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ORIGINAL ARTICLE

Comparison of indices allowing an evaluation of detrusor contractility in women

Comparaison des index permettant l'évaluation de la contractilité du détrusor chez la femme

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KEYWORDS
Detrusor contractility indices;
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Summary
Aims. — To compare 3 detrusor contractility indices, projected isovolumetric pressure (PIP-BCI), PIP1, and *k* from the VBN mathematical model, for women referred for evaluation of various lower urinary tract symptoms (LUTS) in relationship to age, presenting complaint and urodynamic diagnosis.
Methods. — Urodynamic tracings of non-neurologic women were analyzed. Three indices of detrusor contractility were measured from the pressure-flow study. Exclusion criteria were voided volume < 100 mL, stage > 2 prolapse, interrupted flow, abdominal straining. Age sub-groups were pre-, peri- and post-menopause. Urodynamic diagnosis included incontinence findings and detrusor activity during voiding.
Results. — Main complaint was incontinence (354 women); 95 women (Other) had non-incontinence LUTS. PIP-BCI, PIP1 and *k* decreased significantly with ageing in each sub-group. PIP-BCI was significantly different between MUI and Other ($P = .0259$) while PIP1 was significantly higher in UUI vs. Other ($P = .0161$) and *k* in UUI vs. SUI ($P = .0107$), MUI ($P = .0010$) and Other ($P = .0224$). Low value of PIP-BCI for bladder outlet obstruction vs. detrusor overactivity

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while PIP1 and *k* values were high and similar for these two diagnoses and a high value of PIP-BCI for detrusor overactivity with impaired contractility close to the value for bladder outlet obstruction while PIP1 and *k* were low.
Conclusion. — Evaluation of detrusor contractility in women is easily obtained using indices PIP-BCI and PIP1 or using the VBN nomogram giving indice-parameter *k*. PIP1 and parameter *k* produced comparable and consistent results with the urodynamic diagnosis while PIP-BCI leads to inconsistencies.
Level of evidence.— 4.

MOTS CLÉS
Contractilité du détrusor ;
Index de contractilité ;
Femme ;
Urodynamique

Résumé
But. — Comparer 3 indices de contractilité du détrusor : la pression isovolumétrique projetée (PIP-BCI), PIP1 et le paramètre (index) *k* du modèle mathématique VBN, chez les femmes ayant eu un bilan urodynamique pour évaluation de divers troubles urinaires du bas appareil (TUBA), en fonction de l'âge, de la plainte et du diagnostic urodynamique.
Méthodes. — Les tracés urodynamiques de patientes non neurologiques ont été analysés. Les 3 index de contractilité du détrusor ont été calculés à partir des données l'instantané mictionnel. Les critères d'exclusion étaient un volume uriné < 100 mL, un prolapsus de grade > 2, un débit interrompu ou une poussée abdominale. Les sous-groupes d'âge étaient pré-, péri- et post-ménopause. Le diagnostic urodynamique comprenait le bilan de l'incontinence et l'activité du détrusor au cours de la miction.
Résultats. — La plainte principale était une incontinence pour 354 patientes ; 95 patientes (OTHER) avaient des TUBA sans incontinence. PIP-BCI, PIP1 et *k* diminuaient de manière significative avec le vieillissement dans chaque sous-groupe d'âge. Le PIP-BCI était significativement plus élevé pour incontinence mixte vs OTHER ($p = 0{,}0259$), PIP1 pour l'urgenturie vs OTHER ($p = 0{,}0161$) et *k* pour l'urgenturie vs incontinence d'effort ($p = 0{,}0107$), vs incontinence mixte ($p = 0{,}0010$) et vs OTHER ($p = 0{,}0224$). Une valeur basse de PIP-BCI était observée pour obstruction sous-vésicale vs hyperactivité du détrusor alors que les valeurs de PIP1 et *k* étaient élevées et semblables pour ces 2 diagnostics. Une valeur élevée de PIP-BCI était observée pour l'hyperactivité du détrusor avec hypocontractilité, proche de la valeur de l'obstruction sous-vésicale alors que les valeurs de PIP1 et *k* étaient basses.
Conclusion. — L'évaluation de la contractilité du détrusor chez la femme est facilement obtenue à l'aide des index PIP-BCI et PIP1 ou du nomogramme VBN donnant le paramètre *k*. PIP1 et le paramètre-indice *k* conduisent à des résultats comparables, cohérents avec le diagnostic urodynamique, tandis que PIP-BCI conduit à des incohérences.
Niveau de preuve.— 4.

Introduction

Evaluation of detrusor contractility in women remains a great challenge mainly because the concept of contractility has no simple definition and also because first attempts to define a contractility index in women were mostly derived from the evaluation of detrusor contractility in men.

Assessment of detrusor contractility can be made from isometric testing or pressure-flow studies. For isometric testing in a woman, a relatively satisfactory method involves a continuous occlusion of the bladder neck with a balloon [1] but such a technique faces drawbacks including patient discomfort, interference with voiding, and difficulties in keeping the balloon in place. Thus assessments of detrusor contractility using pressure-flow studies (PFS) make more sense in women.

The first index derived from PFS was the Watts factor (WF), introduced by Derek Griffiths in 1985 [2]. However, WF calculation is difficult without computer and its value has poor reproducibility. A simplified approach was proposed by Werner Schafer [3] for obstruction in male patients. The projected isovolumetric pressure (PIP) called later bladder contractility index (BCI) by Paul Abrams [4] uses a linearized bladder output relation. This index is calculated from detrusor pressure at maximum flow $p_{det.Qmax}$ and maximum flow Q_{max} with the following formula: $PIP = p_{det.Qmax} + K^{*}Q_{max}$. Schafer took K to be $5\,cmH_2O/mL.s^{-1}$. So the PIP unit is expressed in cm H_2O.

The same linearized relation was applied to women [5]. But on the basis of measurements (comparison with isovolumetric pressure from mechanical stop test and continuous occlusion test), it was noted that a *K* value of 5 as chosen in men led to a great overestimation in women. This finding was consistent with the properties of female voiding dynamics, which differ from those of men. Clearly, *K* values are not the same for men and women. A simple index called projected isovolumetric pressure 1, ($PIP1 = p_{det.Qmax} + Q_{max}$) was then proposed [5].

The VBN model from our group [6] introduced the parameter *k* (third index), which characterizes detrusor contractility. Recently a nomogram, based on this mathematical model, was proposed to calculate the detrusor contractility in women from a pressure-flow study (PFs).

A nomogram was built from tables giving Q_{max} and $p_{det.Qmax}$ for various combinations of *k* and V_{ini} (volume initial i.e. bladder filling volume or volume voided plus post-void residual). These tables were produced taking into consideration the presence of a urethral catheter (typically 6 F or 7 Fr) during PFs. Curves iso-*k* were drawn in the plane [Q_{max}-$p_{det.Qmax}$]. Then the curves were fitted by algebraic equations so they can be easily solved and programmable in Excel [7] for nomograms and comparison between curves [8]. For all to use, this nomogram in women simply needs 3 measurements: $p_{det.Qmax}$, Q_{max} and initial bladder volume (V_{ini}).

Therefore, with our VBN model and current nomogram, we were in a position of studying detrusor contractility in a large female population. Consequently, the aims of this study were to compare PIP-BCI, PIP1 and *k* in a population of non-neurologic women referred for evaluation of various lower urinary tract symptoms (LUTS) and to evaluate the impact of age, primary urological complaint for which UDS was ordered, and the urodynamic diagnosis findings related to the detrusor contractility findings.

Materials and methods

Urodynamic tracings of non-neurologic women who were referred for investigation of various lower urinary tract symptoms (LUTS) were retrospectively analyzed. All patients were evaluated using medical history, review of medications, bladder diary for at least 48 h including voiding times and voiding volumes both day and night, physical examination and dipstick analysis (to exclude women with urinary tract infection). Each urodynamic session was performed using an urodynamic unit from Laborie (Mississauga Canada). Urodynamic tests were carried out according to the International Continence Society Good Urodynamic Practices [9]. Bladder was filled with saline at room-temperature at a medium filling rate of 50 mL/min. Filling cystometrogram was obtained via a triple lumen urethral catheter 7 F allowing for urethral pressure recording followed by an intubated flow (IF). During IF, $p_{det.Qmax}$ and Q_{max} were measured. Post-void residual volumes (PVR) were measured using a Bladder-scan. The initial bladder volume or V_{ini} was calculated by adding the voided volume to the PVR.

Excluded were women who had a urinary tract infection on presentation and those unable to void during the PFS, who expelled their urethral catheter during the IF, voided less than 100 mL, or had pelvic organ prolapse of grade ≥ 2. In addition, those with an interrupted flow or voiding by abdominal straining were also excluded.

In all patients, the main complaint for undergoing UDS, the UDS final diagnosis, age and the computations of the three studied indices were carried out to allow comparisons between symptomatology, study findings and objective detrusor contractility indices. PIP-BCI and PIP1 were expressed in cm H_2O, whereas *k* was unit less. For age group analyses and, consistent with a prior publication [10], this large population of women was divided between ''reproductive (< 45 y)'', ''peri-menopausal (46–65 y)'' and ''post-menopausal (> 65 y)'' age groups.

According to ICS/IUGA recommendations [11], the main categories of urodynamic diagnoses were bladder outlet obstruction (BOO), detrusor overactivity with impaired contractility (DHIC), detrusor overactivity (DO), detrusor underactivity (DU). Some investigations were found ''normal'' (N) and other related to urethral dysfunction (intrinsic sphincter deficiency [ISD] or voiding triggered by urethral relaxation [URA]).

This retrospective study was conducted in accordance with the declaration of Helsinki. The local practice of our Ethics Committee does not require a formal institutional review board approval for retrospective studies.

Statistical analysis

Data were presented as mean ± SD and range. Analysis of variance (ANOVA), *t* test, and the Chi^2 test were used as appropriate. All statistical results were considered significant at $P < 0.05$. Statistical analyses were performed using SAS, version 5.0 (SAS Institute, Inc., Cary, NC).

Results

From January 2008 to December 2017, we studied and collected data on 4557 women. Four hundred and forty-nine urodynamic tracings met study criteria in non-neurologic women referred for LUTS. Mean age was 59 ± 16 years [20–96 y]. Main complaint was urinary incontinence: stress (96 SUI), mixed (140 MUI), urge (118 UUI). Women with complaints other than incontinence (95 women) were called OTHER; among them, 38 complained of urinary frequency (FR) and 16 from dysuria (D).

Looking at age sub-groups, PIP-BCI, PIP1 and *k* decreased with ageing, each sub-group being significantly different of the others (Table 1).

Table 1 Value of tested indices vs. age.

Age	< 45 y (*n* = 107)	46–65 y (*n* = 159)	> 65 y (*n* = 183)
PIP-BCI	113.25 ± 37.16	94.51 ± 33.10	83.77 ± 36.98
PIP1	49.40 ± 20.18	38.78 ± 16.71	32.54 ± 14.63
k	.588 ± .479	.358 ± .357	.260 ± .388

46–65 y vs. < 45 y: PIP-BCI $P < 0001$; PIP1 $P < .0001$; *k* $P = < .0001$. > 65 y vs. 46–65 y: PIP-BCI $P = .0055$; PIP1 $P = .0005$; *k* $P = .0248$.

Table 2 Value of tested indices vs. main complaint.

Complaint	SUI (96)	MUI (140)	UUI (118)	OTHER (95)
Age	54.8 ± 15.7	61.7 ± 15.9	59.4 ± 15.4	57.8 ± 17.4
PIP-BCI	94.8 ± 35.6	100.0 ± 41.7	93.5 ± 35.1	88.8 ± 36.6
PIP1	38.7 ± 19.2	38.7 ± 17.7	41.9 ± 19.6	35.8 ± 16.4
k	0.30 ± 0.34	0.28 ± 0.33	0.43 ± 0.46	0.30 ± 0.29

SUI: stress urinary incontinence; MUI: mixed urinary incontinence; UUI: urge urinary incontinence; OTHER: lower urinary tract dysfunction without incontinence.

Regarding main complaint for which the UDS was ordered, there was no significant difference in PIP-BCI except between MUI and Other ($P = .0259$) while PIP1 was significantly higher in UUI vs. Other ($P = .0161$) and *k* in UUI vs. SUI ($P = .0107$), MUI ($P = .0010$) and Other ($P = .0224$) (Table 2).

Difference in age was significant between SUI and MUI ($P = .0014$) and between SUI and UUI ($P = .0401$) as SUI women were younger.

Looking at urodynamic diagnoses some surprising results were noted such as:

- a low value of PIP-BCI for BOO vs. DO while PIP1 and *k* values were high and similar for these two UD;
- a relatively high value of PIP-BCI for DHIC close to the value for BOO while PIP1 and *k* were low (Table 3) (Fig. 1).

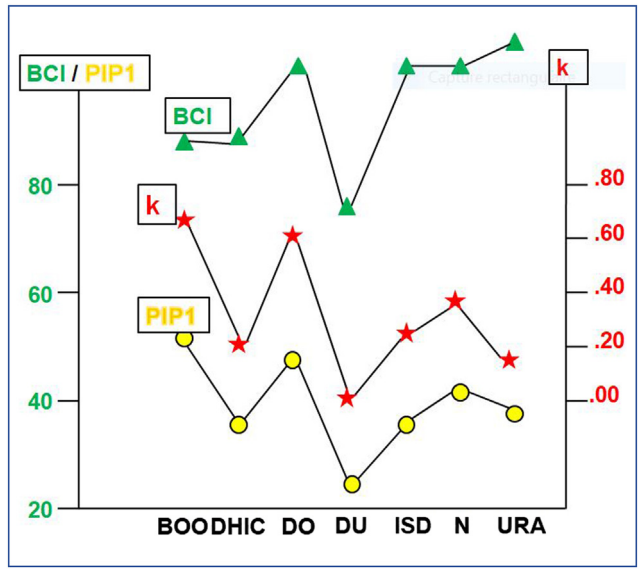

Figure 1. Variations of PIP-BCI, PIP1 and VBN parameter *k* vs. urodynamic diagnosis. BOO bladder outlet obstruction; DHIC detrusor overactivity with impaired contractility; DO detrusor overactivity; DU detrusor underactivity; ISD intrinsic sphincter deficiency; N normal; URA voiding triggered by urethral relaxation.

Discussion

To our knowledge this is the first large study in women that compares three detrusor contractility indices. PIP-BCI and PIP1 were chosen because of the common acceptance of these two indices. The VBN model offered a third index for comparison. Yet, bladder contractility in women has been seldom studied and there is no consensus on the best index to evaluate it.

Until the recent studies of C. Fry [12] and A. Gammie [13], indices to estimate detrusor contraction strength from pressure-flow studies comprised the Watts factor proposed by D. Griffiths [2], the W. Schafer nomogram [7] leading to PIP-BCI index, later modified to PIP1 by Tan et al. [5] in older women, and the VBN nomogram [8] which provides the VBN detrusor contractility parameter *k*. Fry and Gammie proposed indices deduced from the increasing phase of isovolumetric pressure, maximum rate of pressure development (v_{CE}) [12] and detrusor contractility parameter (DCP) also named t_{20-80} (time interval between detrusor pressure rising from 20 to 80% of its value once the flow starts) [12]. Unfortunately, these proposed indices are seldom relevant because of inherent limitations in the urodynamic tracing, including the need for very high quality urodynamic trac-

Table 3 Characteristics (age, value of the different indices and parameter) for urodynamic diagnoses (UD).

UD	*n*	Age (y)	PIP-BCI (cm H_20)	PIP1 (cm H_20)	*k* (no unit)
BOO	47	57.8 ± 18.1	87.5 ± 31.6	51.6 ± 19.6	.69 ± .43
DHIC	24	65.3 ± 13.3	84.5 ± 34.2	32.1 ± 12.5	.22 ± .29
DO	82	57.9 ± 17.2	101.9 ± 37.2	49.4 ± 20.9	.65 ± .50
DU	86	65.5 ± 12.9	75.8 ± 40.7	23.7 ± 9.9	.04 ± .17
ISD	81	59.7 ± 16.3	101.0 ± 38.8	34.8 ± 12.9	.26 ± .33
N	105	52.5 ± 14.3	102.2 ± 29.9	41.6 ± 10.3	.43 ± .22
URA	24	57.0 ± 18.9	105.9 ± 38.9	38.7 ± 26.6	.31 ± .62

BOO: bladder outlet obstruction; DHIC: detrusor overactivity with impaired contractility; DO: detrusor overactivity; DU: detrusor underactivity; ISD: intrinsic sphincter deficiency; N: normal; URA: voiding triggered by urethral relaxation.

ings, time delay on the pressure signal, negligible p_{det} rise before the flow starts, and some assumptions such as the bladder shape is always spherical and the same time constant to reach the maximum isovolumetric pressure P0 in the general population [14]. The Watts Factor calculation is difficult without a computer and its value has poor reproducibility. Reference values were obtained from 8 healthy volunteers who did not always performed ideal voiding tracings. For the PIP-BCI index, it has been mostly measured in men and is being used for women instead of relying on PIP1.

In this study, evaluations of PIP-BCI and PIP1 were obtained from coordinates ($p_{det.Qmax}$ and Q_{max}) of a remarkable point of the intubated flow, i.e. the point of maximum flow. Evaluation of the VBN contractility parameter *k* was also obtained from the values of the coordinates of this point but took into account the filling volume (V_{ini}, $p_{det.Qmax}$ and Q_{max}) to use the nomogram.

Of note, our mathematical model has a few hidden hypotheses including no significant contribution of abdominal pressure between onset of flow and Q_{max} and standard nervous excitations of the detrusor until Q_{max}. The first hypothesis was easily dismissed as we always excluded women who strained to void. However, the second hypothesis holds true in general in the non-neurogenic women population but could otherwise be viewed as a study limitation.

Regardless of the indices measured, detrusor contractility was found to decrease with ageing. This is consistent with prior study from Valentini et al. [15]. Analysis of a population (divided in sub-groups by age decade) of 125 PFs from non-neurogenic women without symptom suggestive of obstruction, no history of prior anti-incontinence surgery, referred for evaluation of lower urinary tract dysfunction (LUTD) show that the value of k remained similar in sub-groups less than 50 years and decreased regularly with ageing. They conclude that detrusor contractility begins to decrease at menopause and deteriorates sharply with further ageing.

This study offered an insight into the relationship between the main presenting complaint for which UDS was ordered and these 3 indices of detrusor contractility. We observed that all indices were lower for women without any urinary incontinence complaint. However, higher values of PIP-BCI were noted in the MUI group, and PIP1 and k for the UUI group. Interestingly, for the *k* index, its high value for UUI was significantly different than its value for the SUI, MUI and no incontinence groups. That condition could be the consequence of some degree of urgency.

When comparing the 3 indices with the UDS diagnosis at the completion of the urodynamic study, PIP1 and *k* gave similar evaluation of detrusor contractility, namely normal values when the urodynamic diagnosis was ''normal'', low for detrusor underactivity, and high for detrusor overactivity and bladder outlet obstruction [15]. This consistent observation confirmed the reliability of the detrusor contractility estimates using the VBN parameter *k* or the PIP1, while PIP-BCI was found to have many inconsistencies.

This finding is novel for PIP1 which has only been studied so far in a group of elderly females (53—89 years old) suffering from urge urinary incontinence. Instead, in our study, 26 of 107 women younger than 45 years complained of urge incontinence. So our study broadens the age range for which PIP1 can be used for detrusor contractility measurements.

Lastly, there are limitations to the use of *k* as a detrusor contractility index, and those are primarily related to the voiding performance. As already alluded to, they include a non-interrupted flow until reaching Q_{max} and no significant abdominal straining. Although these two conditions were applied in the mathematical computation of the *k* index, to our knowledge they have not been evaluated in the development of PIP-BCI and PIP1.

Conclusion

An evaluation of detrusor contractility derived from an intubated flow was obtained using indices BCI, PIP1 or the VBN-derived *k* parameter in a large cohort of women referred for urodynamic testing with or without incontinence symptomatology. PIP1 and the *k* parameter produced comparable and consistent results with the urodynamic diagnosis while BCI had inconsistencies. All three indices of detrusor contractility decreased with aging. Since the PIP1 and *k* indices are easy to measure, they might eventually influence the management of some women with lower urinary tract symptoms.

Disclosure of interest

The authors declare that they have no competing interest.

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