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Value of ultrasound shear wave elastography and gray-scale ultrasonography for assessing the bladder neck status of women with stress urinary incontinence.

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Keywords: bladder neck; elastography; stress urinary incontinence; ultrasonography.

Abstract. We aimed to investigate the value of ultrasound shear wave elastography (US-SWE) and gray-scale ultrasonography for assessing the bladder neck status of patients with stress urinary incontinence (SUI). Seventy-two puerperal women with SUI treated from February 2022 to September 2023 were selected as a research group, while another 50 healthy pregnant women receiving physical examination in the same period were selected as a control group. US-SWE and gray-scale ultrasonography were performed for all subjects. The height, length, circumference and area of the perineal body at rest and the maximum, as well as the thicknesses and elastic moduli of anterior and posterior lips of the bladder neck, were compared. At the maximum Valsalva maneuver (VM), the research group had higher height, smaller length and area, and shorter circumference of the perineal body than those of the control group ($p<0.05$). Maternal SUI was positively correlated with the height of the perineal body ($r>0$, $p<0.05$) but negatively correlated with the length, circumference and area of the perineal body and the elastic moduli of anterior and posterior lips of the bladder neck ($r<0$, $p<0.05$). The elastic moduli of the anterior and posterior lips of the bladder neck and the height, length, circumference, and area of the perineal body at the maximum VM were valuable for assessing maternal SUI. US-SWE and gray-scale ultrasonography parameters are closely related to maternal SUI, and the risk of maternal SUI can be assessed early by the bladder neck status.

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Valor de la elastografía ultrasónica de onda cortante y de la ecografía en escala de grises para evaluar el estado del cuello vesical de mujeres con incontinencia urinaria de esfuerzo.

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Palabras clave: cuello vesical; elastografia; incontinencia urinaria de esfuerzo; ultrasonografía.

Resumen. Nuestro objetivo fue investigar el valor de la elastografía ultrasónica de onda cortante (US-SWE) y la ecografía en escala de grises para evaluar el estado del cuello vesical de pacientes con incontinencia urinaria de esfuerzo (IUE). Setenta y dos mujeres puerperales con IUE tratadas entre febrero de 2022 y septiembre de 2023 fueron seleccionadas como grupo de investigación, mientras que otras 50 mujeres embarazadas sanas que recibieron examen físico en el mismo período fueron seleccionadas como grupo control. A todos los sujetos se les realizó eco de US-SWE y escala de grises. Se compararon la altura, longitud, circunferencia y área del cuerpo perineal en reposo y el máximo, así como los espesores y los módulos elásticos de los labios anterior y posterior del cuello vesical. En el momento de la maniobra de Valsalva máxima (VM), el grupo de investigación tuvo mayor altura, menores longitud y área y menor circunferencia del cuerpo perineal que el grupo control ($p<0,05$). La IUE materna se correlacionó positivamente con la altura del cuerpo perineal ($r>0$, $p<0,05$), pero negativamente con la longitud, circunferencia y área del cuerpo perineal y los módulos elásticos de los labios anterior y posterior del cuello vesical ($r<0$, $p<0,05$). Los módulos elásticos de los labios anterior y posterior del cuello vesical y la altura, longitud, circunferencia y área del cuerpo perineal en el VM máximo fueron valiosos para evaluar la IUE materna. Los parámetros de ecografía de US-SWE y escala de grises están estrechamente relacionados con la IUE materna, y el riesgo de IUE materna se puede evaluar tempranamente por el estado del cuello vesical.

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INTRODUCTION

Maternal stress urinary incontinence (SUI) is a common pelvic floor dysfunction in postpartum women, mainly because the postpartum pelvic floor fascia is too weak to support the bladder and maintain the urethral closure pressure. SUI does not threaten the life safety of puerperae. However, patients are highly prone to leakage of urine when the intra-abdominal pressure increases due to sneezing, laughing, coughing and exercise, which, if not treated promptly, may lead to eczema, local skin ulceration, vaginitis and urinary system diseases. Moreover, negative emotions, such as inferiority and anxiety, may be produced from all kinds of embarrassment, affecting the patient's mental health [1,2]. Female pelvic floor dysfunction is related to perineal injury and abnormal bladder neck status. Therefore, it is crucial to detect perineal injury and bladder neck elasticity to diagnose and treat maternal SUI[3,4]. Characterized by non-invasiveness, simple operation and repeatability, ultrasonography is commonly used in clinical prac-

tice. In particular, gray-scale ultrasonography can record the internal echo of tissue and process the echo into gray-scale images to accurately display the structure and shape of the examination site. Besides, ultrasound shear wave elastography (US-SWE) can objectively quantify tissue hardness and accurately monitor tissue elasticity [5,6]. Based on this, US-SWE and gray-scale ultrasonography were performed in this study to analyze their values for assessing the bladder neck status of patients with SUI.

PATIENTS AND METHODS

Subjects

A power analysis was conducted using G*Power software for the two-tailed independent-samples t-test, assuming a moderate effect size (Cohen's d = 0.5), a significance level of $\alpha = 0.05$, and 80% power. Using the equation $n = 2 \times [(Z_{1-\alpha/2} + Z_{1-\beta})/d]^2$ (with $Z_{1-0.05/2} \approx 1.96$ and $Z_{1-0.20} \approx 0.84$), $n \approx 63$ participants per group was obtained. With 72 puerperae with SUI and 50 healthy controls enrolled, the post hoc analysis confirmed an overall power of approximately 0.78-0.80, supporting the adequacy of our sample sizes to detect clinically significant differences. Seventy-two puerperae with SUI treated in our hospital from February 2022 to September 2023 were selected as the research group, while another 50 healthy pregnant women receiving the physical examination in the same period were selected as the control group.

Inclusion and exclusion criteria

Inclusion criteria were as follows: (1) puerperae who met the diagnostic criteria for maternal SUI in the research group [7], (2) those with a single pregnancy, (3) those aged 22-35 years old, and (4) those who and whose families signed the informed consent form.

Exclusion criteria involved: (1) subjects with a history of constipation or chronic cough, (2) those with a history of pelvic surgery, (3) those with a history of urinary incontinence before pregnancy, (4) those complicated with urinary system diseases, (5) those complicated with pelvic organ prolapse, pelvic tumor or other diseases that can lead to pelvic function impairment, (6) those with infection or neurogenic urinary incontinence, (7) those with a history of bladder or urethral diseases, (8) those who took hormone drugs within the past six months, or (9) those unable to cooperate in the study due to mental illness or communication disorders.

Examination apparatus

Mindray Resona 8S Diagnostic Ultrasound System (China) equipped with an abdominal probe SC5-1U (frequency: 1-5 MHz) and a superficial probe L14-5WU (frequency: 5-14 MHz) or Mindray Neuwa R9 Diagnostic Ultrasound System (China) equipped with an abdominal probe SC6-1U (frequency: 1-6 MHz) and superficial probes L15-3WU (frequency: 3-15 MHz) and DE10-3WU (frequency: 3-10 MHz) was used.

Examination methods and processes

Before examination, the subject was instructed to empty the bladder. First, gray-scale ultrasonography was performed on the subject in the lithotomy position, and the ultrasonic probe was placed in the perineal body at a depth of 3-4 cm on the anorectal median sagittal plane to display the perineal body (a high-echo wedge-shaped muscular tissue) with the bottom facing upward and the tip facing downward. Then, the morphology, peripheral conditions and internal echo of the perineal body were observed, and its height, length, and circumference area at rest and at the maximum Valsalva maneuver (VM) were measured. Afterwards, the ultrasonic probe was adjusted to make the beam perpendicular to the anorectum, and the image was continuously enlarged by gain regulation. When the long axis of the bladder neck became deformed, the image was frozen, and the thicknesses of the anterior and posterior lips of the bladder neck were measured. In addition, in the STE mode, the sam-

pling frame was placed at an appropriate depth, and its size was adjusted so the sampling frame could completely cover the bladder neck, with a measurement range of 100 kPa. The stable images with no mosaics and color loss were frozen and saved. Then, a circle with a diameter of 3 cm and uniform color was selected as the region of interest. The elastic moduli of the anterior and posterior lips of the bladder neck were measured three times by Q-BOX, and the average value was taken. All examinations were performed by the same sonographer with more than three years of experience.

Outcome evaluation

The height, length, circumference and area of the perineal body at rest and the maximum VM were compared between the two groups. Comparisons were also made on the thicknesses and elastic moduli of the anterior and posterior lips of the bladder neck.

Statistical analysis

SPSS 23.0 software was used for statistical analysis. Measurement data (the height, length, circumference and area of the perineal body, and the thicknesses and elastic moduli of anterior and posterior lips of the bladder neck) were described by (mean ± standard deviation) and subjected to the *t*-test. Count data were described by percentage and subjected to the chi-square test. The point-biserial correlation test analyzed the correlations of maternal SUI with US-SWE and gray-scale ultrasonography parameters. The assessment values of US-SWE and gray-scale ultrasonography parameters were analyzed using receiver operating characteristic (ROC) curves, $p<0.05$ was considered statistically significant.

RESULTS

Baseline clinical data

Age, pre-pregnancy body mass index, gestational age, fetal birth weight, parity and delivery mode were comparable between the two groups ($p>0.05$) (Table 1).

Height, length, circumference and area of the perineal body at rest

There were no significant differences in the height, length, circumference and area of the perineal body at rest between the two groups ($p>0.05$) (Table 2).

Height, length, circumference and area of the perineal body at the maximum Valsalva maneuver

At the maximum VM, the research group had higher height, smaller length and area, and shorter circumference of the perineal body than those of the control group ($p<0.05$) (Table 3).

Table 1. Clinical Data Baseline.

Variable		Research group (n=72)	Control group (n=50)	Statistical	p
Age ($\bar{X}$ ± SD, year)		29.04±3.92	28.69±4.12	t=0.475	0.636
Pre-pregnancy BMI ($\bar{X}$ ± SD, kg/m^2)		22.54±1.18	22.37±1.32	t=0.745	0.458
Gestation age ($\bar{X}$ ± SD, weeks)		39.52±0.96	39.46±0.91	t=0.347	0.729
Fetal birth weight ($\bar{X}$ ± SD, g)		3156.28±493.14	3112.09±502.36	t=0.483	0.630
Parity ($\bar{X}$ ± SD, times)		1.42±0.49	1.35±0.43	t=0.815	0.417
Delivery mode [n (%)]	Natural delivery	46 (63.89)	32 (64.00)	χ^2=0.048	0.977
	Cesarean section	21 (29.17)	15 (30.00)		
	Conversion to cesarean section	5 (6.94)	3 (6.00.)		

Table 2. Height, length, circumference and area of the perineal body at rest.

Group	Height (mm)	Length (mm)	Circumference (mm)	Area (cm^2)
Research (n=72)	8.42±1.12	16.06±2.16	10.26±1.14	2.41±0.79
Control (n=50)	8.29±1.29	16.49±2.03	10.34±0.93	2.53±0.65
t	0.592	1.108	0.410	0.886
p	0.555	0.270	0.682	0.378

Data are expressed as $\bar{x}$ ± SD.

Table 3. Height, length, circumference and area of the perineal body at the maximum Valsalva maneuver.

Group	Height (mm)	Length (mm)	Circumference (mm)	Area (cm^2)
Research (n=72)	8.09±1.23	16.58±2.12	12.86±1.11	2.66±0.81
Control (n=50)	6.87±1.34	18.21±2.64	14.15±0.96	3.52±0.60
t	5.194	3.774	6.665	6.386
p	0.000	0.000	0.000	0.000

Data are expressed as $\bar{x}$ ± SD.

Thickness and elastic moduli of anterior and posterior lips of the bladder neck

The elastic moduli of the anterior and posterior lips of the bladder neck were smaller in the research group than those in the control group ($p<0.05$), while the thicknesses of the anterior and posterior lips of the bladder neck had no significant difference between the two groups ($p>0.05$) (Table 4).

Correlations of maternal SUI with US-SWE and gray-scale ultrasonography parameters

Maternal SUI was positively correlated with the height of the perineal body ($r>0$, $p<0.05$) but negatively correlated with the length, circumference and area of the perineal body and the elastic moduli of anterior and posterior lips of the bladder neck ($r<0$, $p<0.05$) (Table 5).

Assessment values of US-SWE and gray-scale ultrasonography parameters for maternal SUI

ROC curves were plotted by using US-SWE parameters (elastic moduli of the anterior and posterior lips of the bladder neck) and gray-scale ultrasonography parameters (height, length, circumference and area of the perineal body at the maximum VM) that differed between research group and control group as test variables, and the incidence of maternal SUI as a state variable (1=Yes, 0=No). The results revealed that the elastic moduli of anterior and posterior lips of the bladder neck and the height, length, circumference and area of the perineal body at the maximum VM were valuable for assessing maternal SUI (areas under the ROC curves: 0.765, 0.667, 0.809, 0.800, 0.828 and 0.833). The predictive value was optimal when their cut-off values were 7.630 mm, 16.850 mm, 13.305 mm, 3.070 cm, 26.205 kPa and 22.010 kPa, respectively (Table 6 and Fig. 1).

DISCUSSION

The dynamic balance and muscle function of pelvic floor support structures are the main factors controlling normal urination. Once such balance is destroyed and

Table 4. Thickness and elastic moduli of the anterior and posterior lips of the bladder neck.

Group	Thickness of anterior lip (mm)	Elastic modulus of anterior lip (kPa)	Thickness of posterior lip (mm)	Elastic modulus of posterior lip (kPa)
Research (n=72)	4.42±0.59	24.68±4.16	5.13±0.76	19.37±3.78
Control (n=50)	4.38±0.61	30.72±4.97	5.09±0.84	25.22±5.49
t	0.363	7.278	0.274	6.974
p	0.717	0.000	0.785	0.000

Data are expressed as $\bar{x} \pm SD$.

muscle function is impaired, it is difficult to maintain the urethral closure pressure, resulting in SUI [8,9]. Transvaginal ultrasonography is commonly used for the clinical diagnosis of SUI, and observation of the perineal body and bladder neck status at rest and the maximum VM by gray-scale ultrasonography play an important auxiliary role in diagnosing SUI [10]. US-SWE can detect soft tissue hardness, quantitatively assess muscle elasticity and reflect muscle strength [11]. Zhao *et al*. found that the state of urethral striated muscle can be quantitatively assessed by US-SWE, which had important significance in diagnosing and treating SUI in females [12].

In the case of muscle damage of the perineal body, the support capacity declines, resulting in pelvic floor dysfunction [13]. The urethral sphincter of females is mainly composed of circular smooth muscle fibers surrounding the bladder neck. Pregnancy and childbirth may alter the bladder neck status and thus impair its function, so the patients cannot consciously store urine [14]. Therefore, imaging is necessary to measure relevant parameters of the perineal body and bladder neck. The gray-scale ultrasonic probe placed in the vagina emits ultrasonic waves to surrounding tissues, and gray-scale images are obtained, by which doctors can observe the height, length, circumference and area of the perineal body. US-SWE reflects the changes in morphology and hardness of the bladder neck in real-time, thereby indirectly reflecting the degree of damage to the neck[15,16]. In this study, at the maximum VM, the research group had higher height, smaller length and area, and shorter circumference of the perineal body than those of the control group, suggesting that the parameters of the perineal body at the maximum VM of SUI patients were inferior to those of healthy pregnant women.

Moreover, the elastic moduli of anterior and posterior lips of the bladder neck were smaller in the research group than those in the control group, indicating that the bladder neck of SUI patients was less elastic than that of healthy pregnant women. During childbirth, the perineal body is passively expanded, and the mobility of the posterior wall of the bladder and trigonum vesicae accordingly increases with rising abdominal pressure, which may lead to the shortening of the perineal body and loose closure of the bladder neck [17,18]. In the third trimester of pregnancy, the pelvic floor muscles are directly pulled and compressed, resulting in pelvic floor muscle dysfunction. During childbirth, the perineal body is exceptionally pulled (up to 200%) as the fetus passes through the birth canal, so SUI and other pelvic floor dysfunction diseases occur easily [19,20].

We herein found that maternal SUI was positively correlated with the height of the perineal body but negatively correlated with the length, circumference and area of the perineal body and the elastic moduli of the anterior and posterior lips of the blad-

Table 5. Correlations of maternal SUI with US-SWE and gray-scale ultrasonography parameters.

	Group	Height	Length	Circumference	Area	Elastic modulus of the anterior lip	Elastic modulus of the posterior lip
Group	-	0.430/0.000	-0.326/0.000	-0.518/0.00	-0.501/0.000	-0.553/0.00	-0.538/0.000
Height	0.430/0.000	-	-0.210/0.020	-0.297/0.001	-0.256/0.004	-0.309/0.001	-0.268/0.003
Length	-0.326/0.000	-0.210/0.020	-	0.257/0.004	0.180/0.048	0.332/0.000	0.213/0.018
Circumference	-0.518/0.00	-0.297/0.001	0.257/0.004	-	0.172/0.058	0.356/0.000	0.294/0.001
Area	-0.501/0.000	-0.256/0.004	0.180/0.048	0.172/0.058	-	0.298/0.001	0.304/0.001
Elastic modulus of anterior lip	-0.553/0.00	-0.309/0.001	0.332/0.000	0.356/0.000	0.298/0.001	-	0.323/0.000
Elastic modulus of posterior lip	-0.538/0.000	-0.268/0.003	0.213/0.018	0.294/0.001	0.304/0.001	0.323/0.000	-

The values are represented as r/p; the point-biserial correlation test was used.

Table 6. Assessment value of US-SWE and gray-scale ultrasonography parameters for maternal SUI.

Variable	AUC	Standard error	p	95%CI		Cut-off value	Sensitivity	Specificity	Youden index
				Lower limit	Upper limit				
Height	0.765	0.045	0.000	0.678	0.852	7.630 mm	0.780	0.653	0.433
Length	0.667	0.051	0.002	0.566	0.768	16.850 mm	0.660	0.528	0.188
Circumference	0.809	0.040	0.000	0.732	0.887	13.305 mm	0.800	0.681	0.481
Area	0.800	0.039	0.000	0.724	0.877	3.070 cm	0.780	0.681	0.461
Elastic modulus of the anterior lip	0.828	0.038	0.000	0.753	0.903	26.205 kPa	0.860	0.667	0.527
Elastic modulus of the posterior lip	0.833	0.040	0.000	0.755	0.911	22.010 kPa	0.800	0.764	0.564

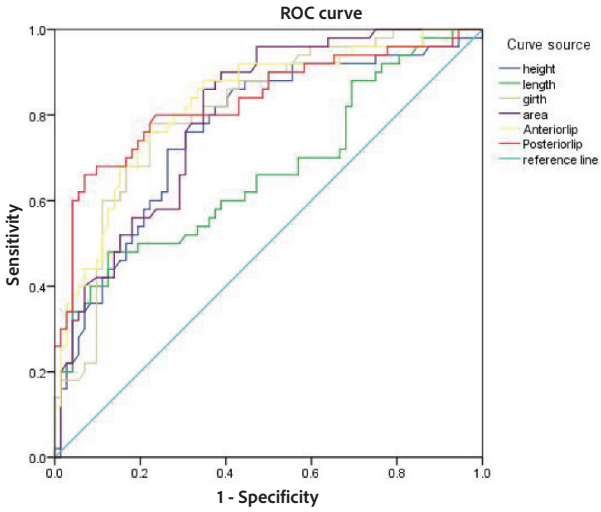

Fig. 1. ROC curves of US-SWE and gray-scale ultrasonography parameters for assessing maternal SUI.

der neck. As indicated by the ROC curve analysis, the elastic moduli of the anterior and posterior lips of the bladder neck and the height, length, circumference and area of the perineal body at the maximum VM were valuable for assessing maternal SUI. The perineal body is the ultimate line of defense against pelvic floor dysfunction and plays an important role in supporting the urethra. Morphological changes of the perineal body affect its support to the vagina and urethra, resulting in cystocele and rectocele, and ultimately SUI [21]. When the bladder neck is less elastic, and the muscle is weak in contraction, it is difficult to control urine, thereby effectively increasing the risk of SUI22. Therefore, patients with postpartum SUI are recommended to receive hot compress and massage to relieve local muscle dysfunction, take anus-lifting exercises to improve muscle relaxation, and undergo medication and surgery to restore the anatomical structure of local tissues if necessary, aiming to ameliorate the prognosis.

Nevertheless, this study is limited. First, the ultrasound technique may have variabilities. Second, this is a single-center study with a small sample size. Third, a subgroup analysis of patients whose ultrasound varies considerably was not conducted. Hence, further multicenter studies with larger sample sizes must confirm our findings.

In conclusion, US-SWE and gray-scale ultrasonography parameters are closely related to maternal SUI, and the risk of maternal SUI can be assessed early by the bladder neck status. US-SWE may be recommended in cases with higher-risk factors, such as a history of multiple pregnancies or advanced maternal age, where monitoring the elasticity and perineal body status of the bladder neck can provide valuable insights into SUI development.

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Conflicts of interest

The authors declare they have no conflicts of interest.

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