Research paper

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Correlation analysis of selected anatomical and functional parameters of the urethra, assessed through ultrasound and urodynamic examinations

Hubert Wójtowicz*[1], Edyta Wlaźlak*[2], Jacek Kociszewski[3], Wiktor Wlaźlak[2], Jan Krakowiak[4], Wojciech Fijołek-Więcławek[2], Andrzej Wróbel[5], Grzegorz Surkont[2]

[1] *Gynecology, Independent Public Health Care Complex, Pruszków, Poland*
[2] *Department of Operative Gynecology and Gynecologic Oncology, 1st Chair of Obstetrics and Gynecology, Medical University of Lodz, Łódź, Poland*
[3] *Gynäkologie, Evangelisches Krankenhaus Hagen-Haspe, Hagen, Germany*
[4] *Department of Social Medicine, Chair of Social and Preventive Medicine, Medical University of Lodz, Lodz, Poland*
[5] *2nd Chair and Department of Gynecology, Medical University of Lublin, Poland*

** First author*

Corresponding author: Edyta Wlaźlak; e-mail: edytawlazlak@gmail.com

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Abstract

Aim: This study aimed to examine the correlations between specific urethral function parameters observed in urodynamic testing and selected urethral characteristics evaluated by pelvic floor ultrasonography. Additionally, the presence of urethral funneling during straining was evaluated in female patients referred for surgical treatment of stress urinary incontinence. **Material and methods:** A retrospective study was conducted on 192 female patients referred for surgical treatment of stress urinary incontinence with the use of retropubic tension-free vaginal tape. Maximum urethral closure pressure and functional urethral length were evaluated urodynamically during resting profilometry. Ultrasound measurements, along with the assessment of funneling, were performed as part of the pelvic floor examination, following the technique described by Kociszewski. Patients with clinically significant pelvic organ prolapse, a history of anterior compartment surgery, prior radiotherapy, or symptoms of overactive bladder were excluded from the analysis. **Results:** The values obtained from urodynamic and ultrasound examinations were evaluated statistically. No correlation was identified between the analyzed urodynamic and ultrasound parameters. Long urethral funneling was confirmed in all patients with stress urinary incontinence assessed as eligible for the placement of tension-free vaginal tape. **Conclusions:** The results indicate that urodynamic and ultrasound examinations assess distinct aspects of urethral anatomy and function, and therefore their findings cannot be used interchangeably. Long urethral funneling assessed during pelvic floor ultrasonography was noted in all patients with clinically and urodynamically confirmed stress urinary incontinence

Introduction

Urinary incontinence (UI) is one of the most prevalent pelvic floor disorders in women. The condition causes significant impairment to the quality of life[(1)]. The most common type of UI is stress urinary incontinence (SUI)[(2)]. Despite the high prevalence of this disorder, its underlying mechanisms and the factors contributing to treatment inefficacy are still not fully understood[(3,4)]. Currently, two primary hypotheses aim to explain the etiology of SUI in women. One theory suggests that damage to the urethral support mechanism, resulting in excessive urethral mobility, may disrupt pressure transmission during increases in abdominal pressure[(5)]. Another potential cause could be damage to the intraurethral structures, leading to dysfunctional urethral closure[(6–8)]. However, the role of various mechanisms and their interplay remains a subject of significant controversy[(3,8,9)].

To optimize the therapeutic procedure, urodynamic (UD) testing and ultrasonography (USG) are used alongside clinical examination in diagnosing SUI. However, there are no clear guidelines on when these examinations should be performed. To assess the intrinsic sphincter function, the maximum urethral closure pressure (MUCP), a parameter evaluated during UD testing, is often used[9,10]. Patients with and without SUI were compared in terms of their UD parameters and urethral support by DeLancey *et al.* The authors found the strongest correlation between SUI symptoms and low MUCP values[11]. MUCP ≤25 mmH_2O, defined as intrinsic sphincter deficiency (ISD), was associated with poorer outcomes of treatment with tension-free vaginal tape[12,13]. Another parameter assessed by UD is functional urethral length (FUL), which likely corresponds to the location of the urethral sphincter[14,15].

Pelvic floor ultrasound is increasingly used in urogynecology, providing real-time assessment of anatomy and function[16]. Urethral mobility and length can be assessed using a pelvic floor ultrasound transabdominal probe (PFU-TA) or a pelvic floor sonography transvaginal probe (PFS-TV)). Both methods demonstrate good or very good repeatability in assessing urethral length and mobility[9,17–24]. The significant variation in women's urethral lengths (from 18 mm to 51 mm)[25] makes the assessment of sonographically measured urethral length (SUL) during PFS-TV useful for determining the optimal position for the vaginal tape, potentially enhancing the efficacy of eliminating SUI after tape implantation[26]. The significance of FUL was not assessed in this respect. Although reduced urethral mobility is considered a key factor negatively affecting the effectiveness of surgical treatment for SUI, various aspects of urethral mobility have not been thoroughly explored.

The occurrence of urethral funneling, resulting from the dilation of the proximal urethral segment, may be a consequence of ISD[12,13,27,28]. Some studies suggest that long urethral funneling diagnosed during PFS-TV, with the funneling length exceeding 50% of the SUL, is a characteristic sign of SUI[29,30]. The diversity of methods used to evaluate funneling may contribute to inconsistent results regarding its significance and utility in diagnosing SUI in women.

To date, no comprehensive analyses have been conducted on the relationship between urethral mobility and length assessed via USG and the urethral function parameters determined by UD testing. Understanding these relationships could enhance insights into the pathomechanism of SUI and support the optimization of diagnosis and treatment.

Aim

The main aim of the study was to analyze the correlations between selected urethral function parameters in the UD examination and selected parameters of the urethra assessed during PFS-TV. An additional aim was to assess the occurrence of urethral funneling during straining in patients referred for surgical treatment of SUI.

Material and methods

A retrospective study was conducted among 192 women scheduled for surgical treatment of SUI using tension-free vaginal tape (TVT) between 2016 and 2019. All patients underwent a routine preoperative diagnostic evaluation including a standardized history, clinical examination, UD testing, and PFS-TV.

Patients were deemed eligible for surgery if they had SUI grade 2 or 3 confirmed by a standardized cough test and UD examination[31,32].

Patients with significant pelvic organ prolapse, defined as a descent of at least one compartment ≥2 on the POP-Q (Pelvic Organ Prolapse Quantification) scale, were deemed ineligible for the TVT procedure[33,34]. Patients with a history of anterior compartment surgery, pelvic radiotherapy, or symptoms of overactive bladder (OAB) including OAB-wet and OAB-dry subtypes, were excluded from the analysis[35].

MUCP and FUL values were measured during resting profilometry in a UD examination, conducted using the Andromeda Ellipse device with an 8 Fr Gaeltec dual microtip electronic catheter, following the established protocol. Based on the obtained MUCP values, two patient groups were distinguished: the first with MUCP values ≤25 mmH_2O, meeting the criteria for ISD diagnosis, and the second with MUCP values >25 mmH_2O.

Ultrasound measurements were conducted using PFS-TV following the technique outlined by Kociszewski[36,37]. The procedure utilized GE Voluson 730 Expert and Pro devices equipped with a GE RIC5-9E 5–9 MHz transvaginal probe operating at a frequency of 6.5 MHz, with an ultrasound beam angle of 160°. The length and mobility of the urethra were evaluated with the bladder filled to approximately 250 ml. This was done by positioning the probe along the patient's longitudinal axis near the external urethral opening, applying minimal pressure to the examined area (Fig. 1, Fig. 2, Fig. 3). Based on the results, patients were categorized into three groups: with short (≤27 mm), typical (28–32 mm), and long (>32 mm) urethra. Urethral mobility measurements were performed during maximum straining sustained for at least 6 seconds. Bladder neck mobility was evaluated based on the bladder neck descent (BND) and vector parameters (Fig. 4)[23,38]. On the basis of the vector parameter, the patients were categorized into three groups: with hypomobile urethra (vector ≤5 mm), normobile urethra (vector >5 to 15 mm), and hypermobile urethra (vector >15 mm)[12].

To evaluate urethral funneling, the vaginal probe was rotated dorsally to achieve an ultrasound beam incidence angle of at least 60° relative to the patient's long axis, optimizing visualization of the bladder neck area (Fig. 5, Fig. 6). Funneling with a length exceeding half of the SUL was defined as long[38].

Pearson's correlation was used to analyze the relationships. A one-way ANOVA was conducted to compare the differences between groups. The assumption of equal variances was tested using Bartlett's test. The normality of data distribution was assessed with the Shapiro-Wilk test and by visual inspection. Student's t-test was used to assess statistical significance, with a critical alpha value set at 0.05. Additionally, the MUCP variable was log-transformed to achieve a distribution closer to normal. All analyses were conducted using Stata software, version 17.

Results

The patients included in the analysis had a mean age of 59 years (range: 36–85 years), a mean BMI of 27, and a mean parity of 2 (range: 0–6), with 83% having delivered vaginally.

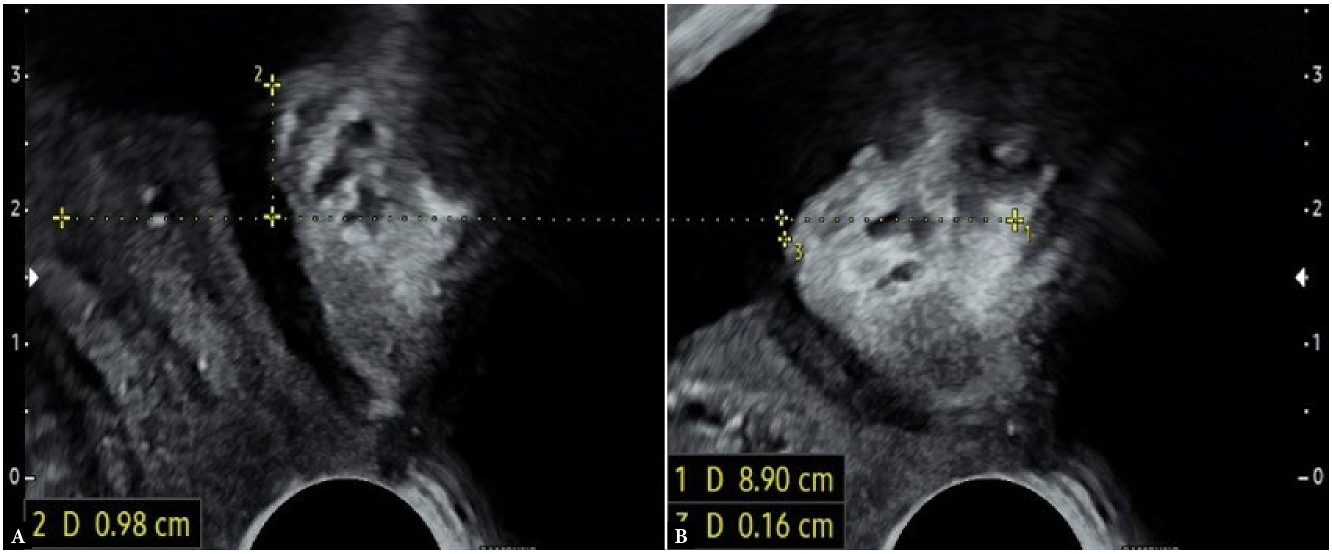

Fig. 1. *Assessment of urethral mobility – examination performed using a transvaginal probe (PFS-TV):* **A.** at rest; **B.** *during straining*

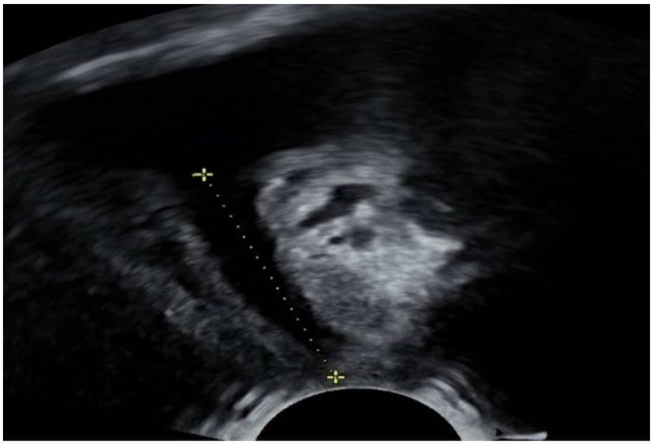

Fig. 2. *Sonographic assessment of urethral length – examination performed using a transvaginal probe (PFS-TV)*

Fig. 3. *Positioning of the transvaginal probe (PFS-TV) to evaluate bladder neck descent (BND) and urethral length during the examination*

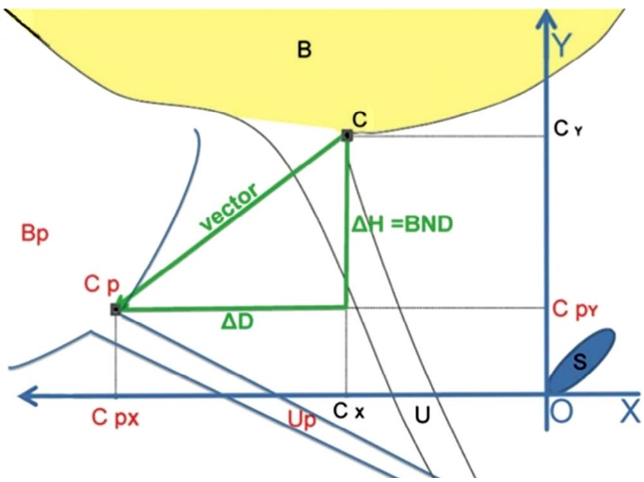

Fig. 4. *Diagram illustrating the assessment of urethral mobility based on bladder neck descent parameters: BND and vector*

Fig. 5. *Examination performed using a transvaginal probe (PFS-TV). Long urethral funneling during VLPP test*

Fig. 6. *Examination performed with a transvaginal probe (PFS-TV): positioning of the probe to assess urethral funneling*

The values obtained during the UD and ultrasound examinations were subjected to statistical analysis (Tab. 1, Fig. 7). No correlation was obtained between the analyzed parameters: UD – MUCP and FUL, and PFS-TV – SUL and urethral mobility (BND, vector).

No statistically significant differences were identified between the two patient groups: those with urodynamic signs of ISD and with MUCP values >25 mmH_2O in relation to SUL, FUL, and urethral mobility (vector and BND parameters) (Tab. 2, Tab. 3).

The comparison of the three patient groups with short, typical, and long SUL (PFS-TV) revealed no statistically significant differences in terms of MUCP, FUL, and urethral mobility (vector and BND parameters) (Tab. 4).

Tab. 1. Descriptive statistics

	Mean	Standard deviation	Minimal values	Maximal values
MUCP	45.99	28.95	5.00	161.00
Functional length	31.91	14.65	5.00	79.00
Urethral length	31.26	4.27	21.03	43.00
BND	16.54	8.36	1.00	46.20
VEC	17.24	8.35	1.61	49.55

MUCP – maximum urethral closure pressure; BND – bladder neck descent
VEC – vector

Tab. 2. Significance level for the test of differences between MUCP means and the variance differences in MUCP for both groups in relation to the SUL, BND, and VEC parameters

	Test	SUL	BND	VEC
Total	1	0.917	0.673	0.673
	2	0.644	0.873	0.873
MUCP >25	1	0.508	0.830	0.830
	2	0.911	0.781	0.781
MUCP ≤25	1	0.556	0.584	0.584
	2	0.810	0.247	0.247

1 – test for differences in means between groups using a one-way ANOVA model, p value; 2 – Bartlett's test for homogeneity of variances, p value; SUL – sonographically measured urethral length; BND – bladder neck descent; VEC – vector; MUCP – maximum urethral closure pressure

Three groups of patients were compared: those with hypomobile, normobile, and hypermobile urethras, based on the vector parameter in the PFS-TV examination. No statistically significant differences were found with respect to MUCP, FUL, and SUL values (Tab. 5). Long urethral funneling was confirmed in all patients with SUI assessed as eligible for TVT placement.

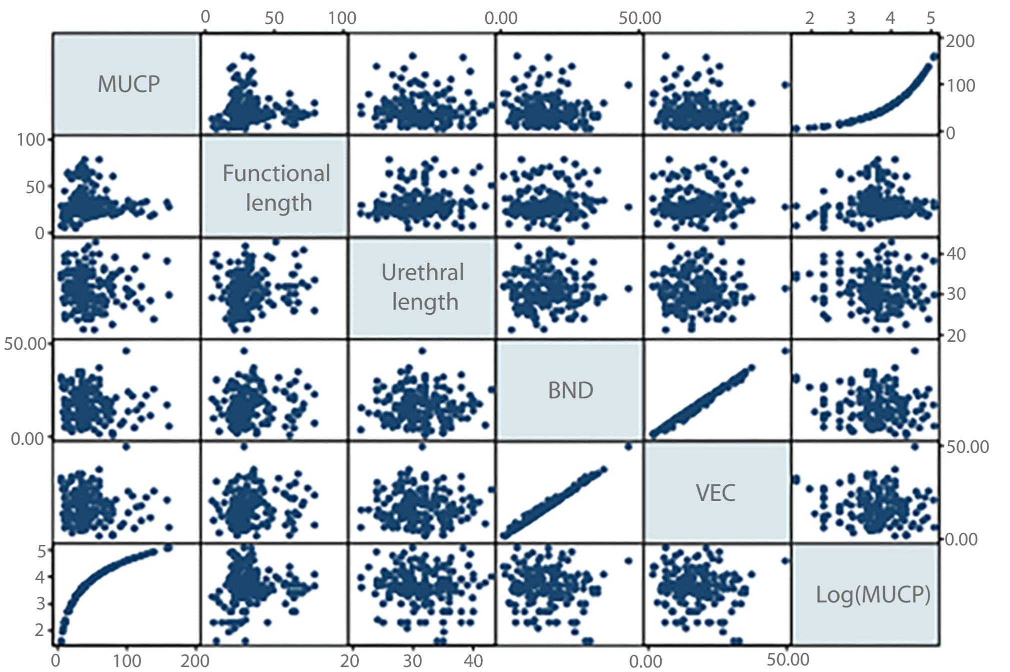

Fig. 7. *Relationships between the analyzed variables. Scatter plot. VEC – vector; Log(MUCP) – logarithmic transformation of MUCP; MUCP – maximum urethral closure pressure; BND – bladder neck descent*

Tab. 3. Correlations between the analyzed ultrasound parameters and MUCP values

	Statistics	MUCP-SUL	MUCP-BND	MUCP-VEC
Total	1 2	–0.0212 0.7706	–0.0852 0.2552	–0.0798 0.2868
MUCP >25 (*N* = 151)	1 2	0.0674 0.4110	–0.0507 0.5507	–0.0416 0.6242
MUCP ≤25 (*N* = 41)	1 2	–0.0237 0.8830	–0.1065 0.5186	–0.0904 0.5840

1 – correlation coefficient; 2 – statistical significance, p value; MUCP – maximum urethral closure pressure; SUL– sonographically measured urethral length; BND – bladder neck descent; VEC – vector

Tab. 4. Correlations between the analyzed parameters based on SUL values

	Statistics	SUL-MUCP	SUL-FUL	SUL-BND	SUL-VEC
Total	1 2	–0.0212 0.7706	0.1125 0.1203	–0.0177 0.8140	–0.0168 0.8227
SUL ≤27 (*n* = 29)	1 2	–0.0385 0.8429	0.3167 0.0942	–0.0260 0.8999	–0.0674 0.7436
SUL 28-32 (*n* = 103)	1 2	–0.0681 0.4945	0.1509 0.1282	–0.0726 0.4753	–0.0728 0.4738
SUL ≥33 (*n* = 60)	1 2	0.1037 0.4302	0.1332 0.3104	0.0735 0.5939	0.0798 0.5623

1 – correlation coefficient; 2 – statistical significance, p value; FUL – functional urethral length; SUL – sonographically measured urethral length; MUCP – maximum urethral closure pressure; BND – bladder neck descent

Tab. 5. Correlations between the analyzed parameters based on VEC values

	Statistics	VEC-MUCP	VEC-FUL	VEC-SUL
Total	1 2	–0.0798 0.2868	0.1205 0.1070	–0.0168 0.8227
VEC ≤5 (n = 7)	1 2	–0.7847 0.0367	–0.3767 0.4048	–0.6453 0.1175
VEC 5–15 (n = 78)	1 2	–0.0701 0.5421	–0.0532 0.6438	–0.0840 0.4645
VEC >15 (n = 107)	1 2	–0.0511 0.6228	0.1291 0.2123	–0.1365 0.1872

1 – correlation coefficient; 2 – statistical significance, p value; VEC ≤5 – hypomobile urethra; VEC5–15 – normobile urethra; VEC >15, hypermobile urethra; VEC – vector; SUL – sonographically measured urethral length; MUCP – maximum urethral closure pressure; FUL – functional urethral length

Discussion

Currently, there are no clear guidelines on when or which examinations should be performed to diagnose and plan treatment for SUI. This is partly due to limited knowledge of available diagnostic methods and ongoing controversy over whether specific examinations can improve therapeutic outcomes[9].

Despite the long-standing use of UD testing to evaluate the intrinsic sphincter function, a single standardized definition of ISD has yet to be established[39,40]. Some researchers consider MUCP ≤ 25 cmH_2O to be the threshold for defining ISD, and this value was used in the present study[10]. Some studies have indicated that MUCP differed most significantly between patients with and without SUI, with values being 43% lower in those with SUI[11,41,42]. FUL is another parameter that has been linked to SUI, with patients presenting with SUI exhibiting lower FUL values[43,44].

Ultrasound is increasingly used to visualize the anatomy and function of the urethra[9]. Among other parameters, SUL and urethral mobility are evaluated in patients with SUI[23,17]. Studies conducted to date using PFS-TV suggest that reduced urethral mobility may be associated with poorer outcomes in the surgical treatment of SUI[26]. It is likely that increased mobility improves the chances of SUI resolution, even when the TVT is positioned suboptimally[12]. It has also been shown that the greater the deviation of urethral length from the mean, the higher the risk of suboptimal vaginal tape placement[45,46].

The results of previous studies suggest that both reduced urethral mobility and ISD are risk factors for the failure of surgical treatment of SUI with TVT[12,13].

The limited studies comparing UD and USG do not offer clear conclusions on whether and to what extent these examinations can be used interchangeably Najjari *et al.* found no correlations between SUL and FUL values; patients with SUI exhibited higher SUL and lower FUL values compared to those without SUI[47]. The study by Shin also observed lower FUL values in patients with SUI compared to those without SUI. A longer urethra, as measured with a Foley catheter, was associated with higher MUCP values and a lower likelihood of SUI[48]. Based on isolated studies, a higher prevalence of ISD was observed in patients with limited urethral mobility[12,49].

The current analysis did not reveal any statistically significant correlations between the parameters obtained during PFS-TV (urethral mobility and SUL) and those from the UD examination (FUL and MUCP). No correlation was observed even after dividing the study population into groups based on urethral mobility, degree of SUL, and the presence or absence of ISD characteristics. The association between low MUCP values, short urethra, and reduced urethral mobility, as shown in previous studies, was not observed. The results of the present study suggest that the UD and PFS-TV parameters are independent of each other. This indicates that combining information from both UD and PFS-TV may enhance the outcomes of surgical treatment for SUI.

There is ongoing controversy regarding the clinical significance of the funneling sign observed on ultrasound, both PFU-TA and PFS-TV. Notably, reports on urethral funneling exhibit a wide range of results, which is likely attributable to variations in study methodologies. According to various authors, in patients with symptoms of SUI, its prevalence ranges from 18.6% to 100%[27,50–56]. Some researchers have suggested that funneling is a defining feature of patients with ISD[27,50].

The results of previous studies using PFS-TV showed that all patients with a bladder containing 250–300 ml of fluid and clinically confirmed symptoms of SUI exhibited funneling longer than 50% of the SUL (referred to as long funneling)[29,30]. The results of the present study, in which PFS-TV was performed using the same technique, showed that long funneling were present in all women with SUI confirmed clinically and in UD findings. The differences between the results obtained with PFS-TV and PFU-TA may be attributed to the varying angles at which the ultrasound beam was applied. Using a transvaginal probe with a beam angle exceeding 60° relative to the urethral axis (PFS-TV) can enhance the quality of urethral imaging at its junction with the urinary bladder. During the PFU-TA examination, the transabdominal probe, which has a larger surface area in contact with the perineum, may have a negative impact on the strength and effectiveness of the VLPP (Valsalva leak point pressure) test. The angle of incidence of the ultrasound beam during PFU-TA is below 60°.

At the same time, it appears that assessing SUI by ultrasound should be done when the urinary bladder contains approximately 250–300 ml of fluid, as is done during urodynamic examination and the cough test.

A limitation of the present study is the absence of a reference group of healthy women. The results suggest that combining UD and PFS-TV examinations may offer more comprehensive information on the structure and function of the lower urinary tract than performing either one alone. It would be beneficial to continue comparative analyses of healthy women and various groups of urogynecological patients using both UD and PFS-TV, as the results could ultimately help improve the outcomes of SUI treatment. Further studies on the relevance of long funneling detected during PFS-TV for diagnosing patients with SUI, including those eligible for both non-surgical and surgical treatment, may result in the incorporation of this parameter into standard SUI diagnostics.

Conclusions

No correlation was found in the present study between the parameters assessed by UD: FUL and MUCP, and by PFS-TV: mobility and SUL. The results indicate that urodynamic and ultrasound examinations assess distinct aspects of urethral anatomy and function. Consequently, their findings cannot be used interchangeably.

Long urethral funneling assessed during PFS-TV was observed in all patients with SUI confirmed clinically and by UD testing.

Conflict of interest

The Authors do not declare any financial or personal links with other persons or organisations that might adversely affect the content of the publication or claim any right to the publication.

Author contribution

Original concept of study: HW, EW, JKo, GS. Writing of manuscript: HW, EW, WW, JKr, WFW, AW, GS. Analysis and interpretation of data: HW, EW, WW, JKr, WFW, AW, GS. Final approval of manuscript: HW, EW, JKo, GS. Collection, recording and/or compilation of data: HW, EW, GS. Critical review of manuscript: HW, EW, JKo, GS.

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