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Demographic features of female urethra length

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Aims: To determine cohort urethral length, identify epidemiological factors influencing the parameter and to establish the percentage of cases with clinically relevant outsized urethras.

Methods: Prospective cohort study conducted in two tertiary clinical centers between 2013 and 2017. Nine hundred and twenty seven consecutive adult, Caucasian females attending outpatients' clinics were included. The urethral length has been measured in pelvic floor ultrasound examination. The exclusion criteria were inadequate bladder filling (<200 mL; >400 mL), previous history of pelvic floor surgery, and no consent.

Results: Urethral length varied from 19 to 45 mm. The distribution of the examined parameter was normal. Obese patients had significantly longer urethras as compared to non-obese subjects. Number of vaginal deliveries was connected with shorter urethral length. The limitations of the study are: analysis only of Caucasian patients and subjects without previous pelvic floor surgeries.

Conclusions: Differences in urethral length in the female population were demonstrated. Thirty percent of patients have atypical urethras that may be a risk factor for sling surgery failure. We therefore postulate introduction of urethral measurement before the procedure.

KEYWORDS
female urethra, pelvic floor, stress urinary incontinence, suburethral slings, urethral length

1 | INTRODUCTION

The female urethra is a tubular structure extending from the internal orifice at the bladder neck to external urethral orifice in the vaginal vestibule. The proximal part of the urethra from the meatus to the point localized approximately 15% of its total length is surrounded by a U-shaped loop of fibers of the detrusor muscle. The next part, extending from 15% to 70% of its length contains fibers of striated sphincter of the urethra. Pubo-urethral ligament, responsible for continence mechanisms is attached between 15% and 50% of its length. From 54% to 76% of the total urethral length (UL) it is surrounded by striated fibers of the urogenital diaphragm.[1] The sphincteric closure of the urethra is normally provided by the urethral striated muscles, the urethral smooth muscle, and the vascular elements within the submucosa.[2]

The length and anatomy of the urethra have been subjects of extensive research. Most data originate from cadaver studies. Among methods of measuring female UL in vivo are: measurement using Foley catheter, measurement during urodynamic examination based on urethral pressure profile, magnetic resonance imaging (MRI), and ultrasound examination. The UL described in textbooks of anatomy is about

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30-50 mm. For example, according to the Gray's Anatomy textbook it measures approximately 40 mm.[3] So far there have been no data concerning population distribution of this feature available.

Till now there has been no evidence that UL itself may influence continence mechanisms or be connected with specific conditions such as stress urinary incontinence or overactive bladder syndrome. The introduction of anti-incontinence procedures based on the principle of inserting the sling beneath the mid-urethra to reinforce or replace the weakened pubo-urethral ligament forced clinicians to pay attention to UL.[4] The inventors of this surgical technique made an assumption that the typical urethra is approximately 30 mm long. They proved that optimal sling location is in the area of the urethra's high-pressure zone, extending between the point of the maximum urethral closure pressure and the urethral knee (53-72% of UL).[5] Therefore, the authors recommended starting the procedure with the vaginal incision 10 mm from the external urethral orifice in order to achieve optimal distal sling location. Further observations demonstrated that proximal sling position (closer to bladder neck) may be one of the causes of failure of anti-incontinence procedures.[6,7] Moreover, it has been proved that measuring the UL before the procedure and adjusting the surgical technique to the individual UL provides much better results in sling procedures. Authors of the above observation suggested performing the vaginal incision in 1/3 of ultrasound UL to achieve optimal sling location independently from the UL.[8]

The aim of the study was to determine cohort UL and establish percentage of patients with atypical urethras who may benefit from modification of the sling procedure. We also tried to establish whether there are any epidemiological factors influencing the length of the urethra and if it is clinical relevant.

2 | METHODS

The cohort of 927 consecutive female patients attending the outpatient clinic in The 1st Department of Obstetrics and Gynecology of Medical University of Warsaw (MUW) (N = 782) and Evangelishes Krankenhaus Hagen-Haspe (EKH) ($N = 145$) underwent pelvic floor ultrasound. The study was performed between 2013 and April 2017 year in MUW and in 2015 in EKH. UL was measured in a standardized manner, with the patient on the gynecological chair in a semi sitting position with the bladder filled to 200-400 mL (the association between the bladder filling and UL in the volume range of 200-400 mL was not statistically significant). Three diameters of the bladder were measured in order to estimate the bladder volume at the beginning of the examination. The probe (a 3.6-8.3 MHz vaginal transducer with a beam angle of 160°) was placed in the vaginal introitus at the level of the external urethral orifice. With the probe in this position, the urinary bladder, urethra, and pubic symphysis with the interpubic disc were visualized in the median sagittal plane, according to Interdisciplinary S2k Guideline: Sonography in Urogynecology.[9] The length of the hypoechogenic core of the urethra was measured from the bladder neck to the pelvic diaphragm. The method of measurement is characterized by high repeatability and reproducibility.[10]

The examinations were performed by a consistent group of trained gynecologists. All women included in this study were adult (>18 years old), Caucasian and had no history of pelvic floor surgery. The exclusion criteria were: inadequate bladder filling during examination (<200 mL; >400 mL), previous history of pelvic floor surgery, pregnancy, and no consent. The ethics committee of Medical University of Warsaw approved the study.

Descriptive statistical analysis expressing the quantitative and categorical variables was performed with the use of Statistica version 12 software. Normality was tested using the Lilliefors and Shapiro-Wilk W-tests. We associated the degree and type of non-adherence using the *T*-test, non-parametric U-Mann Whitney and variance analysis (ANOVA). The Pearson or Spearman correlation test was used to determine the correlation between quantitative variables. Multiple regression analysis was used to present multivariate relationships and to show the influence of independent variables on a dependent variable. *P*-value <0.01 was considered statistically significant.

3 | RESULTS

Nine hundred and twenty-seven female patients were enrolled in the study.

Because of the significant percentage of obese patients in the studied group we decided to analyze the entire cohort, as well as cohort excluding obese patients and a subgroup of obese patients separately. Non-obese subgroup (BMI < 30) contained 565 patients with mean BMI 25.2 ± 2.2, while the obese subgroup (BMI $\geqq$ 30) contained 362 patients with mean BMI 38.0 ± 6.5. The baseline characteristics for entire cohort as well as for non-obese and obese subgroups are presented in Table 1.

We showed that the distribution of UL in the whole examined cohort is normal (Figure 1). Mean UL was 30.1 ± 4.2 mm (minimum 19 mm, maximum 45 mm). Median UL was 30.0 mm, the 15th percentile was 25.7 mm and 85th percentile was 34.2 mm (Table 2).

The associations of the epidemiologic factors and the length of the urethra were investigated with the use of one-factor and multivariate analysis. We found a significant positive association between UL and weight $P < 0.001$, and a negative correlation between the UL and number of vaginal deliveries (Figure 2) ($P < 0.001$).

TABLE 1 Cohort description with analyzed demographic features

Group	Total	Non obese	Obese	~*P*
N	927	565	362	
Age	55.4 ± 13.3	57.7 ± 12.1	51.8 ± 14.3	<0.001
Height (cm)	164 ± 6.3	164 ± 6.1	164 ± 6.6	=0.98
Body weigh (kg)	81.7 ± 22.2	68.0 ± 8.0	102.7 ± 20.4	<0.001
BMI	30.3 ± 7.7	25.2 ± 2.7	38.0 ± 6.5	<0.001
Parity	1.94 ± 1.1	2.01 ± 0.94	1.85 ± 1.24	=0.014
No of vaginal deliveries	1.72 ± 1.17	1.84 ± 1.02	1.56 ± 1.29	<0.001
No of cesarean sections	0.19 ± 0.52	0.14 ± 0.43	0.27 ± 0.62	=0.04
No of instrumental deliveries	0.04 ± 0.20	0.05 ± 0.23	0.02 ± 0.14	=0.023
Average birth weight (g)	3412 ± 545	3405 ± 564	3427 ± 511	=0.65
Average of maximum birth weight (g)	3640 ± 565	3628 ± 565	3662 ± 569	=0.42
Age at birth of 1st child	24.0 ± 5.0	24.4 ± 4.8	23.5 ± 5.2	=0.026
Age at birth of last child	29.1 ± 6.0	29.5 ± 5.8	28.6 ± 6.3	=0.067
Bladder volume (mL)	302 ± 53	306 ± 53	297 ± 52	=0.021
Urethral length (mm)	30.1 ± 4.2	29.0 ± 3.7	31.7 ± 4.5	<0.001

Results shown as mean value ± SD.

The mean UL for non-obese group was 29.0 ± 3.7 mm and 31.7 ± 4.5 mm for obese patients with normal distribution in both groups ($P < 0.001$; appropriate percentile boundaries for both groups are listed in Table 2) (Figure 3). The correlation between weight and UL was stronger with increasing weight. Despite the fact that the obese group had significantly lower number of vaginal deliveries as compared to non-obese subjects, the connection between weight and UL was independent from this factor in multivariate analysis.

We found that the association between UL and body weight was statistically significant among obese patients ($P < 0.001$). Among obese patients each 10 kg of body weight translated into additional 0.74 mm of UL. The negative correlation of the UL and number of vaginal deliveries was significant in whole analyzed group, as well as in obese and non-obese patients and each vaginal delivery translated into smaller length of urethra by 0.5 mm ($P < 0.001$).

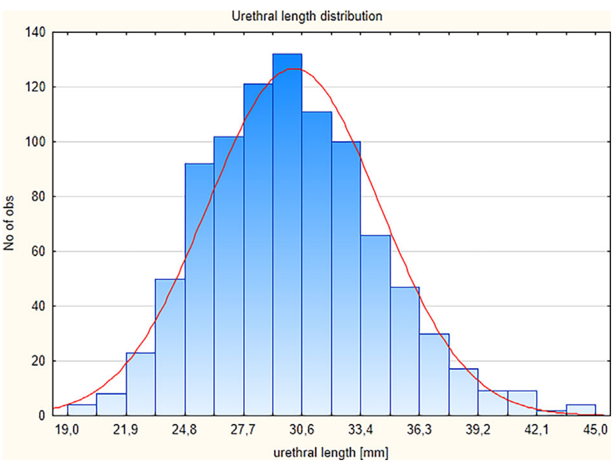

FIGURE 1 Urethral length distribution in entire cohort

Age, height, number of C-sections, average, and maximum birth weight, age at birth of the first and the last child did not correlate with UL. We did not find correlation between urethral length and incidence of lower urinary tract symptoms (LUTS) and continence status.

4 | DISCUSSION

The majority of data concerning the UL come from cadaver studies where it was estimated that the female urethra is approximately 30 mm long. In the observations regarding the anatomical relationship of the trigone of urinary bladder, pelvic ureter, and urethra it was demonstrated that it varies from 19 to 44 mm (mean 29.7 mm; $N = 24$).[11] In another small observational study including four cases it was estimated to be 33.8 mm.[12] The data obtained from cadaver examinations may vary substantially from the functional length of urethra. They may significantly differ from the in vivo examinations due to the loss of muscle tone, straightening of the folded structures or the method of cadaver preservation. On the other hand, in vivo measurements may also differ from one other depending on the selected method and filling of the bladder. Most studies concerning the parameter were based on small groups of cases and did not show population distribution of the UL and its demographic features. In 3D endo-vaginal ultrasound studies the UL was

TABLE 2 Urethral length distribution among all, obese, and non-obese patients

	Percentile boundaries of the urethral length (mm)										
Percentile	**5**	**10**	**15**	**20**	**25**	**50**	**75**	**80**	**85**	**90**	**95**
Urethral length (total)	23.7	24.9	25.7	26.4	27.1	30.0	32.8	33.5	34.2	35.4	37.4
Urethral length (non-obese)	23.3	24.5	25.1	25.9	26.4	29.9	31.5	32.3	33.0	33.7	35.0
Urethral length (obese)	24.9	26.0	27.1	28.0	28.5	31.6	34.7	35.4	36.4	37.5	39.4

estimated to be 36 ± 5 mm ($N = 31$).[13] There are also limited data on the UL measured with the use of MRI. It was shown in a group of seven young women that it ranged from 31 to 36 mm.[14] In another MRI observational study performed in a group of 78 nulliparous women the mean UL (muscular UL from bladder neck to the perineal membrane) was 24 mm and ranged from 20 to 35 mm.[15] The functional UL may be also measured in urethral pressure profile (UPP) and it was estimated to be about 32 mm ± 8 mm (range 10-50 mm) ($N = 549$) with no influence on the severity of incontinence.[16] The mean length of the urethra in 60 patients measured with Foley catheter in a group of patients with stress incontinence was approximately 33 mm.[17] All those observations are in accordance with the currently presented results showing that the mean UL is 30 mm with a fairly wide dispersion, regardless from used method. For the first time in a cohort study, we demonstrated that the UL ranging from 19 to 45 mm has a normal distribution. Moreover, we showed that in approximately 30% of patients the UL differs significantly from the average 30 mm long urethra.

Modern anti-incontinence procedures were introduced over 20 years ago. Mid-urethral sling became a gold standard in SUI treatment and the effectiveness of the procedure is estimated at approximately 70% of the treated patients.[18,19] Despite the fact that these results are quite satisfactory for clinicians and for the patients, there still exists an area for improvement in anti-incontinence surgeries as for almost 30% of patients the surgery does not eliminate the problem of SUI.

The cause of these failures and the question whether there is a chance to change those statistics appear to be the most current issues in anti-incontinence procedures.

As it was previously mentioned, one of the most important factors influencing the effectiveness of the procedure is the optimal sling location beneath the distal part of urethra (area of high pressure zone). It was shown that proximal (closer to bladder neck) sling implantation is connected with persistent or recurrent incontinence.[6,7] On the other hand it was also established that adjusting the surgery technique to individual UL (both in case of retropubic and transobturator approach) helps to achieve better results.[8,20] Basing on those observations, authors suggested that measurement of the UL and changing the procedure technique (ie. modifying the point of the beginning of the vaginal incision) might be important in SUI surgery. In our previous study we showed that among patients with incontinence, distribution of urethral length was normal and modification of surgery technique resulted in distal sling location (66.18 ± 8.43% of urethral length) regardless to above parameter,[21] but we still have not known whether variations in urethral length are represented in whole women population and what is the percentage and risk factors of atypical values.

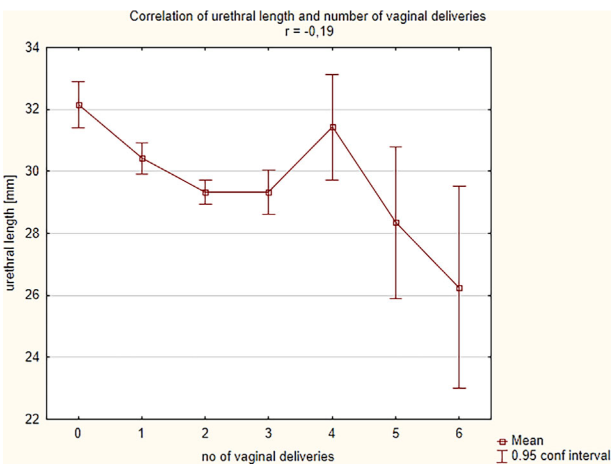

FIGURE 2 Mean urethral length grouped by number of vaginal deliveries with marked 0.95 confidence intervals ($P < 0.001$)

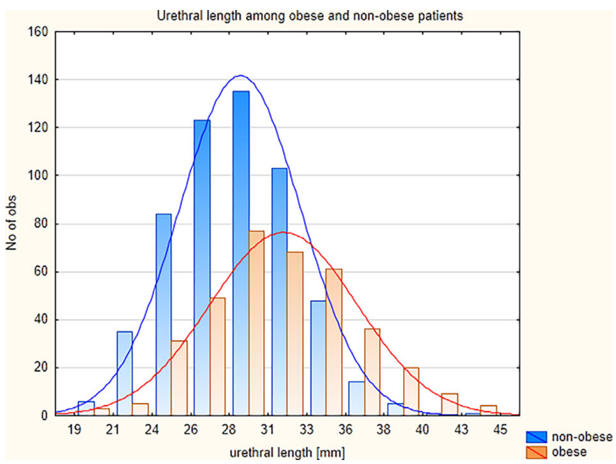

FIGURE 3 Urethral length [mm] distribution: non-obese (BMI <30) versus obese patients (BMI ≥30)

Therefore the pending questions arising from these considerations are: whether urethral measurement is really worth performing, taking into account the potential benefits for surgery effectiveness?

According to Ulmsten principle, the optimal sling position should be in the area of high pressure zone (53-72% of UL). Therefore, in case of a 30 mm long urethra, the vaginal incision beginning 10 mm form the external orifice provides the best clinical effectiveness, resulting in support in approximately 62.5% of its length. Using Ulmsten technique, with an assumption of 1-2 mm tolerability of measurement and surgery technique error, the optimal support of the urethra should be reached in case of urethras 26.1-36.6 mm long.

In cases of shorter or longer urethras, without modifications of the surgery technique the surgeon may not achieve optimal results as he/she implants the sling outside the high pressure zone. Confronting the above assumptions with our cohort observations of UL we suggest that such modifications should be taken into consideration in case of approximately 30% of patients (UL <20% and >90%) if undergoing mid-urethral sling procedures. In such percentage, the female UL differs significantly from the assumed surgical principle of 30 mm (see Table 2). Almost 30% of patients may be in a risk group for mid-urethral sling failure having statistically shorter or longer urethra than its mean length. In cases of shorter urethras, typical vaginal incision (beginning 10 mm from the external urethral orifice) will result with too proximal sling location and more probable persistent SUI. In cases of longer urethras, typical incision will result in too distal sling location (below the high pressure zone) not securing optimal urethra support on exertion, which may result in lower effectiveness of the procedure.

Current literature does not provide data on the relationships between the UL and demographic characteristics of patients. We showed that two independent factors might influence the UL: obesity and the number of vaginal deliveries. According to our results and due to the fact that some authors showed worse results of anti-incontinence procedures in obese patients indicating the group at risk for failure those groups require special attention.[22] At the same time, more than one vaginal delivery was shown to be an important risk factor for reoperation (adjusted odds ratio [OR] 3.5; 95% confidence interval [CI] 1.0-12.6).[23] It is likely that worse effectiveness of mid-urethral sling procedures in the above group of patients might be connected with atypical UL.

The possible cause of the increased UL in obese women may be the abundance of adipose tissue within and above the pelvic diaphragm. In case of multiple multiparas the shortening of the urethra might be dependent on neurological and muscle damages resulting in lower muscle tone within the pelvic diaphragm.[24,25]

The shown differences of urethral length in the group of multiparas and obese patients regardless from continence status might have clinical importance not as a parameter influencing incidence or LUTS and SUI but as a parameter that might be taken into consideration only in the surgery technique.

The main limitation of the study is the fact that only Causasian subjects were included. It cannot be ruled out whether in the other races, the urethras length may be slightly different. The second issue we have not analyzed in our study is the group of patients with the history of pelvic floor surgeries that might influence UL. It should be addressed in further research.

Various UL measurement methods show similar results. We postulate that above parameter should be introduced to the general SUI diagnostics before surgery or intraoperatively. Ultrasound method is lower-cost than MRI, it is not time consuming, eliminates the necessity of catheterization, reducing the risk of infections and patient's inconvenience during profilometry, and is an easy and repetitive modality.[10] Till now there are no data comparing different method of urethral length measurement therefore there is a space to further investigation in this field.

5 | CONCLUSION

The length of the female urethra varies from 19 to 45 mm and its distribution is normal. We demonstrated that approximately 30% of the female adult population has statistically significant shorter or longer urethra and therefore this group of patients might benefit from measurement of the urethra before the sling surgery and from adequate modification of the surgery technique. Multiparous women, as well as obese patients should be considered as the group of special attention because of higher probability of non-typical UL. Ultrasound measurement of the urethra is a simple and inexpensive method with high patient acceptance, showing similar results as formerly described methods (catheter, MRI, profilometry). Nevertheless, introduction of urethral measurement before the procedure should be further investigated.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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