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Obstructive Effect of a Urethral Catheter During Voiding: Myth or Reality?

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ABSTRACT

Introduction: Whether or not the presence of a urethral catheter can provoke an obstructive effect during voiding remains a controversial subject. Using the Valentini–Besson–Nelson (VBN) mathematical micturition model, the purpose of this study was to compare the geometric effect of the urethral catheter in regards to the effect of other mechanical parameters likely to influence the voiding phase during a urodynamic study.

Methods: The VBN mathematical micturition model was used to compute theoretical voidings. Starting from defined voiding conditions ($Q°_{max}$) such as V_{ini} = 300 mL, no catheter, normal detrusor contractility, and no urethral compression, we searched for relationships between changes in Q_{max} and the studied parameters: catheter diameter (Fr), detrusor contractility (k), and urethral compression (urac).

Results: A linearized approximation was obtained for both genders. The geometric obstruction due to the catheter was almost negligible for nonobstructed individuals compared with the volume effect up to a 6 Fr catheter size. Large decreases in Q_{max} resulted from impaired detrusor contractility or urethral compression. Higher effects resulted from concomitant decrease in detrusor contractility and urethral compression. Geometric effect of the catheter could lead to overestimation of bladder outlet obstruction in men.

Conclusion: A decrease in Q_{max} during voiding cystometrogram was found to be more often related to causes other than the catheter size, which, based on the VBN model, appeared to have a weak (almost negligible for nonobstructed individuals) effect, especially for small sizes (≤ 6 Fr).

INTRODUCTION

Invasive urodynamic studies using transurethral catheterization are commonly performed to evaluate bladder outlet obstruction (BOO) in males and to predict voiding dysfunction after anti-incontinence procedures in females. A controversial subject is the potential obstructive effect from the mere presence of the catheter during voiding, which could lead to a false interpretation of these investigations.

A nondebatable effect of the catheter comes from its geometric presence, which reduces the lumen and the urethral cross-section through which urine travels during voiding. The main consequences of this effect are a decreased flow rate and a longer flow time. That geometric effect is difficult to distinguish from other mechanical effects, which can influence the maximum flow (Q_{max}) such as the initial bladder volume (V_{ini}), or the role of urethral compression, which in the early stage

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of an obstructive process can induce a significant hypertrophy of the bladder wall, resulting in stronger detrusor contraction. Additional factors can influence voiding, including the fact that patients are voiding in an unusual environment, which can lead to abnormal nervous excitations mainly due to anxiety in this perceived stressful situation.

Therefore, to reach reliable conclusions on the obstructive effect of the urethral catheter, studies should be conducted on patients with the same kind of lower urinary tract dysfunction (LUTD) and for similar initial bladder volumes.

Although many studies on this subject have been published, no reliable conclusions have been proposed thus far. An obstructive effect of both 5 Fr and 10 Fr catheters has been reported in men with benign prostatic enlargement (BPE) [1], but conversely no significant effect of an 8 Fr catheter was noted in men with lower urinary tract symptoms (LUTS) [2]. In women, publications are even more limited, but controversial, and show opposite findings as follows: significant obstructive effect of a 6 Fr [3], of a 7 Fr catheter in healthy women [4], of different sized catheters [5,6], or 7 Fr [7] in women with LUTS, a positive effect with a 7 Fr catheter [8], and no effect of a 4 Fr catheter [9] or of two 5 Fr catheters [10].

For other parameters such as voided volume and its effect on increasing Q_{max}, more data is available [11,12].

Thus, for both genders, evaluation of the changes in maximum flow rate induced by a urethral catheter remains an unresolved issue. And in men this is a very relevant question since pressure flow studies are the gold standards to determine whether or not BOO is present. Now, if there is an impact from the presence and size of the urethral catheter on maximum flow rate (Q_{max}) and consequently on detrusor pressure (p_{det}), one should wonder about the consequences of such impact on the categorization of BOO using the Abrams-Griffiths number (A-G) or ICS provisional nomogram [13] (3 classes according to the BOO index (BOOI) [14]) which do not take into account the catheter effect.

To try to address this unsettled debate, we applied the VBN mathematical model of micturition, which allows simulations of the possible scenarios likely to influence Q_{max}, including catheter size, initial bladder volume, detrusor contractility, and urethral compression.

METHODS

The VBN mathematical micturition model [15,16] was used to investigate the effect of catheter size during voiding and to tease out its role against other influential parameters of voiding, such as bladder volume, degree of detrusor contractility, and urethral obstruction secondary to outer urethral compression.

In the VBN model, the detrusor contractility (or detrusor force) is characterized by the VBN parameter k (k = 1 for normal detrusor) (no unit) and is independent of gender. Because the anatomy of the urethra differs in men and women, outer urethral obstruction is characterized for each gender by specific parameters: γ for female and pucp (prostatic urethral counter pressure) for male (unit cm H_2O) (γ = pucp = 0 for normal subject).

Reference, nonintricate, and intricate cases were defined. Reference case was defined as normal detrusor contractility (k = 1), normal urethra (no compression, no constriction), normal nervous excitations of the detrusor and sphincter, and no abdominal straining. Nonintricate cases implied nonreference values of detrusor contractility, urethral parameters, simplicity of nervous excitations, and no predominant abdominal straining [17]. Intricate cases implied abnormal nervous excitations, predominant abdominal straining, and interrupted flow curves. Only reference and nonintricate cases were considered in this study.

Computations for nonintricate cases needed only 5 simple entries: gender (mainly due to the anatomic differences in urethra between female and male), catheter size and initial bladder volume, detrusor contractility, and urethral condition.

Simulations were made without a catheter and for a range of catheter sizes frequently utilized during urodynamic studies (UDS): 3.5, 5, 6, 7, and 8 Fr; initial bladder volume range was 100 to 600 mL (the urodynamic parameters during the voiding phase depend on the initial bladder volume). Comparisons were made between the computed Q_{max} in various conditions.

Starting from defined voiding conditions ($Q°_{max}$) such as V_{ini} = 300 mL, no catheter, normal detrusor contractility (k = 1), and no urethral compression (γ = pucp = 0), we searched for relationships between changes in Q_{max} and the studied parameters: catheter diameter (Fr), detrusor contractility (k), and urethral compression (named urac): $Q°_{max}$=37.0 mL/s for women and 29.1 mL/s for men.

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The VBN model gave the value of Q_{max} in any case. In this paper, the global change ΔQ_{max} was fitted by a sum of independent terms, each of them related to a studied parameter X:

$$Q_{max} = Q°_{max} + \Delta_V Q_{max} + \Delta_F Q_{max} + \Delta_k Q_{max} + \Delta_{urac} Q_{max}$$

For each term we searched for the best fitting power law $\Delta_X Q_{max} = \alpha_X * \Delta X^n$. The contribution of each parameter was evaluated, the sum of the contributions was made, and the result compared to the computation in order to evaluate the precision.

For men, A-G was evaluated from computed $p_{det.Qmax}$ and Q_{max} in various conditions.

RESULTS

Characteristic curves $Q_{max} = f(V_{ini}, Fr, k)$ were obtained using the VBN software for women and men (examples are given in Figure 1 for women and Figure 2 for men). From these curves, the global change in Q_{max} was obtained and the coefficients a and n identified for each studied parameter.

Step by step evaluation of the contribution of the parameters

Volume effect (no catheter, normal detrusor contractility, no urethral compression)

The relationship Q(V) has been previously evaluated [10-11]:

$Q_{max} = Q°_{max} + \alpha_V * \Delta V^{1/2}$

with α_V = 1.417 for women and 0.956 for men, and n = ½ for both genders.

Catheter size (normal detrusor contractility, no urethral compression)

$Q_{max} = Q°_{max} + \alpha_V * \Delta V^{1/2} + \alpha_F * \Delta Fr^n$

with α_{cath} = -0.0625 for women and -0.132 for men, and n = 2 for women and 1.8 for men.

Detrusor contractility (no urethral compression)

$Q_{max} = Q°_{max} + \alpha_V * \Delta V^{1/2} + \alpha_F * \Delta Fr^n + \alpha_k * \Delta k$

with α_k = 21.32 for women and 11.90 for men, and n = 1 for both genders.

Urethral compression

$Q_{max} = Q°_{max} + \alpha_V * \Delta V^{1/2} + \alpha_F * \Delta Fr^n + \alpha_k * \Delta k + \alpha_{urac} * \Delta urac$

with α_{urac} = -0.57 for women and -0.60 for men, and n = 1 for both genders.

Figure 1. Effect of various parameters on Qmax for women (initial bladder volume range from 0 to 600 mL, catheter size from 0 to 8 Fr. A) Reference case (k = 1; urac = 0). B) Effect of impaired detrusor contractility (k = 0.6; urac = 0). C) Concomitant effect of detrusor contractility and urethral compression (k = 0.45; urac = 15 cm H_2O).

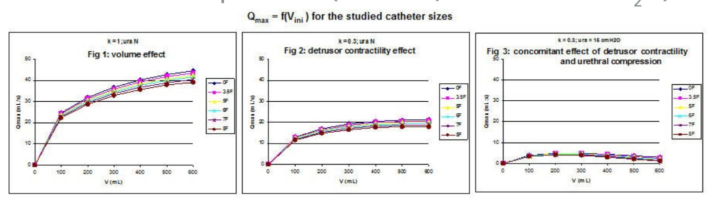
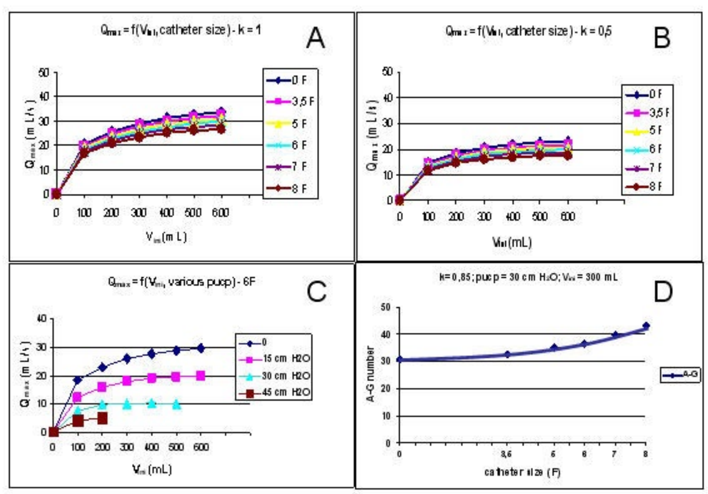


Figure 2. Effect of various parameters on Qmax for men (initial bladder volume range from 0 to 600 mL). A) Reference case, catheter size from 0 to 8 Fr. B) Effect of impaired detrusor contractility (k = 0.5), catheter size from 0 to 8 Fr. C) Effect of urethral compression and a 6 Fr catheter. D) Change in A-G number due to catheter size (k = 0.85, urac = 30 cm H_2O).



Evaluation of change in Q_{max} due to each parameter assuming the linearized equation (Table 1)

Volume effect (no catheter, normal detrusor contractility, no urethral compression)

Table 1. Comparisons of maximum flow rate for initial bladder volume Vini = 300 mL between VBN computation and the value deduced from the linearized equation. One can observe that discrepancies occur for mechanical conditions involving impaired detrusor and urethral compression.

V_{ini} = 300 mL	Women: $Q°_{max}$ = 37.0 mL/s		Men: $Q°_{max}$ = 29.1 mL/s	
Mechanical condition(s)	Computation	Linearized equation	Computation	Linearized equation
6 Fr	34.8 mL/s	34.75 mL/s	25.9 mL/s	25.8 mL/s
k = 0.5	25.3 mL/s	25.35 mL/s	20.5 mL/s	20.5 mL/s
urac = 15 cm H_2O	28 mL/s	28.2 mL/s	20.1 mL/s	20.1 mL/s
6 Fr, k = 0.5	24.7 mL/s	24.3 mL/s	18 mL/s	17.2 mL/s
6 Fr, urac = 15 cm H_2O	26.9 mL/s	26.0 mL/s	17.9 mL/s	16.9 mL/s
k = 0.5, urac = 15 cm H_2O	14.5 mL/s	17.5 mL/s	9.8 mL/s	12.5 mL/s
6 Fr, k = 0.5, urac = 15 cm H_2O	13.9 mL/s	15.3 mL/s	8.5 mL/s	8.2 mL/s

In the usual range of initial bladder volume, an increase in volume led to an increase of Q_{max}. An increase from 200 mL to 400 mL led to ΔQ_{max} = +8.3 mL/s for women and ΔQ_{max} = +5.6 mL/s for men.

Catheter size (normal detrusor contractility, no urethral compression)

The effect of a 6 Fr catheter was ΔQ_{max} = -2.25 mL/s for women and ΔQ_{max} = -3.32 mL/s for men.

For an increase of bladder volume from 200 to 400 mL, the volume effect was always higher than the catheter effect for women, while for men that condition was only observed for catheter sizes smaller than 8 Fr.

Detrusor contractility (no urethral compression)

A large decrease in Q_{max} resulted from a decrease in detrusor contractility for both genders. For example, for V_{ini} = 300 mL, a decrease in detrusor contractility k from 1 to 0.5 led to ΔQ_{max} = -10.5 mL/s for women and ΔQ_{max} = -8.6 mL/s for men.

Urethral compression

A large decrease in Q_{max} resulted from an increase in urethral compression for both genders. For example, for V_{ini} = 300 mL, a urethral compression of 15 cm H_2O led to ΔQ_{max} = -8.8 mL/s for women and ΔQ_{max} = -9.0 mL/s for men.

Table 2. Evaluation of the geometric effect of the urethral catheter on A-G number (or BOOI) in reference case (normal detrusor contractility, normal urethra (no compression, no constriction), normal nervous excitations of detrusor and sphincter, and no abdominal straining).

Catheter size (Fr)	0	3.5	5	6	7	8
Q_{max} (mL/s)	29.1	27.9	26.8	25.9	24.8	23.5
$p_{det.Qmax}$ (cm H_2O)	30	31	32	32.5	33	34
ΔQ_{max} (mL/s)	0	-1.2	-2.3	-3.2	-4.3	-5.6
$\Delta p_{det.Qmax}$ (cm H_2O)	0	1	1.9	2.6	3.3	4
Δ(A-G)	0	3.4	6.5	9	11.9	15.2

Note that k and urac can compensate if $\alpha_{urac}*\Delta urac = \alpha_k*\Delta k$ as in the first stage of BPE; i.e., when the detrusor force can compensate for urethral obstruction.

Comparison of the values of Q_{max} obtained from computation and linear equation (Table 1)

Results are given in Table 1.

Effect of the geometric effect of the catheter on A-G and BOOI

A-G or BOOI (and provisional ICS nomogram) do not take into account the catheter effect and therefore both $p_{det.Qmax}$ and Q_{max} values are all attributed to a urethral compression from BPE.

In fact, the contribution of the catheter should be evaluated. The following are formulas taking into account the obstructive effect of the catheter on both $p_{det.Qmax}$ and Q_{max}:

$\Delta Q_{max} = 0.132*Fr^{1.8}$, $\Delta p_{det.Qmax} = 0.714*\Delta Q_{max}$ and $\Delta A\text{-}G = \Delta p_{det.Qmax} + 2*\Delta Q_{max} = 0.358*Fr^{1.8}$

For example, for a male subject without BOO (V_{ini} = 300 mL, k=1, no urac, and different catheter sizes) the use of the above formulas led to the results given in Table 2. The geometric effect of the catheter introduced an uncertainty in the evaluation of BOO (ICS limits of A-G are from < 20 unobstructed to > 40 obstructed): ΔA-G = + 9 (6Fr) and + 15.2 (8Fr).

In another example shown in Figure 2D, one can see the geometric effect of the catheter on the evaluation of A-G for a man with BPE (V_{ini} = 300 mL, moderate impaired detrusor contractility k = 0.85 and urethral compression of 30 cm H_20).

DISCUSSION

For a given initial bladder volume, the observed Q_{max} during intubated flow is often lower than the Q_{max} during free uroflow. Sometimes the decrease is higher than the expected decrease secondary to the geometric effect of the catheter. In fact, several mechanical effects (such as detrusor contractility, urethral compression, and geometric effect of the catheter) may combine together and functionally affect and modify Q_{max}. Thus, a reliable evaluation of the catheter effect remains difficult. In this study, only mechanical conditions and the possible "urethral reflex" were analyzed due to the foreign material in place [18], and abnormal nervous excitation of detrusor and sphincter are not considered.

Mathematical modeling is a very useful tool to allow simulations of such intricate conditions. For standard voiding, the initial conditions are as follows: V_{ini} = 300 mL; k = 1; urac = 0; no catheter; and thus, one can use an approximation such that the various effects are additive. The coefficients a and n related to each effect have been evaluated. It is clear that this approximation is not reliable when the bladder volume is close to zero or when a patient is nearing retention. In these 2 extreme conditions, the linearized approximation gives only qualitative results.

This manuscript presents comparative orders of magnitude for the different effects. Increases in initial volume leading to increased Q_{max} and the geometric obstruction due to the catheter are almost negligible compared with the volume effect until reaching a 6 Fr catheter size for both genders. On the other hand, strong decreases in Q_{max} are observed with impaired detrusor contractility or urethral compression, with the highest effect when concomitant decreases in detrusor contractility and urethral compression are present.

In a BPE patient needing an evaluation of BOO, the geometric effect of the catheter induces an uncertainty on the obstruction status according to A-G numbers (or BOOI), which may underestimate the degree of obstruction. In their study, Klausner et al. [19] have demonstrated that there was a category migration in the Abrams-Griffiths nomogram, with a change from 5 Fr to 10 Fr catheters, and they concluded, "this category migration might potentially result in unnecessary therapeutic action." Another condition to take into account is in the first stage of BPE when hypertrophy of the bladder wall maintains adequate contractile function; in that situation, the decrease in Q_{max} due to urethral obstruction can be partially or totally compensated by the increase in detrusor contractility. Consequently, Q_{max} is mainly affected by V_{ini} and/or the presence of the urethral catheter.

Finally, it is important to note that any obstruction (including the catheter effect) increases the voiding time. It has been demonstrated [20] that such conditions lead to high residual volumes due to an early closure of the sphincter.

CONCLUSION

The main reason for a decrease in Q_{max} during an intubated flow is low detrusor contractility with or without compressive urethral obstruction. If the decrease in Q_{max} can be due to the presence of the catheter, we found that in this study, using the VBN model, that effect remained negligible for the usual catheter sizes selected for urodynamic testing compared to other causes of Q_{max} decrease.

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