NONINVASIVE ASSESSMENT OF PROSTATIC OBSTRUCTION IN ELDERLY MEN WITH LOWER URINARY TRACT SYMPTOMS ASSOCIATED WITH BENIGN PROSTATIC HYPERPLASIA

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ABSTRACT

Objectives. To investigate what combination of easily available parameters allows the noninvasive prediction of infravesical obstruction in optimal agreement with urodynamic classification. Urodynamically, men with lower urinary tract symptoms suggestive of benign prostatic hyperplasia are classified as nonobstructed or obstructed.

Methods. Mandatory and recommended tests were performed in 160 consecutive men with lower urinary tract symptoms suggestive of benign prostatic hyperplasia. The classification of the International Continence Society, the group-specific urethral resistance factor, and Schäfer's obstruction grade were estimated from urodynamic studies. The frequency-volume charts were analyzed. A separate group of 173 consecutive men was used for validation.

Results. The formula, prostate volume (in cubic centimeters) − 3 × maximal urinary free flow rate (in milliliters per second) − 0.2 × mean voided volume (in milliliters; as estimated from frequency-volume charts), was optimal in the classification compared with the urodynamic classification. Extension of this formula to more than three parameters did not result in better selection. As estimated from receiver operating characteristic curves, the accuracy of the formula appeared to be good. The method of quantifying urethral resistance minimally affected the classification that resulted from the combination. From the results, a diagram was created presenting the probability of an individual to have infravesical obstruction. The validation results were satisfactory.

Conclusions. The prediction of the probability of a man with lower urinary tract symptoms suggestive of benign prostatic hyperplasia to have infravesical obstruction can be deduced from a diagram based on a formula composed of three readily available parameters: prostate volume, maximal urinary free flow rate, and mean voided volume.   UROLOGY **63**: 476–480, 2004. © 2004 Elsevier Inc.

I n the past, methods were developed to diagnose bladder outlet obstruction (BOO) noninvasively in men with lower urinary tract symptoms (LUTS) suggestive of benign prostatic hyperplasia (BPH). The clinical prostate score (CLIPS), introduced by Rosier et al.,[1] was composed of scores for prostate volume, maximal urinary flow rate, postvoid residual urinary volume, and voided volume and had a superior correlation with urodynamically objec-

tive BOO than did isolated parameters. The BOO number (BOON) introduced by van Venrooij and Boon,[2] was calculated from the prostate volume, maximal urinary free flow rate, and relative postvoid residual urine volume, defined as the postvoid residual urine volume divided by the bladder volume at a strong desire to void (times 100%). Schacterle et al.[3] combined the maximal urinary flow rate and American Urological Association symptom index,[4] and Steele et al.[5] combined the symptom score, maximal free flow rate, and prostate volume for predicting BOO. Ockrim et al.[6] developed a BOO index based on the maximal free flow rate and prostate volume. Kuo[7] established a clinical prostate score by summing the scores of seven prostate and uroflowmetry items.

Agreement exists about the use of prostate volume and maximal free urinary flow rate in the formula, but disagreement exists about the optimal number of parameters needed to classify men as obstructed.

In all methods, a cutoff value is used to select a group of men in whom the prevalence of obstruction is high. By increasing the cutoff value, the size of the selected group decreases, but the prevalence of obstruction in that group increases. However, the prevalence of obstruction in a group represents the average probability to have obstruction and, therefore, the probability for an individual in that group to be obstructed may be higher or lower. None of the methods have dealt with predicting the probability of obstruction on an individual level.

The American Urological Association symptom index and quality-of-life score[4] are accepted as mandatory tools in the clinical evaluation of BPH.[8] Transrectal ultrasonography is accepted as a reliable method of estimating the prostate volume.[8] Uroflowmetry is frequently used.

A reliable estimation of the postvoid residual urine volume is sometimes difficult.[9] Drainage of the bladder by a catheter gives a quantitative value, but it is invasive, and the bladder may be incompletely drained in about 25% of patients.[10] Therefore, determination by ultrasonography is recommended. However, in an outpatient department, the estimation of postvoid residual urine volume immediately after voiding is sometimes difficult to realize.

The Urodynamics Subcommittee of the International Consultation on BPH recommends[11] the International Continence Society nomogram[12] to classify patients. In that nomogram, men are obstructed when the Abrams-Griffiths number, defined as the detrusor pressure (in centimeters of water) at maximal flow minus 2 times the maximal flow (in milliliters per second), is greater than 40.

The group-specific urethral resistance factor (URA)[13] and the obstruction grade as proposed by Schäfer[14] are also frequently used to classify the pressure-flow relation: URA greater than 29 cm H_2O indicates obstruction and a Schäfer grade of 3 or greater indicates obstruction.

Because all methods are based on the passive urethral resistance relation,[15] all methods give the same results in classifying clearly obstructed and clearly unobstructed pressure-flow relations. In classifying intermediate urethral resistance, a lack of agreement exists.[16]

Our objectives were to rank the different parameters according to their correlation with the Abrams-Griffiths number and to estimate which linear combination best discriminates between obstructed and unobstructed men; to establish the optimal number of easily available parameters to

be used in these combinations; to compare the performance of the final combination with that of the other classification methods; to evaluate the impact of using the different definitions of obstruction on our findings; to construct a diagram allowing the prediction of the probability of obstruction on an individual level; and to validate our method.

MATERIAL AND METHODS

In men with LUTS suggestive of BPH, the basic standard evaluation and recommended tests, conforming to the recommendations of the International Consensus Committee on BPH from 1993 (updated[8] in 2001) were performed. In our outpatient department, it is common practice to perform filling cystometry and pressure-flow studies in all these men. Pressure-flow studies were analyzed according to the International Continence Society nomogram,[12] Schäfer's obstruction grade,[14] and the URA.[13]

Patients were included if they were 50 years old or older, did not have any of the specified exclusion criteria of the International Consensus Committee on BPH,[8] voided a sufficient volume (greater than 150 mL) during one or more free uroflowmetry studies, had reliable pressure-flow relationships, had frequency-volume charts completed for at least 24 hours,[17] had a reliable estimate of postvoid residual urine volume, and had prostate volume determined by transrectal ultrasonography.

Consecutively, 160 men (65.1 ± 8.3 years old, range 50 to 85) were included in the analyses. A separate group of 173 consecutive men (64.8 ± 8.0 years old, range 50 to 88) was used for validation. All included patients were part of an extensive study on treatment of LUTS; all men provided informed consent.

Correlations were calculated with the distribution-free rank correlation test of Kendall and Gibbons. The accuracy of the constructed classification method was measured by the area under the receiver operating characteristic curve. The Fisher-Irwin test for two-by-two tables was used for validation. The level of significance (two-tailed probability) was $P = 0.05$.

RESULTS

According to the International Continence Society nomogram, of our 160 men, 87 (mean age 64.6 ± 7.7 years) were obstructed and 73 were not (mean age 65.3 ± 9.0 years). Table I shows the correlations of variables and combinations of variables with the obstruction parameters. A linear combination of two parameters may correlate better with another parameter than each parameter alone; however, such improvement in the correlation is mathematically limited to a maximum of 40%.

As estimated by logistic regression analysis, the best discrimination between obstructed and unobstructed men was obtained by the formula: prostate volume − 3 × maximal urinary flow rate − 0.2 × mean voided volume. We defined the expression prostate volume − 3 × maximal urinary flow rate − 0.2 × mean voided volume as the BOON. Extension of the BOON with the relative postvoid residual urine volume only slightly increased the correlation with the obstruction parameters (Table I).

TABLE I. *Kendall and Gibbons correlations of variables and combination of variables with Abrams-Griffiths number, urethral resistance factor, and Schäfer's obstruction grade in group of 160 men*

Variable	Abrams-Griffiths Number	Urethral Resistance Factor	Schäfer's Obstruction Grade
Maximal free flow rate (Qmax)	−0.41*	−0.48*	−0.43*
Prostate volume (Vprost)	+0.27*	+0.26*	+0.29*
Mean voided volume (Vvoid)	−0.23*	−0.25*	−0.23*
Relative residual volume (Rrel)	+0.24*	+0.24*	+0.23*
Residual volume (R)	+0.21*	+0.21*	+0.20*
Symptom index	+0.15*	+0.16*	+0.16*
Quality-of-life score	+0.06	+0.04	+0.05
Vprost − 3 × Qmax	0.45*	0.49*	0.47*
Vprost − 3 × Qmax − 0.2 × Vvoid	0.48*	0.52*	0.49*
Vprost − 3 × Qmax − 0.2 × Vvoid + 0.25 × Rrel	0.49*	0.53*	0.50*
Ockrim's bladder outlet obstruction index[6]	0.46*	0.52*	0.48*
Rosier's clinical prostate score[1]	0.46*	0.51*	0.46*

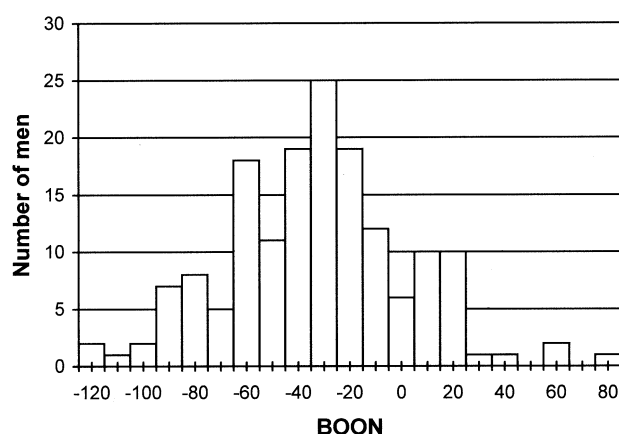** Correlation statistically significant at 0.01 level (two-tailed).*

FIGURE 1. *BOON distribution.*

The optimal number of parameters in a linear combination appears to be three to maximize the correlation with the urethral obstruction parameters. Figure 1 shows the distribution of BOON in the original population of 160 men. The performance of the BOON in the classification of these men as unobstructed or obstructed in relation to the urodynamic classifications is given in Table II. Figure 2 shows the predicted probability for an individual to be obstructed depending on his BOON.

The correlation coefficient between the CLIPS of Rosier *et al.*[1] and URA in our 160 men was 0.51. Modifying the CLIPS by omission of the postvoid residual urine volume did not change the correlation with URA in our group.

We applied the threshold values proposed by Schacterle *et al.*[3] Of 160 men, 16 had both a maximal urinary flow rate less than 10 mL/s and a symptom score greater than 20. Of the 16 men, 13 (81%) were obstructed. We could only select 10 men (6.3%) according to the cutoff values proposed by

Steele *et al.*[5]: maximal urinary flow rate of 10 mL/s or less, prostate volume of 40 cm³ or greater, and symptom index greater than 20. Nine of them were obstructed. Of the 51 men with a BOON greater than −20, 45 (88%) were obstructed (Table II). Fifty-one of our men had an Ockrim index greater than 53, and 42 (82%) were obstructed. Finally, 34 of our men had a BOON greater than −10, and 30 (88%) were obstructed (Table II). Thirty-four men had an Ockrim index greater than 62, and 29 (86%) were obstructed.

The calculations carried out on the original population of 160 men were also performed in the separate group of 173 consecutive men for validation. None of the calculated distributions in these 173 men differed significantly from the distributions presented in Table II for the original population of 160 men.

COMMENT

Our BOON and the indexes of others[1–3,5–7] select groups of men in whom the prevalence of obstruction is high, or, conversely, in whom the prevalence of obstruction is low. Moving the cutoff point to a higher BOON value will select fewer men but the prevalence of obstruction will be greater (upper part of Table II), and thus, the specificity will improve but the sensitivity will decrease. The same arguments apply to the improvement of specificity to select unobstructed men by moving the cutoff point to a lower BOON value (lower part of Table II). Thus, a tradeoff occurs between sensitivity and specificity. This is reflected in Figure 2: high BOON values are associated with a high probability of obstruction and low values with a high probability of nonobstruction. The intermediate values of BOON are less informative. The accuracy of the

TABLE II. *Nonobstructed and obstructed men according to International Continence Society nomogram, urethral resistance factor, and Schäfer's grade in relation to bladder outlet obstruction number*

	Men	International Continence Society Nomogram		Urethral Resistance Factor		Schäfer's Obstruction Grade	
		Nonobstructed Men	Obstructed Men	Nonobstructed Men	Obstructed Men	Nonobstructed Men	Obstructed Men
All men	160 (100)	73 (46)	87 (54)	71 (43)	89 (57)	70 (44)	90 (56)
Men with BOON > −40	95 (59)	26 (27)	69 (73)	20 (21)	75 (79)	25 (26)	70 (74)
Men with BOON > −20	51 (32)	6 (12)	45 (88)	3 (6)	48 (94)	6 (12)	45 (88)
Men with BOON > −10	34 (21)	4 (12)	30 (88)	1 (3)	33 (97)	4 (12)	30 (88)
Men with BOON ≤ −40	65 (41)	47 (72)	18 (28)	51 (78)	14 (22)	45 (69)	20 (31)
Men with BOON ≤ −60	38 (24)	33 (87)	5 (13)	32 (84)	6 (16)	31 (82)	7 (18)
Men with BOON ≤ −80	16 (10)	15 (94)	1 (6)	14 (87)	2 (13)	15 (94)	1 (6)
Area under ROC curve		0.83		0.87		0.82	

KEY: BOON = bladder outlet obstruction number; ROC = receiver operating characteristic.
Data in parentheses are percentages.
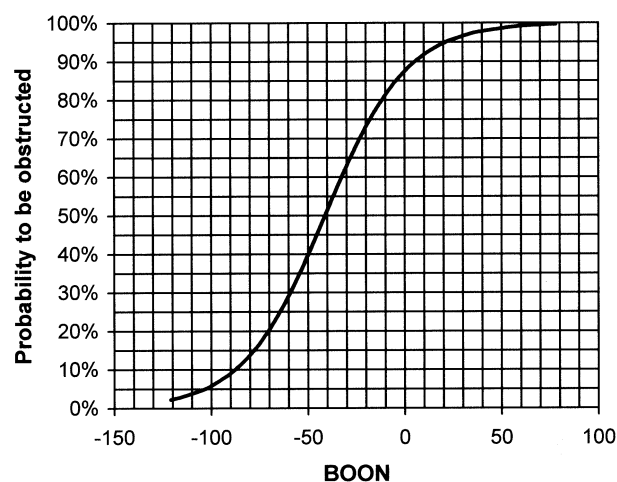Accuracy of BOON in separating those with obstruction and without obstruction is measured by area under ROC curve.

FIGURE 2. *Probability of obstruction according to BOON.*

BOON as deduced from the receiver operating characteristic curves (Table II) is classified by the traditional academic point system as good.

The applicability of our BOON is similar to the applicability of the CLIPS.[1] The CLIPS contains parameters comparable to those in our BOON, plus the postvoid residual volume, and thus requires reliable estimation of the residual volume. However, in our group, omission of the postvoid residual volume score used in the CLIPS did not decrease its correlation with obstruction grade. Similarly, extension of our BOON with the postvoid residual urine volume hardly increased its correlation with obstruction grade (Table I).

The CLIPS can thus be simplified by omission of the postvoid residual urine volume.

The selection of our BOON was slightly better than the BOO index of Ockrim et al.,[6] which may be attributed to our incorporation of a third parameter in the formula. The formula of Ockrim et al.[6] is rather complicated and requires a calculator or computer. The performances of the indexes of Schacterle et al.[3] and Steele et al.[5] in our group were rather limited. Regardless of which method is used, and thus which definition is applied for obstruction, patient selections by the BOON were relatively similar (Table II).

Frequency-volume charts are completed reliably.[17] Transrectal ultrasonography is accepted as a reliable method to estimate prostate volume.[8] Strictly speaking, it is not noninvasive, but its morbidity is comparable to that of the digital rectal examination. Uroflowmetry has become the most frequently used urodynamic examination. Thus, in most urologic outpatient departments, the mean voided volume, prostate volume, and maximal urinary flow rate are easy-to-access parameters. On the basis of the easily applicable and validated formula: prostate volume − 3 × maximal urinary flow rate − 0.2 × mean voided volume, we developed a diagram (Fig. 2) that allows the noninvasive prediction of the probability of an individual to have or not have BOO. None of the other reports have dealt with the estimation of the probability of obstruction at an individual level. The BOON may contribute to the noninvasive selection of men in

whom it is questionable whether their LUTS are due to BOO and in whom additional investigation is indicated. For instance, if one considers as acceptable a chance of 80% or greater of having or not having obstruction, the BOON must be −10 or greater (35 men in our group) or −70 or less (23 men in our group), respectively. Thus, in 102 men (64%), additional investigation was indicated. If one accepts a chance of 70%, additional investigation would be indicated in 40% of the men.

CONCLUSIONS

The BOON may be calculated with an easily applicable formula composed of readily available parameters: prostate volume, maximal urinary flow rate, and mean voided volume estimated from frequency-volume charts. The easy to use formula is BOON = prostate volume (in cubic centimeters) − $3 \times$ maximal urinary flow rate (in milliliters per second) − $0.2 \times$ mean voided volume (in milliliters). Extension of the formula to more than three parameters did not result in a better correlation with obstruction grade and thus a better classification of men. The results depend very little on the method used to quantify the urethral resistance and thus to classify obstructed and unobstructed men. The validation results were satisfactory. From the BOON, a diagram was constructed, allowing the prediction of the probability of obstruction on an individual level.

REFERENCES

1. Rosier PF, de Wildt MJ, Wijkstra H, *et al:* Clinical diagnosis of bladder outlet obstruction in patients with benign prostatic enlargement and lower urinary tract symptoms: development and urodynamic validation of a clinical prostate score for the objective diagnosis of bladder outlet obstruction. J Urol **155:** 1649–1654, 1996.
2. van Venrooij GE, and Boon TA: The value of symptom score, quality of life score, maximal urinary flow rate, residual volume and prostate size for the diagnosis of obstructive benign prostatic hyperplasia: a urodynamic analysis. J Urol **155:** 2014–2018, 1996.
3. Schacterle RS, Sullivan MP, and Yalla SV: Combinations of maximum urinary flow rate and American Urological Association symptom index that are more specific for identifying obstructive and non-obstructive prostatism. Neurourol Urodyn **15:** 459–470, 1996.
4. Barry MJ, Fowler FJ Jr, O'Leary MP, *et al,* for the Measurement Committee of the American Urological Association: The American Urological Association symptom index for benign prostatic hyperplasia. J Urol **148:** 1549–1557, 1992.
5. Steele GS, Sullivan MP, Sleep DJ, *et al:* Combination of symptom score, flow rate and prostate volume for predicting bladder outflow obstruction in men with lower urinary tract symptoms. J Urol **164:** 344–348, 2000.
6. Ockrim JL, Laniado ME, Patel A, *et al:* A probability based system for combining simple office parameters as a predictor of bladder outflow obstruction. J Urol **166:** 2221–2225, 2001.
7. Kuo HC: Clinical prostate score for diagnosis of bladder outlet obstruction by prostate measurements and uroflowmetry. Urology **54:** 90–96, 1999.
8. Chatelain C, Denis L, Foo JKT, *et al:* Evaluation and treatment of lower urinary tract symptoms (LUTS) in older men, in Chatelain C, Denis L, Foo KT, *et al* (Eds): *Benign Prostatic Hyperplasia.* Plymouth, United Kingdom, Plymbridge Distributors, 2001, pp 519–534.
9. Abrams P, Blaivas JG, Stanton SL, *et al:* Standardisation of terminology of lower urinary tract function. Neurourol Urodyn **7:** 403–427, 1988.
10. Stoller ML, and Millard RJ: The accuracy of a catheterized residual urine. J Urol **141:** 15–16, 1989.
11. Abrams P, Griffiths D, Höfner K, *et al:* The urodynamic assessment of lower urinary tract symptoms, in Chatelain C, Denis L, Foo KT, *et al* (Eds): *Benign Prostatic Hyperplasia.* Plymouth, United Kingdom, Plymbridge Distributors, 2001, pp 227–281.
12. Griffiths D, Höfner K, van Mastrigt R, *et al:* Standardization of terminology of lower urinary tract function: pressure-flow studies of voiding, urethral resistance, and urethral obstruction. Neurourol Urodyn **16:** 1–18, 1997.
13. Griffiths D, van Mastrigt R, and Bosch R: Quantification of urethral resistance and bladder function during voiding, with special reference to the effects of prostate size reduction on urethral obstruction due to benign prostatic hyperplasia. Neurourol Urodyn **8:** 17–27, 1989.
14. 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 **13:** 47–58, 1995.
15. Schäfer W: The contribution of the bladder outlet to the relation between pressure and flow rate during micturition, in Hinman F Jr (Ed): *Benign Prostatic Hypertrophy.* New York, Springer-Verlag, 1983, pp 470–496.
16. Eckhardt MD, van Venrooij GE, and 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 **20:** 175–185, 2001.
17. Gisolf KW, van Venrooij GE, Eckhardt MD, *et al:* Analysis and reliability of data from 24-h frequency-volume charts in men with lower urinary tract symptoms due to benign prostatic hyperplasia. Eur Urol **38:** 45–52, 2000.