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ORIGINAL ARTICLE

Account for high flow rate-low detrusor pressure voids in female: Contribution of VBN model

suppl. Informations

Analyse des mictions avec grand débit et faible pression (qp) chez la femme : contribution du modèle VBN

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KEYWORDS
High flow rate-low detrusor pressure voids;
Urethral elasticity;
Female;
VBN model.

Summary
Introduction. — Nomograms using the VBN model of women micturition allowed evaluating detrusor contractility (k) and urethral obstruction (U) from pressure-flow (PFs) recordings. While the model worked for most of the patients, an intriguing result, negative U value was observed for patients with high flow-low detrusor pressure (Qp voids). To explain that condition, our hypothesis was a weak urethral resistance to dilatation or increased expansibility (URD).
Methods. — The area offered to the fluid at each point of the urethra (its dilatation) is a function of the time depending difference between inside and outside pressures. In the VBN model, this function is sigmoid-like, the same for all women. For Qp voids, $Q_{recorded}$ was more higher than it would be with the recorded pressure (VBN analysis). So, modeling allowed computing abnormally increased urethral wall expansibility (URD) whose consequence would be an increased flow.
Results. — Among 222 non-neurologic women referred for investigation of various lower urinary tract symptoms, 27 (mean age 66.3 ± 11.4 y) had Qp void: $Q_{max} = 27 \pm 6$ mL/s; $p_{det.Qmax} = 7.5 \pm 4.7$ cm H_2O. Mean URD value was .36 ± .67. Introduction of URD in a modeled analysis of urodynamic traces led to a good fitting between recorded and computed traces for the 27 Qp.

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Conclusion. — Mathematical modeling of micturition allows proposing an explanation of the unexpected observations of Qp voids. They would be due to abnormal urethral wall elasticity. Despite major challenges measurement of this elasticity would be the next step.
Level of evidence. — 3.

MOTS CLÉS
Mictions avec grand débit et basse pression du détrusor ;
Élasticité urétrale ;
Femme ;
VBN modèle

Résumé
Introduction. — Des nomogrammes obtenus en utilisant le modèle de miction VBN permettent d'évaluer la contractilité du detrusor (k) et l'obstruction urétrale (U) à partir des enregistrements d'instantanés mictionnels chez la femme. Alors que le modèle donne des résultats cohérent pour la plupart des patientes, un résultat étonnant, une valeur négative de U, est observé lors de mictions à grand débit et faible pression (mictions Qp). Pour expliquer cette condition, notre hypothèse était une faible résistance urétrale à la dilatation ou expansibilité augmentée (URD).
Méthodes. — La surface de section de la veine fluide en chaque point de l'urètre (sa dilatation) est une fonction de la différence entre pressions interne et externe. Dans le modèle VBN, cette fonction est assimilable à une sigmoïde, identique pour toutes les femmes. Lors des mictions Qp, le débit enregistré est plus élevé qu'il ne serait étant donné la pression du détrusor (VBN analyse). La modélisation permet de calculer l'expansibilité anormale de l'urètre (URD) dont la conséquence est une augmentation du débit.
Résultats. — Parmi 222 patientes non neurologiques évaluées pour divers troubles du bas appareil urinaire, 27 (âge moyen $66,3 \pm 11,4$ ans) présentaient une miction Qp : $Q_{max} = 27 \pm 6$ mL/s ; $p_{det.Qmax} = 7,5 \pm 4,7$ cm H_2O. La valeur moyenne de l'URD était $0,36 \pm 0,67$. L'introduction de l'URD dans le modèle VBN permettait une bonne restitution des courbes enregistrées pour les 27 Qp.
Conclusion. — La modélisation mathématique de la miction permet de proposer une explication à l'observation des mictions Qp. Celles-ci résulteraient d'une élasticité anormale de l'urètre. Malgré de nombreuses difficultés de réalisation, l'étape suivante devrait être la mesure de l'élasticité urétrale.
Niveau de preuve.— 3.

Introduction

During normal voiding the urethra should open and dilate easily following the detrusor contraction, i.e. an increase in detrusor pressure. In some women, an unexpected observed condition is a high flow rate concomitant with a very low detrusor pressure (Qp void). If repetitive for successive voids that pattern is a characteristic of a given patient.

Whatever the definition of urethral resistance, such flows imply a weak ''urethral resistance'' which depends on the law of urethral elasticity. Condition for weak urethral resistance is a highly expansible urethra. Observation of low detrusor pressure implies no external compression of the urethra.

That particular condition has been little investigated and rough hypothesis have been proposed without scientific proof and numerical justification. A presumed mechanism is complete pelvic floor relaxation. However, during a normal void, forces possibly affecting the urethral flow include not only pelvic floor muscle relaxation but also urethral wall elasticity, sphincters tone, and possible abdominal straining.

High flow-low pressure voidings are currently, without conclusive evidence, associated to stress urinary incontinence [1,2]. Some attempts to explain that phenomenon have been made involving either the mechanism of opening of the urethra [3], or a urethral dysfunction [4]. None of these proposals explains the high flow rate.

Urethra comprises from the center to the periphery: the mucosa, the sub-mucosa (longitudinally arranged collagen fibers with a rich vascular plexus), the smooth muscle in a loose connective tissue matrix and a thick striated muscle which encircles the inner urethral layers [5]. In the VBN knowledge mathematical model of micturition [6], urethra is described as an elastic tube partly surrounded by a contractile sheath (sphincter); there was only a difference in the anatomical description of the urethra between genders, urethral elasticity (standard) being assumed the same.

A nomogram allowing evaluation of detrusor contractility (VBN parameter k) and urethral obstruction (anatomical or ''urethral resistance'') (VBN urethral parameter U) from a pressure flow study (PFs) has been established [7,8]. But, when applied to high flow rate-low detrusor pressure voids the nomogram leads to intriguing results such as negative value of U parameter. So, Qp voids are clearly due to an abnormally weak ''urethral resistance''.

But the intuitive notion of ''urethral resistance'' cannot be used in a quantitative manner: it would be inconsistent with general laws of hydrodynamics. During voiding, the flow rate is determined by a governing zone located at the site of the main sonic transition which may be deduced from pressure-flow studies [9] and which is in most of cases the meatus. If the meatus governs the flow, as it is the out the abdominal compartment, the active pressure is the sum of the vesical pressure and of an about 3 cm H_2O altitude component.

Our purpose was to search for a contribution of the urethra which would be related to the urethral elasticity to explain Qp voids.

Study design, materials and methods

In the VBN knowledge mathematical model [6] a compressive obstruction was described by the VBN parameter U in woman. The law of urethral elasticity describes the cross—section of the urethra (A) vs. the difference between inside and outside pressure (Δp). It is a sigmoid-like function with a maximum bend $dA/d\Delta p \approx 2$ [6]; hypothesis was a homogenous behavior along the urethra. Similar laws have been proposed [9,10].

U negative values, found during VBN analysis of Qp voids, would correspond to a negative obstruction which would make no sense. If U was negative, it was certain that the urethra was more dilatable than usual. If U was slightly positive, it was unclear whether properties of the urethra were normal or not.

Our hypothesis was that the primary mechanism resulting in a Qp void was an abnormally increased urethral wall expansibility, with an amplitude inversely proportional to the density of urethral elastic fibers by length unit.

Adjustment of the urethral model was then performed in order to deal with these negative values; more expansible urethra was then described in the VBN model [6] by multiplying the standard elasticity by a parameter called urethral resistance to dilatation (URD) whom value was lower than one in a Qp void. A low value of this parameter will have the effect of increasing the flow. Boundary condition was URD = 1 when U approached zero.

Retrospectively urodynamic recordings of a population non-neurologic women, without symptom suggestive of obstruction (i.e. no hesitancy, straining to void, double voiding, slow stream...), no history of prior anti-incontinence surgery and referred for investigation of various lower urinary tract symptoms (LUTS) were analyzed for research of high flow/low pressure (Qp) voiding pattern to test that hypothesis.

Each urodynamic session was performed using a urodynamic unit from Laborie (Mississauga Canada). Urodynamic tests were carried out according to the International Continence Society Good Urodynamic Practices [11]. Urodynamic study included one FF in private condition (sitting position) followed by one cystometry(triple lumen urethral catheter 7F allowing for urethral pressure recording) and intubated flow (IF) in sitting position. Bladder was filled with saline at room-temperature at a medium filling rate of 50 mL/min.

Exclusion criteria were voided volume < 100 mL, prolapse of grade ≥ 2, abdominal straining higher than 5 cm H_2O during the voiding phase and urodynamic diagnosis of detrusor underactivity [12].

Statistical analysis

Data are presented as mean ± SD and range. Statistical analysis was performed using SAS, version 5.0 (SAS Institute, Inc., Cary, NC). All statistical results were considered significant at $P < 0.05$.

Results

From urodynamic recordings of 222 non-neurogenic women investigated for various lower urinary tract symptoms and no obstruction, 27 (12.1%) women exhibited a high flow/low detrusor pressure (Qp) voiding pattern during their PFs study ($Q_{max} = 27 \pm 6$ mL.s^{-1}; $p_{det.Qmax} = 7.5 \pm 4.7$ cm H_2O); mean value of U was -9.0 ± 6.2 cm H_2O while a positive value (19.4 ± 14.2 cm H_2O) was observed for the other part of the population.

Mean age of the Qp population was 66.3 ± 11.4 y [42—88 y]; predominant urinary complaint was stress urinary incontinence (9), mixed incontinence (9), frequency (5), urgency (2) and recurrent urinary tract infection (2). Urodynamic diagnoses were detrusor hyperactivity with impaired contractility (5), intrinsic sphincter deficiency (11), voiding with only relaxation of the urethra (9) and ''normal'' (2). Of note, those urodynamic studies were carried out with a 7 Fr triple lumen catheter allowing for urethral pressure recording.

Bladder voiding efficiency (BVE) was > 90%, no abdominal straining was observed during the intubated flow and abdominal pressure kept a constant value during void.

Evaluation of detrusor contractility for the Qp population was $k = .29 \pm .14$ while $k = .49 \pm .25$ for the other part of the population.

For the sub-population with high Q_{max} and low $p_{det.Qmax}$ the mean URD value was $.36 \pm .67$. Introducing URD in the VBN computations allowed a good fitting between recorded and computed traces.

An example is given in the Fig. 1 where a significant recording was analyzed with VBN model; data are $Q_{max} = 18$ mL.s^{-1}, $p_{det.Qmax} = 7$ cm H_2O (ratio $Q/P = 2.6$). In the right traces, the VBN model is roughly applied to analyze urodynamic traces (standard urethral elasticity, URD = 1.0). One observes the absence of fitting between recorded curves (flow in red, detrusor pressure in fuchsia) and computed curves (flow in blue, detrusor pressure in grey). A good fitting is obtained with introduction of an increased urethral elasticity constant all along voiding (URD = 0.15).

This woman was 42 years old, with complaint of mixed urinary incontinence and urodynamic diagnosis of intrinsic sphincter deficiency (maximum urethral closure pressure 35 cm H_2O).

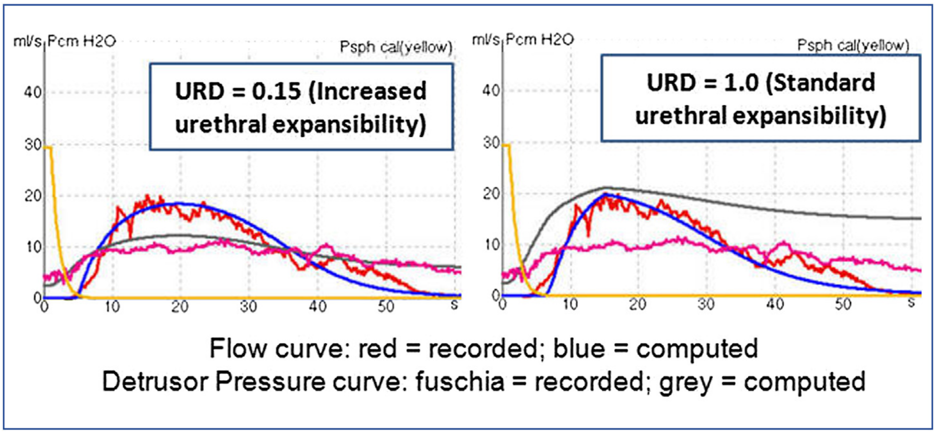

Figure 1. Analysis of urodynamic traces of an example of high flow-low pressure void (Qp). Flow curve: red recorded, blue computed; detrusor pressure curve: fuchsia recorded, grey computed. Right: Rough analysis of urodynamic traces with the VBN model with standard urethral expansibility. Absence of fitting between recorded and computed curves of flow and detrusor pressure. Left: Good fitting between recorded and computed curves obtained with introduction of an increased urethral expansibility in the computation.

Discussion

To date, no satisfactory explanation had been proposed for voidings with concomitant high maximum flow rate and low detrusor pressure (Qp). Our hypothesis is that changes in urethral elasticity would be only a change in the density of elastic fibers; so the law of urethral elasticity for one fiber is the usual one. A second hypothesis is a change in the histological structure of the urethral wall (urethral epithelium, vasculature and smooth muscle) and would imply a different law of elasticity (change in maximum bend, not in the density of fibers). Mathematical modeling allows testing different laws of urethral elasticity.

A remarkable result is the good restitution of urodynamic recordings applying the first hypothesis with introduction of a low urethral resistance to dilatation and the new parameter URD.

Studying the second hypothesis, the lack of sufficiently precise data on the histological structure of the urethral wall during the life span prevents confirmation or denial of that hypothesis. Effect of ageing has been described by Carlile et al. [13] in women of age range [19—88 year old]: decrease in the relative volume of striated muscle and blood vessels and an increase in the relative volume of connective tissue. The changes in the volume of the muscle bulk have been closely related to stress urinary incontinence [5]. That second approach does not allow a good restitution of urodynamic recordings.

Other hypotheses to explain Qp voids are related to an underactive detrusor or stress urinary incontinence.

Hypothesis that an underactive detrusor would only be the cause is not satisfactory as this condition is associated with low flow rate. In our study, women with urodynamic diagnosis of detrusor underactivity have been excluded.

Hypothesis of a relationship with stress urinary incontinence is not verified as in the studied population only 9 (33%) patients complained of stress urinary incontinence and only 11 (41%) were diagnosed as intrinsic sphincter deficiency without urodynamic stress incontinence [14].

To be discussed, hypothesis testing of pelvic floor relaxation would need imaging, difficult to implement during voiding. Note that such relaxation is equivalent to the opening of a sphincter while the Qp condition appears only when the sphincter is fully opened.

Our findings are consistent with the conclusion of DJ Griffiths [9]: ''mechanical properties of the flow governing zone during micturition may be deduced from PFs''.

In the absence of obstruction, the sonic transition in women is located at the meatus (outside of the abdominal compartment) [9], so the driving pressure is the bladder pressure plus an altitude component, which is due to the difference in height between the bladder and the urethral meatus when the urethra is well-supported. That last component cannot be negligible in Qp voids because the detrusor pressure is very low. If the sonic transition remains at the meatus, variations in flow cannot due to local changes in urethral wall elasticity. Modeling allows an explanation of this intriguing high flow/low pressure voiding phenomenon, which involves abnormal elasticity of the urethral wall. Direct measurement of urethral wall elasticity would be desirable but seem technically difficult. Ultrasound shear wave elastography (SWE) could perhaps be a useful method [15].

Main limitations of this study are its retrospective design and the small studied population. Other limitations are to do not take into account the mechanical behavior of the different layers of the urethra. This assumption results from the lack of sufficiently precise data on the histological structure of the urethral wall during the life span.

Another limitation is the assumption that elasticity is not time dependent; that is to neglect hysteresis while we know that bladder elasticity show hysteresis which explains the difference between quick and slow filling. It has been observed by urethral pressure reflectometry [4] a urethral hysteresis: for the same cross section A, the pressure is lower at the end of voiding than at its beginning.

To summarize, VBN model analysis allows proposing an explanation of voidings with high flow rate and low detrusor pressure in women.

Further studies would be quantification of density of elastic fibers in the urethra or identification of a urethral component responsible for this abnormal behavior.

A study with a larger population would eliminate some assumptions and guide the management of the patients.

Conclusion

Mathematical modeling of micturition allows proposing an explanation for voidings with high flow rate and low detrusor pressure in women which would be an increased expansibility of urethral wall. Future studies will focus on histological urethral wall changes to possibly confirm these modifications in urethral elasticity.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.purol.2019.10.003.

Disclosure of interest

The authors declare that they have no competing interest.

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