bladder neck configuration and mobility during urinary leakage in supine and standing positions [3]. However, the mid-urethral mobility rather than the bladder neck mobility may account for SUI [11].

This study aimed to describe the urethral course and positions during urine leakage in supine and standing positions using transperineal ultrasound with a visualized UMP and to compare the differences between the two positions.

Methods

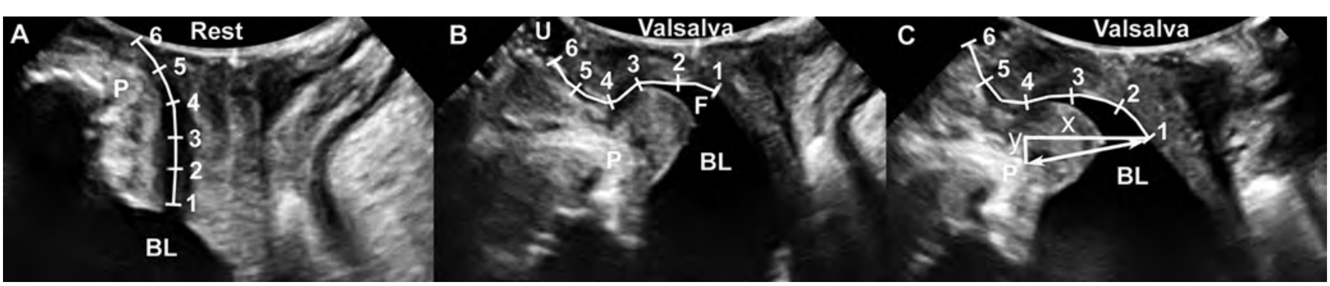
This was a prospective study of 100 incontinent women and 100 continent women recruited from gynecological clinics. All women underwent a standard interview using the ICIQ-SF questionnaire and a cough stress test (CST) with transperineal ultrasound (TPUS) in supine and standing positions between Nov. 2018 and May. 2020. Data collection was approved by the Human Research Ethics Committee (no. 2020–038). Informed consent was sought from each subject.

The exclusion criteria were a medical history of (1) previous pelvic or pelvic floor surgery, physiotherapeutic interventions, or irradiation; (2) pelvic organ prolapse beyond the hymen; (3) other lower urinary tract symptoms such as urinary frequency, urgency, dysuria, nocturia, etc.; (4) voiding symptoms; or (5) fistulas.

Clinical SUI was diagnosed if a patient complained of involuntary urine leakage caused by physical activity such as coughing, sneezing, or laughing and had a positive CST in a standing position [12]. The CST was performed with a bladder volume of less than 50 ml. The patient coughed forcefully 1–4 times. Leakage of fluid from the urethral meatus simultaneous to the coughing was considered a positive test [13].

TPUS followed the CST, using a Voluson E10 system (GE Healthcare, Milwaukee, WI, USA) equipped with a 4–8 MHz curved array transducer placed on the perineum in the midsagittal direction. For women with SUI, the Valsalva maneuver lasted until leakage was shown on the image. Leakage was identified if urine was seen in the urethra or between the external urethral orifice and the probe (▶ **Fig. 1**). At least 3 volumes during Valsalva maneuvers were acquired per patient in both supine and standing positions.

Post-processing analysis was performed later. The urethral mobility profile (UMP) software automatically placed six equidistant points along the length of the urethra, after manual tracing of the urethra in the midsagittal plane, from the bladder neck (point 1) to the external urethral meatus (point 6) (▶ **Fig. 1**). It determined the x and y coordinates of the points relative to the dorso-



▶ **Fig. 1** Urethral mobility course and position in supine and standing positions. **A** shows the urethral course and six points at rest. **B** shows the urethral course during urine leakage on Valsalva in the supine position. **C** shows the urethral course in the standing position. Six equidistant points from the bladder neck (point 1) to the external urethral meatus (point 6) were placed automatically by the UMP software. The x and y coordinates were determined by the UMP software. The distance between point 1 and the symphysis pubis (double arrow) was calculated by the formula SQRT ($x^2 + y^2$). P: symphysis pubis, BL: bladder. U: urine between the external urethral orifice and the surface of the probe.

▶ **Table 1** Distances between the urethra (six points) and the symphysis in the SUI and control groups in the two positions (n = 168).

Variables	SUI women (n = 90)		Continent women (n = 78)		Independent t-test (p)
	Mean ± SD	Range	Mean ± SD	Range	
Distances between the urethra and the symphysis at rest					
Dist. 1(cm)	2.84 ± 0.37	2.06 – 3.63	2.70 ± 0.48	0.77 – 3.50	0.035
Dist. 2(cm)	2.17 ± 0.33	1.37 – 2.87	2.09 ± 0.36	0.76 – 2.81	0.118
Dist. 3(cm)	1.54 ± 0.30	0.71 – 2.15	1.47 ± 0.29	0.74 – 2.22	0.113
Dist. 4(cm)	1.03 ± 0.26	0.42 – 1.64	0.94 ± 0.31	0.35 – 1.68	0.025
Dist. 5(cm)	0.81 ± 0.22	0.33 – 1.38	0.77 ± 0.28	0.21 – 1.46	0.313
Dist. 6(cm)	0.99 ± 0.29	0.47 – 1.80	1.00 ± 0.27	0.48 – 2.01	0.669
Distances between the urethra and the symphysis in supine position					
Dist. 1(cm)	2.21 ± 0.52	1.18 – 3.49	2.04 ± 0.45	1.13 – 3.58	0.022
Dist. 2(cm)	1.86 ± 0.43	0.76 – 2.83	1.61 ± 0.43	0.86 – 2.97	≦ 0.001
Dist. 3(cm)	1.59 ± 0.33	0.75 – 2.33	1.32 ± 0.38	0.43 – 2.46	≦ 0.001
Dist. 4(cm)	1.52 ± 0.28	0.97 – 2.21	1.31 ± 0.34	0.36 – 2.01	≦ 0.001
Dist. 5(cm)	1.94 ± 0.37	1.13 – 2.89	1.71 ± 0.41	0.48 – 2.61	≦ 0.001
Dist. 6(cm)	2.70 ± 0.45	1.41 – 3.68	2.37 ± 0.53	1.13 – 3.35	≦ 0.001
Distances between the urethra and the symphysis in standing position					
Dist. 1(cm)	2.45 ± 0.52	1.18 – 3.87	2.14 ± 0.44	1.11 – 3.70	≦ 0.001
Dist. 2(cm)	2.08 ± 0.43	1.24 – 3.31	1.74 ± 0.42	0.86 – 3.10	≦ 0.001
Dist. 3(cm)	1.80 ± 0.37	1.12 – 2.73	1.50 ± 0.39	0.73 – 2.56	≦ 0.001
Dist. 4(cm)	1.70 ± 0.33	1.01 – 2.79	1.49 ± 0.32	0.60 – 2.10	≦ 0.001
Dist. 5(cm)	2.07 ± 0.37	1.33 – 3.12	1.90 ± 0.37	1.05 – 2.70	0.004
Dist. 6(cm)	2.78 ± 0.46	1.93 – 4.00	2.58 ± 0.48	1.48 – 3.60	0.007

caudal margin of the symphysis pubis [6, 7]. The distance between the six points and the symphysis pubis (dist. 1 to 6) was calculated using the formula SQRT ($x^2 + y^2$). The visualized urethral mobility profile was created by reproducing the six points at rest and on maximal Valsalva.

Statistical analyses were undertaken using SPSS v.21 (SPSS, Inc., Chicago, IL, USA). US findings were compared between the two positions using the paired t-test, while US findings in women with and without SUI were compared using the independent t-test. A p-value of < 0.05 was considered statistically significant.

Results

Of the 200 women, 22 continent women with an ineffective Valsalva maneuver due to levator co-activation, and 10 incontinent women without leakage in the supine position were excluded. Complete data was collected from 90 women with SUI and 78 continent women (total 168).

The mean age was 44.1 ± 4.2 (range: 22 to 71) years and 49.3 ± 8.0 (range: 30 to 72) years for the control and SUI group. The mean BMI was 21.7 ± 2.9 (range: 16.0 to 31.1) kg/m^2 and 24.1 ± 2.8 (range: 19.0 to 30.4) kg/m^2 for the control and SUI group, respectively. Significant differences in age ($p = 0.005$) and BMI ($p < 0.001$) between the two groups were identified by independent t-test.

Between the two positions, distances 1 to 5 were significantly increased for the SUI group ($p \leqq 0.001$, 0.001, 0.001, 0.001, 0.003, respectively) in the standing position. For the control group, distances 1 to 6 in CST ($p \leqq 0.011$, 0.001, 0.001, 0.001, 0.001, 0.001, respectively) were significantly increased in the standing position (▶ **Table 1**, ▶ **Fig. 2**).

Between the two groups, distances 1 and 4 were significantly greater in the SUI group than in the control group at rest. Distances 1 to 6 were significantly increased in the SUI group on Valsalva maneuver (all $p < 0.05$) in the two positions (▶ **Table 1**, ▶ **Fig. 2**).

The visualized UMP for the two groups at rest and on maximal Valsalva in supine and standing positions was created by reproducing the coordinates of the six points in the scattergram (▶ **Fig. 3**) and mimicked by a diagram (▶ **Fig. 4**). The scattergram showed a very similar but irregular upper urethral course in the two groups at rest and during the Valsalva maneuver. The mid-urethra rotated down around the symphysis during the Valsalva maneuver. The gap between the mid-urethra and symphysis was wider in the SUI group than in the control group.

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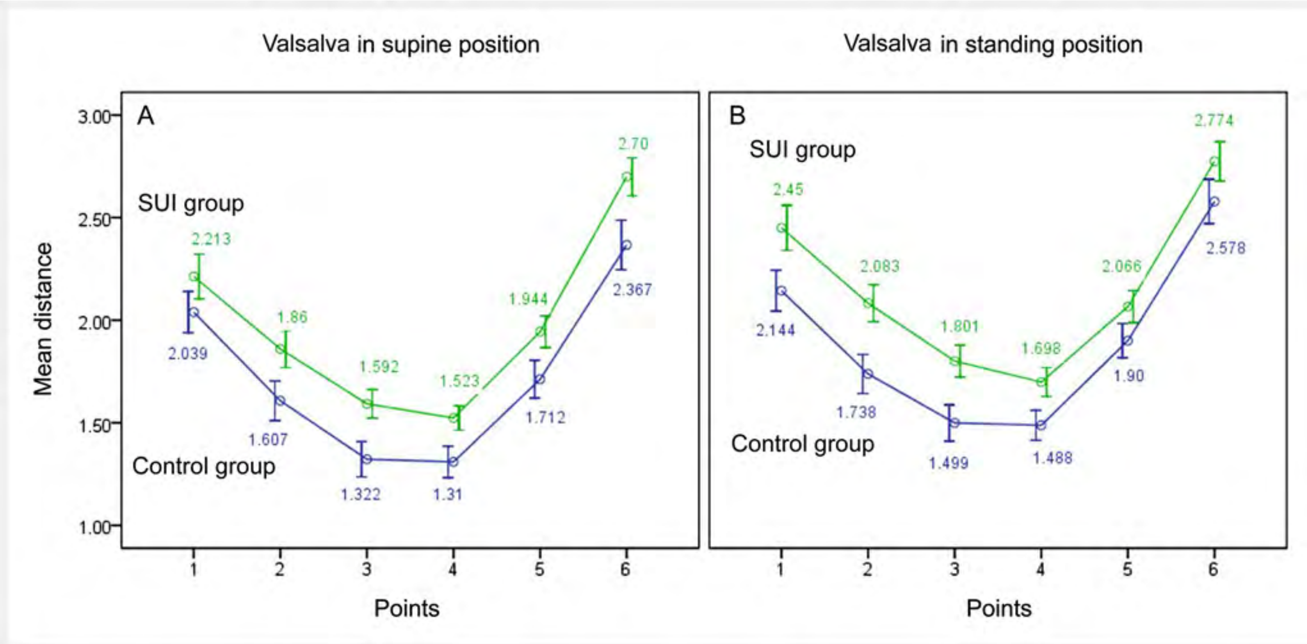
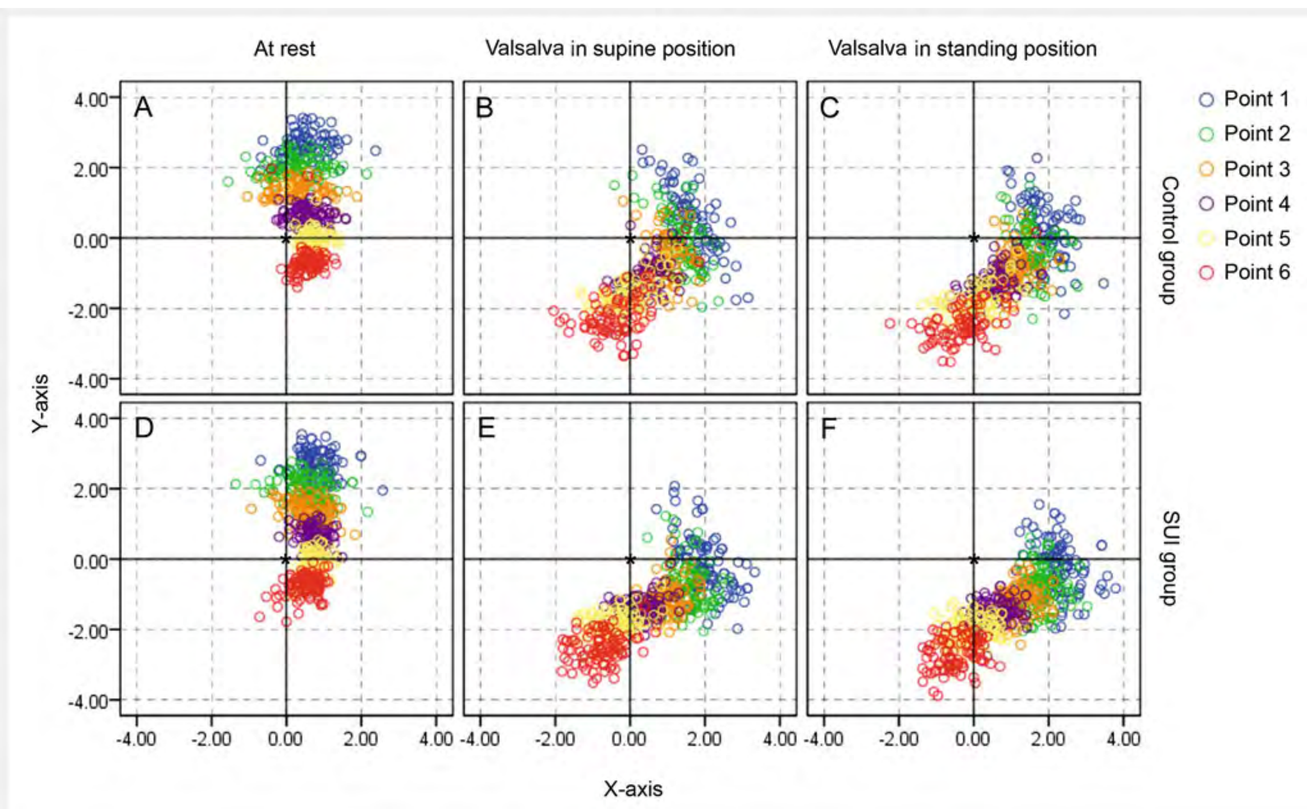
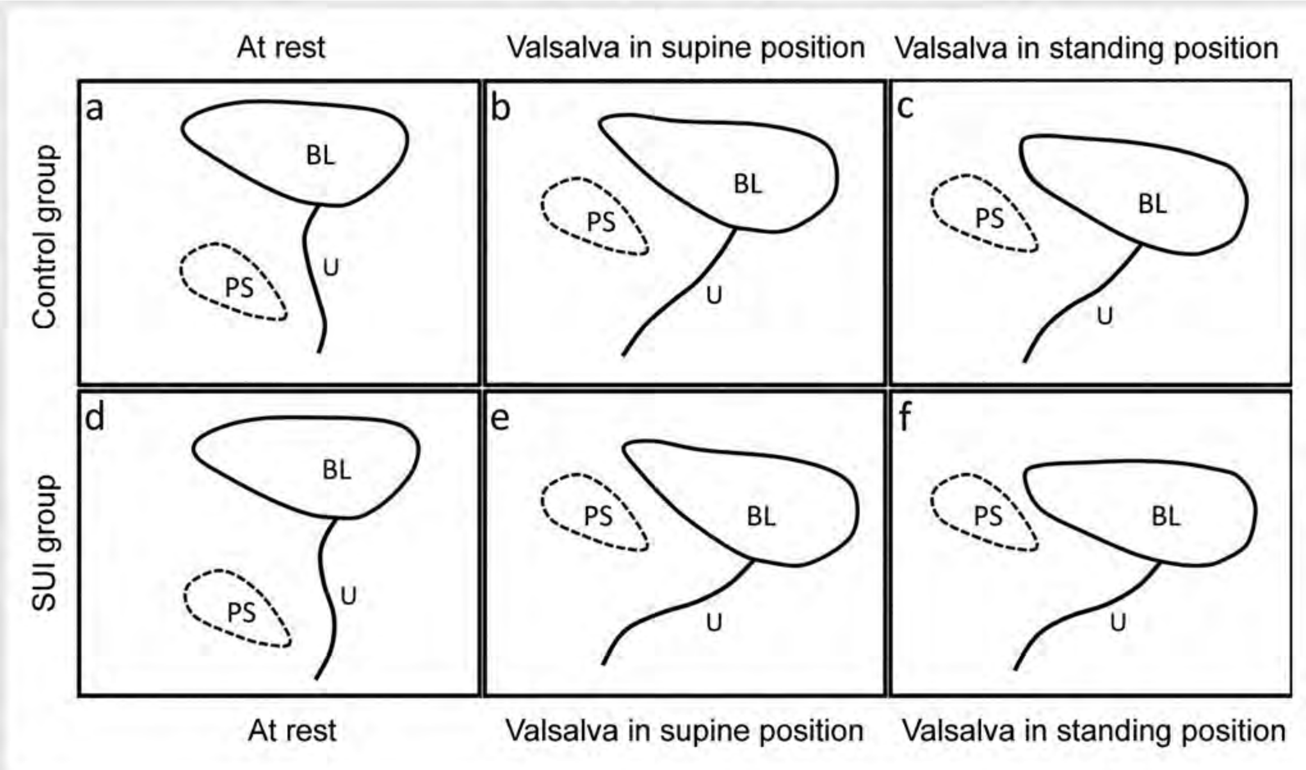


▶ **Fig. 2** The mean value and 95 % CI of the distance between the six points and the symphysis pubis during Valsalva in the two groups in the two positions. **A** shows the distances between points 1–6 and the symphysis pubis on maximal Valsalva in the supine position. **B** shows the distances in the standing position. The upper lines display the distances for the SUI group. The lower lines for the control group.



▶ **Fig. 3** The scattergrams show the urethral mobility profile (UMP) for the two groups in the two positions. **A**, **B**, and **C** show the UMP and six points for the control group; **D**, **E**, and **F** show it for the SUI group. **A** and **D** show the urethral course at rest, **B** and **E** show the urethral course on maximal Valsalva in the supine position. **C** and **F** show the urethral course on maximal Valsalva in the standing position. The origin of coordinate (*) is the position of the posterior-inferior margin of the symphysis pubis. Blue plots show the position for point 1, green for point 2, yellow for point 3, purple for point 4, pale yellow for point 5, and red for point 6.



▶ **Fig. 4** Diagram of the urethral mobility profile (UMP) for the two groups. **a**, **b**, and **c** show the UMP in supine and standing positions for the control group. **d**, **e**, and **f** show it for the SUI group. **a** and **d** show the urethral course at rest, **b** and **e** show the urethral course on maximal Valsalva in the supine position. **c** and **f** show the urethral course on maximal Valsalva in the standing position. PS: symphysis pubis, BL: bladder neck, U: urethra.

Discussion

The morphology and anatomic changes of the lower urinary tract are not only important to understand the etiology of SUI but also important for implementing surgical therapy [14, 15, 16]. Since the use of ultrasound to assess SUI thirty years ago, the detection of urethral hypermobility has become more focused [17, 18, 19]. The real-time urethral anatomic change demonstrated by ultrasound during urine leakage is similar to the real condition in SUI. This study firstly showed a visualized UMP by real-time TPUS in supine and standing positions. Vector data of the segmental urethra was used to show the degree of movement as determined from the points at rest to maximal Valsalva, relative to the symphysis pubis. A limited difference was shown between the two positions. Hence, TPUS in supine position or standing position can be used to investigate urethral mobility in SUI.

The visualized UMP clearly described the urethral course and position in SUI. The scattergram showed a very similar but irregular upper urethral shape in the two groups at rest and during Valsalva. This indicated that bladder neck hypermobility couldn't signify urethral hypermobility in SUI. Previous imaging studies showed major overlap in the bladder neck and proximal urethral support between women with and without SUI [8]. Though the parameters to describe bladder neck mobility were related to SUI or urodynamic stress incontinence, not one of them could be a diagnostic sign of SUI [4, 9, 10, 11].

The visualized UMP illustrated by the scattergrams from at rest to Valsalva showed that the mid-urethra rotated down around the symphysis, as real-time ultrasound recorded when intraabdominal pressure increased. US findings showed that the mid-urethra (points 3 and 4) was closer to the symphysis than the upper and lower urethra, at rest and on maximal Valsalva maneuver. This indicated that the relationship between the mid-urethra and the symphysis pubis might account for urinary continence.

At rest, the distance between the symphysis and mid-urethra (point 4) was significantly longer in women with SUI than in those without SUI, which indicated a looser connection between the mid-urethra and the symphysis in SUI. During Valsalva, the distance between the mid-urethra and the symphysis was much longer. This represented weak support of the mid-urethra in SUI and explained the mid-urethral hypermobility and its predicted performance in SUI [9, 10, 11]. Anatomic study and MRI provided evidence of the damaged mid-urethral support in SUI [20, 21, 22, 23, 24].

There is no doubt that this study has many limitations that need to be acknowledged. First, our findings are not based on urodynamic measurements. As the combination of pressure profiles and morphology, urodynamic tests help in diagnosing SUI [5, 9, 19, 25]. Second, the UMP in our study was limited to describing the urethral mobility of pure SUI. Further studies are needed to explore the UMP in SUI with cystocele. Third, to date, the UMP is only for offline image analysis and cannot be used in everyday practice [6, 7, 11]. Future studies are needed to explore how to apply the UMP in practice.

Conclusion

The visualized UMP described the urethral course and position during urine leakage. In supine and standing positions, the UMP showed no difference in the bladder neck and upper urethral stability between women with and without SUI. However, mid-urethral stability was weaker in pure SUI. Further studies are needed to explore the UMP in SUI with cystocele and how to apply the UMP in practice.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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