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Constrictive versus compressive bladder outflow obstruction in men: Does it matter?

Wouter van Dort[1] | **Peter F. W. M. Rosier**[1] | **Thomas R. F. van Steenbergen**[1] | **Bernard J. Geurts**[2] | **Laetitia M. O. de Kort**[1]

[1]Department of Urology, University Medical Center Utrecht, Utrecht, The Netherlands

[2]Department of Applied Mathematics, Mathematics of Multiscale Modeling and Simulation, University of Twente, Enschede, The Netherlands

Correspondence
Wouter van Dort, Department of Urology, University Medical Center Utrecht, Utrecht, The Netherlands.
Email: w.vandort-2@umcutrecht.nl

Abstract

Introduction: Bladder outflow obstruction (BOO) is a urethral resistance (UR) at a level above a clinically relevant threshold. UR is currently graded in terms of the existence and severity of the BOO based on maximum flowrate and associated detrusor pressure only. However, the pressure-flow relation throughout the course of voiding includes additional information that may be relevant to identify the type of BOO. This study introduces a new method for the distinction between the provisionally called compressive and constrictive types of BOO and relates this classification to underlying patient and urodynamic differences between those BOO types.

Methods: In total, 593 high-quality urodynamic pressure-flow studies in men were included in this study. Constrictive BOO was identified if the difference Δp between the actual minimal urethral opening pressure (p_{muo}) and the expected p_{muo} according to the linearized passive urethral resistance relation (linPURR) nomogram was >25 cmH_2O. Compressive BOO is identified in the complementary case where the pressure difference Δp ≤ 25 cmH_2O. Differences in urodynamic parameters, patient age, and prostate size were explored.

Results: In 81 (13.7%) of the cases, constrictive BOO was found. In these patients, the prostate size was significantly smaller when compared to patients diagnosed with compressive BOO, while displaying a significantly lower maximum flowrate, higher detrusor pressure at maximal flowrate and more postvoid residual (PVR).

Conclusion: This study is an initial step in the validation of additional subtyping of BOO. We found significant differences in prostate size, severity of BOO, and PVR, between patients with compressive and constrictive BOO. Subtyping of voiding-outflow dynamics may lead to more individualized management in patients with BOO.

KEYWORDS

bladder outflow obstruction, pressure flow study, urethral resistance, urodynamics

1 | INTRODUCTION

Bladder outflow obstruction (BOO) is a common diagnosis in the older male population with lower urinary tract symptoms (LUTS).[1] The presence and severity of the urethral resistance (UR) can be graded using a pressure-flow study (PFS), part of the ICS standard urodynamic test (UDS).[2] BOO is identified if a UR above a specific threshold is observed, that has proven to be of clinical relevance.[2]

For grading and qualification of the UR, several models of the urethral outflow tract physiology were proposed,[3] which all include a defined relation between the flowrate (Q) and the detrusor pressure (p_{det}) during voiding. Those models are based on the distensible and collapsible tube—flow-controlling zone hydrodynamic paradigm.[4,5] Most models include a quadratic relation between Q and p_{det} during the voiding following the moment of maximal flow (Q_{max}), which is seen as the most representative to grade UR and to diagnose BOO in men with an enlarged prostate.[6] This defined (but also conceptual or idealized) relation between p_{det} and Q was stated to be the passive urethral resistance relation (PURR) and can be observed in the PFS-plot, were p_{det} is plotted against Q, as the lower pressure border, see also Figure 1.[3] From the PFS-plot several urodynamically relevant parameters can be extracted, including Q_{max}, and the corresponding p_{det} referred to as $p_{detQmax}$. Also

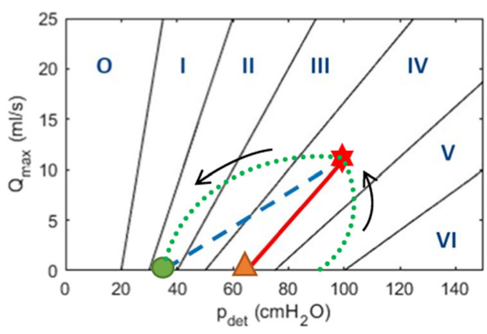

FIGURE 1 Discrimination between constrictive and compressive bladder outflow obstruction (BOO). The green dotted line sketches the pressure-flow relation during voiding. The red asterisk indicates the pressure and flowrate at maximal flow, pdetQmax, and Q_{max}. The blue line indicates the actual linPURR relation of a case, with a minimal urethral opening pressure (pmuo) of 35 cmH_2O (green dot). The red line indicates the expected relation according to the linPURR nomogram for compressive BOO, with an extrapolated pdetQmax of 65 cmH_2O (orange triangle). As the actual pmuo was 30 cmH_2O lower than the extrapolated pdetQmax, constrictive BOO is diagnosed. linPURR, linearized passive urethral resistance relation; pdet, detrusor pressure; pdetQmax, pdet at maximal flow; Q_{max}, maximal flow.

the minimal urethral opening pressure (p_{muo}), found at the end of voiding is obtained.

The PURR was simplified into a linear variant referred to as linPURR to quantify UR by linearly connecting the point ($p_{detQmax}$, Q_{max}) to the point (p_{muo}, 0) in the PFS-plot expressed using a horizontal p-axis and a vertical Q-axis. In urological literature this is often shortened saying that $p_{detQmax}$ is connected linearly to p_{muo}, taking the reference to the corresponding flows as implicitly clear. The ICS BOO index (BOOI) is a further simplification and uses only $p_{detQmax}$ and Q_{max}, with a fixed linear extrapolation.[7] Both the linearized PURR and the index are simplifications and reduce the information that can be obtained from the PFS plot on the dynamics of the voiding.

It is possible to evaluate an additional distinction of the outflow tract during voiding, above simplified grading of the UR with BOOI, based on the slope of the PURR, between $p_{detQmax}$ and p_{muo}. Referring to Figure 1, a relatively low slope of the straight line between these points would, as was postulated in an earlier publication, be categorized as the "constrictive" subtype of BOO and the steeper slope would represent a "compressive" obstruction.[6] The terms "compressive" and "constrictive" can cause confusion, as they seem to suggest a cause for the BOO, instead of a physiological phenomenon.[8] Compressive BOO implies an increase of p_{muo}, due to increased pressures caused by the tissues around the urethra, which also results in an increase of $p_{detQmax}$.[6,9] As this physiology was most frequently observed in men with an enlarged prostate, this type was defined as the "normal" BOO. Constrictive BOO is defined to represent a limited distensibility of the flow-controlling zone, with relatively lesser elevation of P_{muo} and a relatively greater reduction of $p_{detQmax}$. Limitation of distensibility is present in an extreme form when there is an urethral stricture, causing the horizontally flattened uroflowrate in the graph, but, when such a stricture is absent, the constrictive type of BOO shows a lesser severe grade of this feature.

The new SUFU-ICS PFS standard committee has not been able to decide about the relevance of this subtyping as well as about the appropriate terms that should be used in BOO-subtyping despite being proposed in an earlier standard.[8] Additional proof about and the clinical relevance of compressive/constrictive subtyping was considered necessary.

The urodynamic differences of compressive or constrictive BOO may justify differences in the selection of the optimal treatment when these differences reflect different pathophysiology of the voiding dysfunction. We consider it conceptually relevant to explore whether this urodynamic subtyping associates with clinical differences. Therefore, the aim of this fundamental study is to create clear urodynamic definitions of compressive and constrictive BOO and to explore clinical and urodynamic parameters of male patients with constrictive BOO versus compressive BOO.

2 | METHODS

2.1 | Data acquisition

Five hundred and ninety-three PFS's were included in this retrospective study. Those were selected from all 5657 PFS's of men, performed between 2003 and 2020. Patients with relevant interventions in the past (e.g., transurethral prostatic resection or other prostatic interventions) or with urethral stricture, based on cystoscopy, were excluded. Inclusion criteria were referral for LUTS, failing on initial treatment by the general practitioner, PFS's with minimal or no artifacts based on an earlier developed computer algorithm, which can be found in the appendix of an earlier publication[2] and with physiological urodynamic values ($2\,mL/s < Q_{max} < 35$ mL/s while the voided volume >100 mL), resulting in 1650 PFS's. Subsequently, 286 (17.3%) of the PFS's were excluded, as they displayed a substantial p_{det} increase of >15 cmH_2O after Q_{max}, which could result in unrealistic values of p_{muo}.[2] Finally, only PFS's with obstruction, defined by linPURR grade ≥III (equals BOOI ≥40 cmH_2O) were included, resulting in 593 PFS's. To reduce the potential error caused by postvoid dribbling artifacts, the average p_{det} corresponding to a flowrate between 0.5 and 1 mL/s at the end of voiding was taken as a substitute for p_{muo}.[10] Data was acquired from routine clinical care urodynamic studies (water filled system, 6 fr urodynamic two-way catheter, Eclipse urodynamics machine with AUDACT software; Andromeda Medizinische Systeme GmbH), which were performed in accordance with the ICS Good Urodynamic practices.[2,11] More about data acquisition and selection can be found in an earlier publication.[10] Data selection and analysis steps were performed in Matlab R2022b (The Mathworks Inc.), and statistical analysis was performed in SPSS, version 27 (IBM).

2.2 | Data analysis

The analysis of the data is aimed at dividing all PFS's into a compressive and a constrictive subtype. Distinction between these two subtypes was based on the difference between the expected p_{muo} according to the linPURR nomogram and the observed p_{muo} as defined above. When a difference >25 cmH_2O was found, the PFS was classified as constrictive and compressive otherwise, see also Figure 1 and Table 1. The cut-off is based on the initially proposed distinction between compressive and constrictive BOO.[9] A further discussion about this distinction between compressive and constrictive BOO can be found in Appendix S1.

TABLE 1 Overview of the urethral resistance classes: no BOO, compressive BOO, and constrictive BOO with the corresponding classification rules.

linPURR < III	linPURR ≥ III	
	p_{muo} difference ≤25 cmH_2O	p_{muo} difference >25
No BOO	Compressive BOO	Constrictive BOO

Abbreviations: BOO, bladder outflow obstruction; linPURR, linearized passive urethral resistance relation; p_{muo}, minimal urethral opening pressure.

To analyze differences in clinical patient characteristics between compressive and constrictive BOO, variations in patient age and prostatic size, measured by transrectal ultrasound, were explored. In addition, differences in PFS-postvoid residual (PFS-PVR), percentage voided (PFS-void%), UR grading methods (BOOI, linPURR, URA, 3PM),[2] PFS-Q_{max}, $p_{detQmax}$, p_{muo}, detrusor contraction index (DCI; formerly bladder contractility index, BCI), maximum of Watts factor (WF_{max}), and Watts factor at Q_{max} (WF_{Qmax}) based on the PFS measurement were analyzed using the Mann–Whitney *U* test, as the data has no normal distribution. If available, parameters of the free flow (FF) uroflowmetry, performed in the same session before the PFS, FF-Q_{max}, FF-PVR, and FF-void%, were explored. A *p*-value < 0.05 was considered significant.

As the detrusor voiding contraction (DVC) strength is affecting the PVR and void% in addition to BOO, a subanalysis was performed including only PFS's with a normal DVC (DCI > 100).[12] In addition, the correlation between prostate size, DVC (quantified with in the DCI), and UR (quantified with p_{muo} or BOOI) was studied for both compressive and constrictive BOO.

Lastly, the PFS's were divided according to the linPURR measure of BOO and also divided in five p_{muo} bins, <40, 40–50, 50–60, 60–80, and >80 cmH_2O, to be able to explore BOO-"severity" in association with the subtyping and the other parameters.

3 | RESULTS

3.1 | Compressive/constrictive BOO characteristics

Of the 593 included PFS, in 81 cases (13.7%) constrictive BOO was found. The mean age was 63 years in both groups; compressive and constrictive obstruction. The men with constrictive obstruction showed a significantly higher UR, expressed by BOOI, URA, or linPURR, but also a significantly lower p_{muo} and 3PM, as by definition (Table 2). In addition, a smaller prostate size was found in men with constrictive BOO. The PVR was not significantly different between the two BOO types.

In 32 patients (with constrictive BOO), urethral stricture was explicitly excluded by cystoscopy or retrograde urethrography. In 31 patients, the medical record regarding investigations was not available and in 18 patients, cystoscopy or retrograde urethrography was not conducted. No significant differences between the patients with or without urethral stricture exclusion by cystoscopy were found (Mann–Whitney U >0.05) for all assessed parameters.

When analyzing the patients with a normal detrusor contraction (DCI > 100) only ($N = 424$, 16.3% constrictive), the PFS-PVR was significantly higher (Mann–Whitney U, $p = 0.029$) in the men with constrictive BOO, showing a mean of 98 mL, compared to 64 mL for compressive BOO. This significant difference was also found in the FF-PVR ($p = 0.044$) of these patients.

In the entire group ($N = 593$), the correlation between prostate size and p_{muo} was significant and similar weak for compressive (Pearson's 0.236, $p < 0.001$) and constrictive (Pearson's 0.350, $p = 0.017$) BOO. The correlation between prostate size and BOOI was insignificant for constrictive BOO ($p = 0.107$) and weak for compressive BOO (Pearson's 0.240, $p < 0.001$). A strong correlation between the BOOI and DCI was found for constrictive BOO (Pearson's 0.773, $p < 0.001$), with a moderate correlation for compressive BOO (Pearson's 0.557, $p < 0.001$). This difference was not found when p_{muo} was taken as measure for UR, with a similar correlation for compressive (Pearson's 0.520, $p < 0.001$) and constrictive (Pearson's 0.550, $p < 0.001$) BOO.

The analysis per linPURR grade showed an increasing percentage of constrictive BOO with higher linPURR

TABLE 2 Overview of the characteristics of compressive and constrictive BOO.

	Compressive BOO		Constrictive BOO		Mann–Whitney U
Feature	N	Mean (SD)	N	Mean (SD)	p
Age (years)	512	62.8 (12.7)	81	63.4 (11.4)	0.854
Prostate size (cm^3)	289	53.1 (30.8)	46	40.6 (20.6)	0.004
PFS-voided volume (mL)	512	260 (110)	81	250 (100)	0.409
PFS-PVR (mL)	274	76 (111)	40	94 (121)	0.201
PFS-void% (%)	274	0.82 (0.22)	40	0.77 (0.22)	0.187
BOOI	512	62 (19)	81	91 (28)	<0.001
linPURR	512	3.6 (0.7)	81	4.7 (0.9)	<0.001
URA	512	42 (12)	81	60 (19)	<0.001
3PM	512	47 (19)	81	44 (21)	0.133
PFS-Q_{max} (mL/s)	512	7.7 (3.4)	81	6.3 (2.7)	<0.001
$p_{detQmax}$ (cmH_2O)	512	77 (19)	81	104 (26)	<0.001
p_{muo} (cmH_2O)	512	54 (17)	81	41 (21)	0.003
DCI	512	116 (28)	81	135 (28)	<0.001
WF_{max}	512	12.0 (3.3)	81	14.8 (4.3)	<0.001
WF_{Qmax}	512	10.8 (3.0)	81	13.2 (4.4)	<0.001
FF-voided volume (mL)	154	160 (130)	29	180 (130)	0.492
FF-PVR (mL)	154	53 (93)	29	87 (119)	0.144
FF-void% (%)	154	0.82 (0.25)	29	0.71 (0.31)	0.123
FF-Q_{max} (mL/s)	154	8.7 (4.1)	29	7.9 (4.1)	0.017

Abbreviations: BOOI, bladder outflow obstruction index; DCI, detrusor contractility index; FF, free-flow uroflowmetry; linPURR, linearized passive urethral resistance relation; PFS, pressure-flow study; p_{muo}, minimal urethral opening pressure; PVR, postvoid residual; URA, urethral resistance A; WF, watts factor; 3PM, three-paramater method.

TABLE 3 Distribution of compressive and constrictive BOO over the linearized passive urethral resistance relation (linPURR) grades (A) and for the minimal urethral opening pressure (p_{muo}) bins (B).

	Total	Compressive	Constrictive	%Constrictive
[A] linPURR grade				
III	270	263	7	2.6%
IV	222	191	31	14.0%
V	77	51	26	33.8%
VI	24	7	17	70.8%
[B] p_{muo} bin				
<40 cmH_2O	189	150	39	20.6%
40–50 cmH_2O	146	135	11	8.1%
50–60 cmH_2O	111	97	14	12.6%
60–80 cmH_2O	108	95	13	12.0%
>80 cmH_2O	39	35	4	10.3%

Abbreviation: BOO, bladder outflow obstruction.

grade, but not for the p_{muo} bins, as clarified in Table 3. The average prostate size was significantly smaller in constrictive BOO compared to compressive BOO (37 vs. 72 mL), for linPURR grade 5 (Mann–Whitney *U*, $p < 0.001$). In patients with other linPURR grades and between different P_{muo}-bins, there was no difference in prostate size between compressive and constrictive BOO.

4 | DISCUSSION

Although the possibility to differentiate between a constrictive or a compressive subtype of BOO was proposed decades ago,[3,6–8] substantial evidence regarding the relevance of this distinction is not available. The clinical relevance of the subtyping was not established, possibly because at the time of these earlier reports in the 1980's treatment for BOO was limited to classic transurethral resection of the prostate only. We propose a quantitative discrimination method to differentiate between compressive and constrictive BOO (cf. Table 1) We found significant differences in prostate size between patients with constrictive and compressive BOO. In particular, prostate size tends to be larger in compressive BOO compared to constrictive BOO. A similar relationship was found for DVC affecting PVR.

The correlation of prostate size with increasing grade of BOO was absent in patients with constrictive BOO versus weak in patients with compressive BOO. In fact, patients with constrictive BOO had more obstruction with higher detrusor voiding pressures, lower PFS-flowrates and more PFS-PVR. This, in combination with our observation of a lesser effect of prostate size, with significant smaller prostate sizes found in constrictive BOO, supports the hypothesis that a constrictive BOO is the result of a relatively inelastic outflow tract, showing less distensibility than expected. This is further strengthened by the finding that within a linPURR grade, the prostate size was smaller when constrictive BOO was found. The outflow tract is challenging the detrusor to generate more force and work and the sheer volume effect of the prostate seems of lesser relevance in these patients.

Based on the distensible—collapsible tube paradigm as model for the urethra, p_{muo} is hypothesized to be the most independent parameter describing the obstruction caused by an enlarged prostate.[4,5] When the PFS's were divided into p_{muo} bins, no significant difference between compressive and constrictive BOO was found for the prostate size. Inelasticity or stenosis is expected to have no or little influence on p_{muo}, as, according to the urethral model, the collapse of the flow controlling zone at the end of the voiding is not (or less) affected by inelasticity.[3–7] This is further strengthened by the similar correlation for compressive and constrictive BOO between the prostate size and p_{muo}, indicating that the prostate has a similar role in determining the flow controlling zone-collapse at the end of voiding.

A positive correlation between DCI and the UR was observed, for both compressive and constrictive BOO. This was found earlier,[13] and later confirmed[1] although in both studies no distinction was made between compressive and constrictive BOO. The correlation between DCI and BOOI was significantly stronger for constrictive obstruction compared with compressive obstruction, while this difference was not visible when p_{muo}, conceptually the most independent qualifier for obstruction,[2] was used as parameter for UR. The similar correlation of DCI with p_{muo} is an additional indication that at the end of the voiding, the flow controlling zone is identical in compressive and constrictive BOO, while the difference at Q_{max}, expressed in the BOOI, indicates that the flow limitation caused by the physiological flow controlling zone could have different causes.

Although the subtyping seems to reveal two different mechanisms of BOO voiding, interdependence cannot be ruled out and a combination of compressive and constrictive BOO could be possible. In this study, we did not consider this combination, as our distinction is based on classifications made in earlier publications, which did not consider their combination. However, a new classification based on the underlying (patho) physiology with terminology referring to this physiology could be considered for further studies.

To place the findings into perspective, we discuss the relevant limitations next. As a quantitative distinction between compressive and constrictive BOO is not defined in literature, we created a measure, based on the explorations made in the past. However, the cut-off value in this measure is debatable and the reported results may be different with other thresholds. Although thresholds are defined based on a nonquantitative cut-off,[7] new studies including clinical outcomes or more in-depth theoretical explorations can result in a threshold value which is optimal. In addition, the retrospective nature of this study could have resulted in a non-generalizable population. However, as all high-quality, ICS-standard-UDS data from almost 20 years of testing are included, intra-center selection bias is not very likely, although slight inter-center variations in urodynamic techniques cannot be ruled out. Furthermore, cystoscopy was not conducted or available in all patients which showed an constrictive BOO, but significant differences between patients which had cystoscopy and patients without cystoscopy were not found. We also excluded all patients who showed a substantial increase of p_{det} after Q_{max}. As these only included 17% of the data set, we do not expect them to cause a bias in this study about the difference between compressive and constrictive BOO. However, it could be interesting to analyze this population in a further study. Lastly, it is likely that most patients had tried alpha blockers before UDS, as it is prescribed in the primary care and the study was conducted at a third level referral center. The current use of this medication could not be retrieved, and usage differences between the two groups are not likely.

In clinical practice, the only BOO parameter used is presence and grade of obstruction, without any further subtyping. This study showed worse voiding parameters in patients with constrictive BOO than with compressive BOO, with smaller prostate volume and similar p_{muo}, indicating different pathophysiology between the subtypes. This finding may imply that in patients with constrictive BOO, pharmacotherapeutic, and surgical interventions focused on the reduction of the prostate size only, may be less effective. With the availability of more therapeutic modalities addressing BOO, the most accurate diagnosis is recommended to provide the best possible treatment.[1] Further studies may become necessary to reveal which type of treatment is most suitable for compressive and which for constrictive obstruction if genuine differences of pathophysiology are discovered or confirmed.

5 | CONCLUSION

This study is an initial step in establishing the validity of an additional subtyping of BOO. We found, using a sample of nearly 600 high quality PFS, significant and substantial differences in prostate size as well as urodynamic differences between constrictive and compressive BOO. As these differences were not found when using p_{muo} as (the current standard) measure for UR, this suggests a different effect of the prostate on the flow controlling zone dynamics between the two types of BOO.

AUTHOR CONTRIBUTIONS

Wouter van Dort and Peter F. W. M. Rosier contributed to the design and implementation of the research, to the analysis of the results. Thomas R. F. van Steenbergen contributed to the writing of the manuscript. Bernard J. Geurts and Laetitia M. O. de Kort supervised the work. All authors were involved in writing of the manuscript and provided input for the analysis.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Wouter van Dort http://orcid.org/0009-0007-8703-1529
Peter F. W. M. Rosier http://orcid.org/0000-0003-0445-4563

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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