Work Capacity of the Bladder During Voiding: A Novel Method to Evaluate Bladder Contractile Function and Bladder Outlet Obstruction

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Abstract

Background: Work in voiding (WIV) of the bladder may be used to evaluate bladder status throughout urination rather than at a single time point. Few studies, however, have assessed WIV owing to the complexity of its calculations. We have developed a method of calculating work capacity of the bladder while voiding and analyzed the associations of bladder work parameters with bladder contractile function and bladder outlet obstruction (BOO).

Methods: The study retrospectively evaluated 160 men and 23 women, aged >40 years and with a detrusor pressure at maximal flow rate ($P_{det}Q_{max}$) of ≥40 cmH$_2$O in men, who underwent urodynamic testing. The bladder power integration method was used to calculate WIV; WIV per second (WIV/t) and WIV per liter of urine voided (WIV/v) were also calculated. In men, the relationships between these work capacity parameters and $P_{det}Q_{max}$ and Abrams-Griffiths (AG) number were determined using linear-by-linear association tests, and relationships between work capacity parameters and BOO grade were investigated using Spearman's association test.

Results: The mean WIV was 1.15 ± 0.78 J and 1.30 ± 0.88 J, mean WIV/t was 22.95 ± 14.45 mW and 23.78 ± 17.02 mW, and mean WIV/v was 5.59 ± 2.32 J/L and 2.83 ± 1.87 J/L in men and women, respectively. In men, WIV/v showed significant positive associations with $P_{det}Q_{max}$ ($r = 0.845$, $P = 0.000$), AG number ($r = 0.814$, $P = 0.000$), and Schafer class ($r = 0.726$, $P = 0.000$). Conversely, WIV and WIV/t showed no associations with $P_{det}Q_{max}$ or AG number. In patients with BOO (Schafer class > II), WIV/v correlated positively with increasing BOO grade.

Conclusions: WIV can be calculated from simple urodynamic parameters using the bladder power integration method. WIV/v may be a marker of BOO grade, and the bladder contractile function can be evaluated by WIV and WIV/t.

Key words: Bladder Function; Bladder Outlet Obstruction; Urodynamics; Work in Voiding

INTRODUCTION

Standard urodynamic methods used to evaluate bladder contractile function and bladder outlet obstruction (BOO) in older men include measurements of group-specific urethral resistance factor (URA) and Abrams-Griffiths (AG) number, as well as linearized passive urethral resistance relation (linPURR) analysis.[1-7] These methods, however, are mainly based on analysis of maximum detrusor pressure and maximum flow rate in voiding; thus, they represent only a single time point during voiding, not the entire urination process. These methods would, therefore, yield inaccurate results in patients with low detrusor pressure and weak flow rate, for example.[8-12]

Evaluation of the work capacity of the bladder may reflect bladder function during the entire urination process, not just at certain time points.[13] In addition, evaluation of work capacity would be less affected by low detrusor pressure or minor artifacts of curves.[14,15] Furthermore, the work capacity of the bladder can be calculated using several simple urodynamic parameters. However, this method is

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seldom used, probably owing to the relative complexity of the calculations.[16,17]

This study was designed to analyze the work of voiding (WIV) of the bladder in a group of older men and women. Specifically, this study addressed the optimal method of measuring WIV and the relationships of work capacity parameters with bladder contractile function and BOO.

METHODS

Patients

Between January 2002 and January 2010, 566 men and 102 women who underwent urodynamic testing for lower urinary tract symptoms or suspicion of BOO were screened in the Urology Department at Beijing Jishuitan Hospital. Exclusion criteria were as follows: (1) Age <40 years, (2) previous history of neurological disease, pelvic surgery or other diseases that tend to affect detrusor function, (3) obvious artifacts in urodynamic curves or failure to void in urodynamic tests, and (4) detrusor pressure at maximal flow rate <40 cmH$_2$O in men. Ultimately, 160 men and 23 women were included in this study.

Definition of urodynamic parameters

Urodynamic investigations and evaluations (UDS-600, LABORIE Co., Canada) were performed according to the standards recommended by the International Continence Society.[18] Informed consent was obtained from all patients prior to testing. From the pressure-flow study, the AG number was defined as $P_{det}Q_{max} - 2Q_{max}$, with $P_{det}Q_{max}$ = detrusor pressure at the maximal flow rate and Q_{max} = maximal flow rate. BOO grade was expressed as Schafer class, which was determined by LinPURR analysis.

Measuring work capacity parameters

Data sheets of voiding phase

Data from the urodynamic testing process were exported using UDS-600 software (LABORIE Co.) and saved as data sheets, with data intervals of 0.33 s. Detrusor pressure (P_{det}) and its corresponding flow rate (Q) were recorded at each data point. Each data sheet was corrected manually by comparison with the original urodynamic curve and erasing any artifacts. The irrigation phase was deleted manually by checking the

flow rates; if multiple urinary flows exited during the voiding phase, the data of the curves without flow were deleted. Thus, only the pure voiding phase was retained in each data sheet.

Creation of the bladder power curve

The bladder power at each data point on the data sheets was calculated using the formula $P_{det} \times Q$.[16,17] The data sheets were subsequently imported into SigmaPlot version 11.5 (Systat Software Inc., CA, USA), a graph editing software program, which created the bladder power curves during voiding phase [Figure 1].

Definition of work capacity parameters

The WIV of the bladder, in joules, was computed by the SigmaPlot software, which calculated the areas under the bladder power curve using the trapezoidal rule. WIV per second (WIV/t) was defined as WIV/t (J/s or W) and WIV per liter of urine voided (WIV/v) as WIV/v (J/L). For unit conversion, 1 cmH$_2$O·ml/s = 0.000,098 J/s = 0.000,098 W = 0.098 mW.[16,17]

Statistical analysis

Data were expressed as mean ± standard deviation. Work capacity parameters between men and women were compared using Student's t-test. Relationships of work capacity parameters with $P_{det}Q_{max}$ and AG number in men were assessed using linear-by-linear association tests; and relationships between work capacity parameters and BOO grade were evaluated using Spearman's association tests. All data were analyzed using SPSS version 13.0 (SPSS, Inc., Chicago, IL, USA), with a $P < 0.05$ was considered statistically significant.

RESULTS

General characteristics of the patients

The general clinical and urodynamic characteristics of 160 men and 23 women are shown in Table 1. WIV/v in men was significantly higher than in women ($t = 2.820, P = 0.006$), while no differences in WIV ($t = -1.651, P = 0.082$) and WIV/t ($t = -0.623, P = 0.648$) were found between men and women.

Association between work capacity parameters and detrusor pressure at maximal flow rate in men

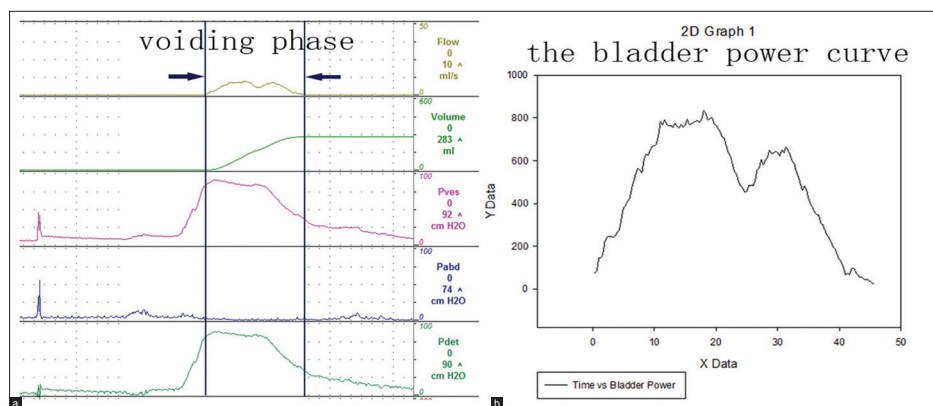Scatter diagrams of $P_{det}Q_{max}$ and work capacity parameters

Figure 1: Examples of (a) a urodynamic curve and (b) a bladder power curve during voiding phase.

are shown in Figure 2. $P_{det}Q_{max}$ showed a positive linear association with WIV/v ($r = 0.845$, $P = 0.000$), but not with WIV ($r = 0.124$, $P = 0.118$) or WIV/t ($r = 0.089$, $P = 0.265$).

Association between work capacity parameters and Abrams-Griffiths number in men

Scatter diagrams of AG number and work capacity parameters are shown in Figure 3. AG number showed a positive linear association with WIV/v ($r = 0.814$, $P = 0.000$), but not with WIV ($r = 0.035$, $P = 0.695$), or WIV/t ($r = 0.152$, $P = 0.054$).

Association between work capacity parameters and bladder outlet obstruction grade in men

Of the 160 men, 28 (17.5%), 43 (26.9%), 40 (25.0%), 17 (10.6%), 20 (12.5%) and 12 (7.5%) were in Schafer classes I, II, III, IV, V, and VI, respectively. The work capacity parameters in these groups are shown in Table 2.

The Spearman association test indicated a positive association between Schafer class and WIV/v ($r = 0.726$, $P = 0.000$). In men with BOO (Schafer class > II), WIV/v
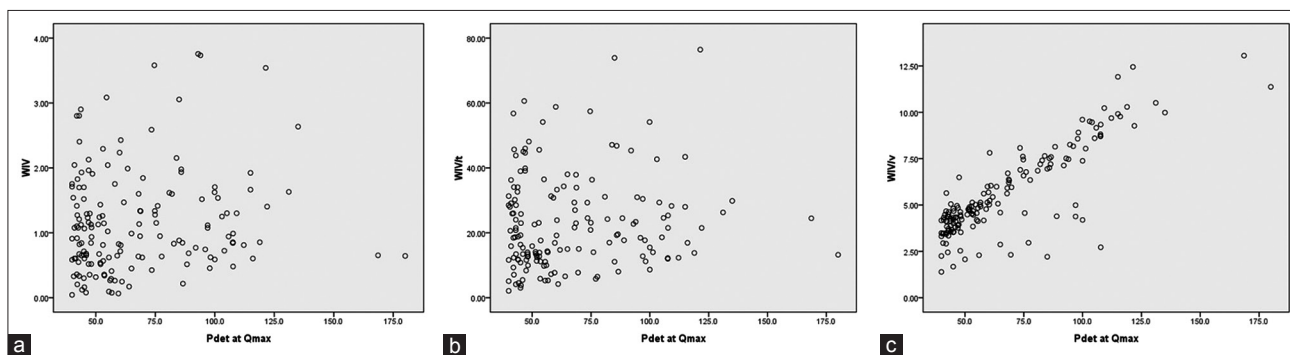
Figure 2: Scatter diagrams of the relationships between $P_{det}Q_{max}$ and work capacity parameters ($n=160$): (a) Work in voiding (WIV) ($r=0.124$, $P=0.118$); (b) WIV per second ($r=0.089$, $P=0.265$) and (c) WIV per liter of urine voided ($r=0.845$, $P=0.000$).
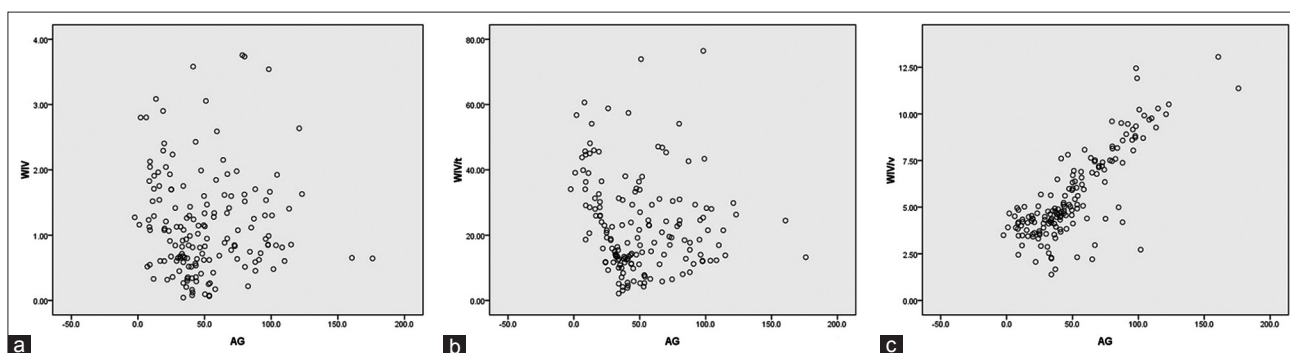
Figure 3: Scatter diagrams of the relationships between Abrams-Griffiths number and work capacity parameters ($n=160$): (a) Work in voiding (WIV) ($r=0.035$, $P=0.695$); (b) WIV per second ($r=0.152$, $P=0.054$) and (c) WIV per liter of urine voided ($r=0.814$, $P=0.000$).

Table 1: General characteristics of all patients in this study

Parameters	Men ($n=160$)		Women ($n=23$)	
	Range	Mean ± SD	Range	Mean ± SD
Age (years)	40–84	62.20 ± 11.95	41–79	55.09 ± 11.08
MBC (ml)	50–814	311.84 ± 155.35	50–602	345.96 ± 143.41
Voided volume (ml)	20–686	230.07 ± 148.56	61–632	317.70 ± 162.86
Voiding time (s)	8.33–195	55.45 ± 32.57	15.33–113	43.49 ± 27.75
$P_{det}Q_{max}$ (cm/H$_2$O)	40–180	67.22 ± 27.25	10.0–87.5	26.14 ± 16.19
Q_{max} (ml/s)	1.6–23.0	8.40 ± 5.04	5.0–30.0	14.42 ± 7.14
Q_{ave} (ml/s)	0.7–11.22	4.48 ± 2.91	2.0–26.3	9.37 ± 6.39
AG number	−2.4–176	50.42 ± 32.14		
Schafer class (LinPURR)	1–6	2.96 ± 1.50		
WIV (J)	0.04–3.76	1.15 ± 0.78	0.18–2.29	1.30 ± 0.88
WIV/t (mW)	2.11–76.43	22.95 ± 14.45	2.42–79.79	23.78 ± 17.02
WIV/v (J/L)	1.39–13.05	5.59 ± 2.32	1.19–10.56	2.83 ± 1.87

AG: Abrams-Griffiths number; MBC: Maximum bladder capacity; $P_{det}Q_{max}$: Detrusor pressure at maximal flow rate; Q_{max}: Maximal flow rate; Q_{ave}: Average flow rate; WIV: Work in voiding; WIV/t: Work in voiding per second; WIV/v: Work in voiding per liter of urine voided; SD: Standard deviation; LinPURR: Linearized passive urethral resistance relation.

Table 2: Work capacity parameters in patients with different degrees of bladder outlet obstruction

Parameters	Schafer class						r	P
	I	II	III	IV	V	VI		
n	28	43	40	17	20	12		
Age (years)	48.86 ± 7.91	62.93 ± 12.42	64.30 ± 10.52	66.59 ± 11.56	67.85 ± 7.46	68.08 ± 6.47	0.430	0.000
WIV (J)	1.59 ± 0.77	0.90 ± 0.53	0.96 ± 0.84	1.42 ± 0.77	1.24 ± 0.92	1.15 ± 0.65	−0.063	0.428
WIV/t (mW)	37.07 ± 10.82	16.60 ± 10.38	19.21 ± 14.82	25.51 ± 14.83	23.49 ± 16.04	20.69 ± 6.76	−0.155	0.051
WIV/v (J/L)	4.03 ± 0.60	3.98 ± 1.07	5.40 ± 1.19	6.45 ± 1.88	8.48 ± 1.85	9.62 ± 2.44	0.779	0.000

WIV: Work in voiding; WIV/t: Work in voiding per second; WIV/v: Work in voiding per liter of urine voided.

increased continuously with increasing BOO grade. Schafer class, however, was not significantly associated with WIV ($r = −0.063$, $P = 0.428$) or WIV/t ($r = −0.155$, $P = 0.051$).

DISCUSSION

Urodynamic test such as URA, AG number, and LinPURR analysis have become the standard methods of evaluating bladder contractile function and BOO in older men.[1-7] However, these methods are not flawless. For example, in patients with low detrusor pressure and weak flow rate, AG number and LinPURR analysis would not be very accurate, mainly because of defects in the methods of calculation.[8-12] Because AG number and LinPURR are based mainly on maximum flow rate and corresponding detrusor pressure, they are calculated at a certain time point during voiding. However, the remainder of the urination process is neglected.[2,4,5] Therefore, new methods are needed to evaluate the entire urination process.

Our study proposed a new method to evaluate bladder WIV. The bladder power integration method involved two principles. First, bladder power during voiding is the product of detrusor pressure and flow rate.[16,17] Second, WIV can be regarded as the definite integral of bladder power during voiding because voiding is of limited duration, and it can be computed by calculating the areas under the bladder power curves using the trapezoidal rule.[19] Thus, measuring WIV is mathematically feasible using graphing and editing software. The data intervals in our study were set at 0.33 s, which was considered sufficient to ensure the basic accuracy of the results. All calculations were based on simple urodynamic parameters, including detrusor pressure, flow rate, and voiding time, and no other complex parameters were required.

The new method has several advantages. By assessing bladder function over a period of time rather than a specific time point, bladder WIV can be used to describe the entire process of urination.[13] Consequently, bladder WIV is not subject to low detrusor pressure status or minor artifacts in curves.[14,15] Furthermore, bladder WIV can be calculated from the results of current urodynamic tests, thus requiring no additional instruments. The three work capacity parameters calculated, WIV, WIV/t, and WIV/v, represent the total work of the bladder, the average bladder

power, and the work of the bladder per liter of urine during voiding, respectively.

The study was mainly performed in men aged >40 years. Healthy volunteers were not available, so patients undergoing urodynamic testing in our department were enrolled. Because urodynamic parameters measured in men were used as reference indicators for work capacity parameters,[1,2,4,5] we omitted men with low detrusor pressure (<40 cmH$_2$O) to avoid its interference with AG number and LinPURR analysis.[8-12] We also measured WIV parameters in a number of age-matched women. Because the number of cases was small, and no BOO diagnostic criteria in women are generally accepted, we simply compared WIV parameters of women with those of the men and did not carry out more complex analysis.

The evaluation of WIV parameters has certain clinical significance. First, we found that WIV/v was strongly correlated with P$_{det}$Q$_{max}$ and AG number, and WIV/v increased continuously with increasing BOO grade, indicating that WIV/v may be a new parameter for evaluating BOO grade, although further studies are needed to test its reliability and validity. Based on our study, we tentatively propose that a WIV/v ≥4.5 J/L could be a criterion for the diagnosis of BOO. However, it is likely that the accuracy of this cut-off is not very accurate owing to the small number of patients. Further studies with larger samples are required to determine the diagnostic criteria for BOO.

Evaluation of BOO is very important in urodynamic tests. However, low detrusor pressure status significantly hampers the diagnostic accuracy of BOO. Eckhardt quantified the degree of agreement between different diagnostic methods of BOO and found that almost all the disagreements of different methods were related to low detrusor pressure.[10] The calculation of WIV, nevertheless, would not be affected by the detrusor pressure, making WIV/v more suitable for low detrusor pressure status.

Second, WIV and WIV/t may be used to evaluate the contractile function of the bladder. Bladder contraction has two different aspects: bladder contraction strength and duration.[16,20] P$_{det}$Q$_{max}$ and other parameters, such as projected isovolumetric pressure and power, are associated with bladder contraction strength but not with bladder contraction duration.[16,20] Conversely, bladder WIV

involved the entire process of urination, and WIV/t reflected the work efficiency of the bladder. These parameters are associated with both of these aspects of bladder contractile function, making them better at describing bladder contractile function.

We observed some interesting results regarding the associations between work capacity parameters and BOO grade. In men with BOO and suspicious BOO (Schafer class > II), WIV and WIV/t increased with increasing BOO grade until Schafer class IV but declined in patients with Schafer class V and higher. This may be attributed to the bladder's compensatory function in different BOO grades. The work and power of the bladder increased in patients with moderate BOO (Schafer class ≤ IV), indicating that the bladder was in the compensatory stage. In contrast, the work and power of the bladder declined in severe BOO (Schafer class > IV), indicating that the bladder was in the decompensatory stage. These results have important clinical value, because to our knowledge, there has been no effective parameter to express the bladder compensatory status,[21-23] but the WIV parameters can be used to evaluate the bladder compensatory function. According to our study, the operation of BOO should not be delayed until Schafer class V, otherwise the bladder function would be in the decompensatory stage and continue to deteriorate further.

Third, WIV parameters can be a rational method for the evaluation of urodynamic tests in women. Because low detrusor pressure is more prevalent in women, it is very hard to explore the strict criteria for detrusor contractile function, as well as BOO in women.[24,25] Moreover, the urodynamic pattern was overly different in both genders to compare them with routine urodynamic parameters.[26,27] WIV parameters had definite physical significance, making them appropriate to explore explicit diagnostic criteria in women and to make a comparison between the two genders. Our preliminary results showed that WIV/v in women was significantly lower than that in men, indicating a significant lower urethral resistance in women.

This study had several limitations. First, because of the study was performed in patients with lower urinary symptoms or BOO, the results may not be representative of the general population. Second, our urodynamic instruments were routinely set at data intervals of 0.33 s; this interval should be shortened for more accurate results. Third, WIV was frequently calculated manually; because this was time-consuming, the software should be developed to facilitate this process.

In conclusion, we have described a method of measuring the WIV of the bladder, and we showed that these work capacity parameters can be used to evaluate bladder contractile function and BOO. Future research should follow these directions: (1) To study large samples to determine the standard data of the WIV parameters in the normal population; (2) to explore the diagnostic value of WIV/v

for BOO in men with "low detrusor pressure and weak flow rate;" (3) to carry out similar studies in women to evaluate detrusor contractile function and BOO. These studies are currently underway.

Conflicts of interest
There are no conflicts of interest.

References

1. Madersbacher S, Alivizatos G, Nordling J, Sanz CR, Emberton M, de la Rosette JJ. EAU 2004 guidelines on assessment, therapy and follow-up of men with lower urinary tract symptoms suggestive of benign prostatic obstruction (BPH guidelines). Eur Urol 2004;46:547-54.
2. Schäfer W. Analysis of bladder-outlet function with the linearized passive urethral resistance relation, linPURR, and a disease-specific approach for grading obstruction: from complex to simple. World J Urol 1995;13:47-58.
3. van Venrooij GE, Eckhardt MD, Boon TA. Noninvasive assessment of prostatic obstruction in elderly men with lower urinary tract symptoms associated with benign prostatic hyperplasia. Urology 2004;63:476-80.
4. Griffiths DJ. Pressure-flow studies of micturition. Urol Clin North Am 1996;23:279-97.
5. Eri LM, Wessel N, Tysland O, Berge V. Comparative study of pressure-flow parameters. Neurourol Urodyn 2002;21:186-93.
6. Rosier PF, de la Rosette JJ, de Wildt MJ, Debruyne FM, Wijkstra H. Comparison of passive urethral resistance relation and urethral resistance factor in analysis of bladder outlet obstruction in patients with benign prostatic enlargement. Neurourol Urodyn 1996;15:1-10.
7. Khoury JM, Marson L, Carson CC 3rd. A comparative study of the Abrams-Griffiths nomogram and the linear passive urethral resistance relation to determine bladder outlet obstruction. J Urol 1998;159:758-60.
8. Chapple C. Overactive bladder and underactive bladder: a symptom syndrome or urodynamic diagnosis? Neurourol Urodyn 2013;32:305-7.
9. Zhao J, Zhao Z, Song J, Ji Z, Tian Y. The diagnostic accuracy and lower cutoff value of three methods for quantifying urethral resistance in men. Urol Int 2011;86:90-4.
10. Eckhardt MD, van Venrooij GE, Boon TA. Urethral resistance factor (URA) versus Schäfer's obstruction grade and Abrams-Griffiths (AG) number in the diagnosis of obstructive benign prostatic hyperplasia. Neurourol Urodyn 2001;20:175-85.
11. Ding YY, Lieu PK. Comparison of three methods of quantifying urethral resistance in men. Urology 1998;52:858-62.
12. Vírseda M, Salinas J, López A, Esteban M. Usefulness of Dynamic Urethral Resistance Relation (DURR) measurement for differential diagnosis between static and dynamic urinary obstruction in male spinal cord injury patients. Neurourol Urodyn 2012;31:549-55.
13. Cormier L, Ferchaud J, Galas JM, Guillemin F, Mangin P. Diagnosis of female bladder outlet obstruction and relevance of the parameter area under the curve of detrusor pressure during voiding: preliminary results. J Urol 2002;167:2083-7.
14. Hogan S, Gammie A, Abrams P. Urodynamic features and artefacts. Neurourol Urodyn 2012;31:1104-17.
15. Liao LM, Schaefer W. Effects of retrospective quality control on pressure-flow data with computer-based urodynamic systems from men with benign prostatic hyperplasia. Asian J Androl 2007;9:771-80.
16. Griffiths D. Detrusor contractility – order out of chaos. Scand J Urol Nephrol Suppl 2004;215:93-100.
17. Rosier PF, de Wildt MJ, de la Rosette JJ, Debruyne FM, Wijkstra H. Analysis of maximum detrusor contraction power in relation to bladder emptying in patients with lower urinary tract symptoms and benign prostatic enlargement. J Urol 1995;154:2137-42.

18. Abrams P, Cardozo L, Fall M, Griffiths D, Rosier P, Ulmsten U, *et al.* The standardisation of terminology in lower urinary tract function: report from the standardisation sub-committee of the International Continence Society. Urology 2003;61:37-49.

19. Gabrielsson J, Weiner D. Non-compartmental analysis. Methods Mol Biol 2012;929:377-89.

20. van Mastrigt R, Griffiths DJ. An evaluation of contractility parameters determined from isometric contractions and micturition studies. Urol Res 1986;14:45-52.

21. Osman NI, Chapple CR. Contemporary concepts in the aetiopathogenesis of detrusor underactivity. Nat Rev Urol 2014;11:639-48.

22. van Koeveringe GA, Rademakers KL, Birder LA, Korstanje C, Daneshgari F, Ruggieri MR, *et al.* Detrusor underactivity: Pathophysiological considerations, models and proposals for future research. ICI-RS 2013. Neurourol Urodyn 2014;33:591-6.

23. Liu N, Man LB, He F, Huang GL, Wang H, Li GZ, *et al.* Multiple factors related to detrusor overactivity in Chinese patients with benign prostate hyperplasia. Chin Med J 2012;125:3778-81.

24. Zhang P, Yang Y, Wu ZJ, Zhang XD, Zhang CH. Video-urodynamics study on female patients with bladder neck obstruction. Chin Med J 2012;125:1425-8.

25. Dybowski B, Bres-Niewada E, Radziszewski P. Pressure-flow nomogram for women with lower urinary tract symptoms. Arch Med Sci 2014;10:752-6.

26. Onyishi SE, Twiss CO. Pressure flow studies in men and women. Urol Clin North Am 2014;41:453-67, ix.

27. Hameed N, Ali MA, Azim W. Urodynamic findings in female patients reporting with lower urinary tract symptoms. J Ayub Med Coll Abbottabad 2009;21:8-10.