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Urological Neurology and Urodynamics

ANALYSIS OF MAXIMUM DRETRUSOR CONTRACTION POWER IN RELATION TO BLADDER EMPTYING IN PATIENTS WITH LOWER URINARY TRACT SYMPTOMS AND BENIGN PROSTATIC ENLARGEMENT


From the Department of Urology, University Hospital Nijmegen, Nijmegen, The Netherlands

ABSTRACT

Purpose: We evaluate the relationship among post-voiding residual urine volume, bladder outlet obstruction and maximum detrusor contractility power.

Materials and Methods: We investigated urodynamically and retrospectively 242 elderly men with various grades of bladder outlet obstruction and symptoms.

Results: Residual urine predominantly correlated with bladder outlet obstruction and not with maximum detrusor contractility power. Maximum detrusor contractility power showed significant positive correlation with bladder outlet obstruction. Urodynamically, the detrusor compensates for bladder outlet obstruction with elevated maximum detrusor contractility power. Decay of contraction during micturition however, hampers effective emptying.

Conclusions: Maximum detrusor contractility power limits for normal detrusor contractility must be related to bladder outlet obstruction grade. Based on the results of our analysis, new limits showing improved correlation with complete emptying were derived.

KEY WORDS: urodynamics, prostatic hypertrophy, bladder neck obstruction, urination disorders

Urodynamic investigation can provide objective and detailed information on the function of the lower urinary tract. The domain of interest in the urodynamic investigation of patients with prostatic enlargement is the evaluation of detrusor and outlet function during micturition. Regarding detrusor function during micturition in general, the International Continence Society standardization committee defined detrusor underactivity as "A detrusor contraction of inadequate magnitude or duration, or both, to effect bladder emptying with a normal time span." Furthermore, "A normal detrusor contraction will effect complete emptying in the absence of obstruction." In the International Continence Society standardization report, detrusor function during micturition is not defined when bladder outflow obstruction exists. However, it is stated that "for a given detrusor contraction, the magnitude of the recorded pressure will depend on the degree of outlet resistance." Post-void residual urine is the result of incomplete emptying of the bladder. In elderly men with an enlarged prostate, bladder emptying is hampered by the condition of bladder outflow obstruction. However, it is also assumed that the detrusor compensates as a result of bladder outlet obstruction. The clinical proof of this compensation is noted when in patients with bladder outlet obstruction the detrusor pressure at the termination of voiding is lower than that at the moment of maximum flow. Another study among patients with bladder outlet obstruction showed evidence for a subgroup with compensation of the detrusor on one hand and a group with normal detrusor reflex function (or hyperreflexia) on the other hand. These definitions and observations suggest that different qualities of the detrusor function exist but, moreover, that analysis of detrusor contractility of the individual patient must be performed in relation to (or corrected for) the grade of bladder outlet obstruction and the amount of post-void residual urine.

Neither the detrusor pressure nor the intravesical pressure (nor the flow) by itself is a good representation of the work that the detrusor generates in terms of muscle mechanics. In detrusor muscle mechanics the (maximum) isometric contraction is a standard to quantify detrusor power. For clinical purposes, the detrusor contractility power factor (watts factor) provides a quantification of detrusor function during micturition. The watts factor results from a calculation of the detrusor pressure in relation to the bladder volume (representing muscle length) at that moment and the flow rate at that same moment (representing shortening velocity). The watts factor curve allows observation of the detrusor contraction power function throughout the duration of the entire micturition, whereas the bladder working function and the estimation of maximum contraction velocity of the bladder indicate the maximum of contraction strength and/or velocity. The terms contractility and contraction are often used in a confusing manner. We will use the term (maximum) contraction power, referring to the watts factor. We are aware of the fact that the maximum contraction power that we observe is an estimation of the maximum of the spontaneous contraction power during that single micturition, which is not similar to the genuine maximum (for example isometric) contraction strength of the particular detrusor muscle of the patient studied, as could be observed in laboratory testing with a detrusor muscle strip.

An example of a watts factor curve is shown in figure 1. Since the 'zero' on a graph is normally the lower left corner, cystometric capacity (full bladder) is seen at the right axis.
ANALYSIS OF MAXIMUM DETRUSOR CONTRACTION POWER

Fig. 1. Explanatory watts factor (WF) graph. X axis shows bladder volume and y axis shows watts factor (watts per m.2). With time, curve starts at right side of graph, which is full bladder (urodynamic bladder capacity) and stops at y axis when bladder is emptied completely, or it stops earlier resulting in certain amount of post-void residual (PVR). Top of graph indicates maximal detrusor contractility power (Wmax). Voiding percentage at maximal detrusor contractility power and voiding percentage are indicated by dotted vertical lines, as well as voiding percentage at end of contraction (ENDVol). WmaxVol, voided volume at maximal detrusor contractility power.

and bladder volume diminishes throughout the micturition to the left side. The top of the curve indicates the maximum contraction power. Others have shown that patients sometimes have an initially good contraction that is decreasing during emptying, leaving a large amount of post-void residual urine (fig. 2, A). Other patients present with a weak, unsustained contraction type throughout the entire micturition (fig. 2, B). The pattern of figure 2, C is considered to be the good contraction, with an increasing power towards the left y axis and efficient emptying.6

Low maximum detrusor contractility power in patients without bladder outlet obstruction has been demonstrated to be a predictor of a prolonged postoperative (transurethral resection of the prostate) retention period in a small series of patients.9 One study reported a significant decrease in maximum detrusor contractility power after transurethral resection of the prostate.10 However, in a later study reporting a larger group of patients, no significant change after transurethral resection of the prostate was observed.9 On the other hand, watts factor at maximum flow showed dependency on changes in urethral resistance factor in a small number of patients.11 Clinically marginal but statistically significant increase in maximum detrusor contractility power was observed in relation to increasing urine flow rate and increasing detrusor pressure at maximum flow rate in a group of patients with benign prostatic hyperplasia (BPH) treated by androgen deprivation.12 In children the value of maximum detrusor contractility power was used to define 2 types of lower urinary tract dysfunction, correlating with different types of vesicourethral reflux.13 The parameter maximum detrusor contractility power has been used in these clinical studies without complete clarity about the relationship of maximum detrusor contractility power with individual outlet characteristics.

Questions about detrusor contractility frequently arise in clinical practice, as well as in clinical and fundamental re-

Fig. 2. A, watts factor (WF) curve shows patient with initially good (right side of graph) but fading contraction. Value of watts factor decreases to left side. Maximal detrusor contractility power (WFmax) is 16.6 watts per m.2, volume (opV) voided at maximal detrusor contractility power is 50 ml. and voiding percentage is 49.6%. B, watts factor curve of weak contraction throughout entire micturition. Maximal detrusor contractility power is 8.9 watts per m.2, volume voided at maximal detrusor contractility power is 275 ml. and voiding percentage is 84.0%. C, watts factor curve of patient with efficient emptying. Maximal detrusor contractility power is 11.3 watts per m.2, volume voided at maximal detrusor contractility power is 14 ml. and voiding percentage is 100%.
search. There have been a number of recent fundamental research reports on changes in the (laboratory animal and human) detrusor muscle subsequent to bladder outlet obstruction.14-17 To provide further clinical and fundamental knowledge of detrusor contractility, we investigated the relationship of bladder outlet obstruction with maximum detrusor contraction power during micturition in symptomatic patients.

PATIENTS AND METHODS

Urodynamic voiding investigations of 242 unselected elderly men with ultrasound confirmed BPH and lower urinary tract symptoms were reviewed. All patients were considered neurologically normal based on history, symptoms and physical examination (no motor, sensory or reflex deficits). Urine sediment and culture results were negative at investigation.

Urodynamic investigations were performed with an 8F transurethral lumen catheter with an intravesical microtip pressure sensor. Abdominal pressure was recorded intrarectally with an 8F microtip sensor catheter. The pressure sensors were set at zero to atmospheric pressure before introduction. After an initial voiding, the bladder was filled with water at 20°C and a filling speed of 50 ml. per minute with the portion of the graph. Minimal pressure during voiding and passive urethral resistance relation curve at the lowest pressure let obstruction, pressure-flow graphs were fitted with a program developed at our department. To quantify bladder output, which he was allowed to do in private while standing.

After pressure-flow recording the amount of residual urine was measured again. Voiding was stopped when the patient expressed a strong urge to void, which he was allowed to do in private while standing. After pressure-flow recording the amount of residual urine was measured again.

Digitally stored data on the urodynamic investigations were analyzed with a urodynamic analysis computer program developed at our department. To quantify bladder outlet obstruction, pressure-flow graphs were fitted with a passive urethral resistance relation curve at the lowest pressure portion of the graph. Minimal pressure during voiding and theoretical urethral lumen were derived using the passive urethral resistance relation curve.18 Derivation of the urethral resistance factor was based on maximum flow and corresponding detrusor pressure.11 Correction for (maximal) flow artifacts was performed when necessary. A urethral resistance factor value of more than 28 cm. water indicated bladder outlet obstruction. The linearized passive urethral resistance relation pressure-flow nomogram was used as a clinical measure.19 The maximum detrusor contraction power in the watts factor curve was automatically indicated by the computer program but corrected by hand when necessary, predominantly in the case of straining at the termination of micturition. Based on recovery of complete micturition after transurethral resection of the prostate, a maximum detrusor contractility power of more than 10.85 watts per m.² is considered good contractility.20 We use the terms high and low maximum contracture power for values of more than or less than this borderline value.

Figure 2 shows that it is important to evaluate the maximum detrusor contractility power in combination with the emptied volume at the moment of maximum detrusor contractility power. The voided volume at maximum detrusor contractility power is used in this study as a parameter to evaluate the volume-related aspect of the detrusor contraction. In the patient shown in figure 2, A the moment of maximum contraction power is seen at the start of micturition and the voided volume at maximum detrusor contractility power is small. Maximum detrusor contractility power can be observed just before the termination of voiding (fig. 2, C) and in that case the voided volume at maximum detrusor contractility power is large.

Since individual voided volumes and post-void residual urine volumes depend on the cystometric capacity, the efficiency of micturition is quantified by voiding percentage in this study to ensure a more reliable evaluation not dependent on storage capacity. (Voiding percentage is the percentage of cystometric capacity, voided.21) To correct for the differences in cystometric capacity and the differences in voided volume, the voided volume at maximum detrusor contractility power is given as a percentage of the cystometric capacity as well. (Voiding percentage at maximum detrusor contractility power; figure I.)

Differences between mean parameter values were tested with a paired samples test when appropriate, or with a Wilcoxon matched pairs signed rank test. Kruskal-Wallis 1-way analysis of variance was used to test the variance of values among more than 2 groups. Pearson’s coefficient of correlation was used for correlation analysis. Resulting p values are given.

RESULTS

The mean age of the 242 patients was 64.2 years (range 47 to 84) and the mean prostate volume was 43.5 ± 23.5 cm.³ (plus or minus standard deviation, range 22 to 160). Table 1 shows the various mean cystometric and pressure-flow analysis parameters in relation to the grade of bladder outlet obstruction as defined by the linear passive urethral resistance relation classes. It can be noted that in relation to

| Table 1. Values of the parameters of flow analysis, pressure-flow analysis and voiding efficiency parameters in relation to the linear passive urethral resistance classes of obstruction |
|---|---|---|---|---|---|---|---|
| Class | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| No. pts. | 19 | 33 | 50 | 47 | 60 | 28 | 4 |
| Flow analysis: |
| Capacity (ml.) | 438 | 447 | 407 | 392 | 386 | 348 | 424 |
| Vol. (ml.) | 367 | 381 | 398 | 273 | 248 | 196 | 163 |
| Post-void residual vol. (ml.) | 82 | 87 | 72 | 118 | 114 | 157 | 270 |
| Maximum flow rate (ml/sec.) | 12 | 11 | 8.1 | 7 | 6.4 | 4.5 | 4.6 |
| Flow time (sec.) | 86.5 | 80.3 | 90.6 | 78.4 | 78.9 | 90.9 | 42.5 |
| Pressure-flow analysis: |
| Detrusor pressure at maximum flow rate (cm. water) | 19.4 | 37.3 | 48.6 | 63.5 | 80.4 | 106.3 | 144.9 |
| Minimal pressure during voiding (cm. water) | 7.8 | 18.4 | 24.6 | 34.0 | 40.4 | 60.5 | 88.9 |
| Theoretical urethral lumen (mm.²) | 8.2 | 5.8 | 3.9 | 2.9 | 2.4 | 1.6 | 1.3 |
| Urethral resistance factor (cm. water) | 11.7 | 20.1 | 28.9 | 37.9 | 47.9 | 57.9 | 69.0 |
| Maximum detrusor contractility power (watts/m.²) | 10.5 | 9.1 | 9.6 | 12 | 13.9 | 16 | 16.9 |
| Voided vol. at maximum detrusor contractility power (ml.) | 208 | 220 | 179 | 151 | 98 | 68 | 50 |
| Voiding efficiency parameters: |
| Voiding % | 82 | 84 | 83 | 71 | 70 | 58 | 26 |
| Voiding % at maximum detrusor contractility power | 55 | 49 | 43 | 38 | 27 | 18 | 10 |
| Voiding % during cessation of contraction | 27 | 35 | 28 | 32 | 43 | 40 | 16 |

* Kruskal-Wallis test.
increasing obstruction, mean maximum flow rate and mean
voided volume are decreasing, and mean post-void residual
urine is increasing. Four patients with severe obstruction
showed a large average capacity. No tendency towards longer
(or shorter) flow time correlating with bladder outlet obstruc­
tion was observed.

The parameters defining the bladder outlet properties (ta­
ble 1) are, logically, correlated with the linear passive ure­
thral resistance relation classes, with all parameters indicat­
ing increasing bladder outlet obstruction in the higher
classes. Maximum detrusor contractility power is also signif­
ically higher in the higher classes of bladder outlet obstruc­
tion. A decrease in absolute voided volume at maximum
detrusor contractility power and relative bladder volume,
emptied at the moment of maximum detrusor contractility
power (voiding percentage at maximum detrusor contractil­
ity power) correlated with higher grades of bladder outlet
obstruction. The percentage voided from the moment of max­
dimum detrusor contractility power to cessation of flow was
not significantly altered in the patients with bladder outlet
obstruction.

Of the 149 patients with a significant residual urine vol­
ume (more than 50 ml.) 74.5% had bladder outlet obstruction
according to the analysis with urethral resistance factor
(more than 28 cm. water). On the other hand, only 49.0% of
the patients with a large post-void residual urine showed a
low maximum detrusor contractility power. Of the 107 pa­
tients with an arbitrary low voiding percentage of less than
75% 68.8% had obstruction and 57.1% had a low maximum
contraction power. On further analysis of these data, we
compared patients with and without bladder outlet obstruc­
tion (table 2). The significant differences in maximum flow
rate and post-void residual urine (and voiding percentage)
between these 2 groups are not unexpected. There was, how­
ever, a significant difference between maximum detrusor
contractility power in patients with versus those without
bladder outlet obstruction as well. A majority of the patients
with bladder outlet obstruction (63%) had a high maximum
contraction power. On the other hand a minority of the pa­
tients without bladder outlet obstruction (29%) had a max­
dimum detrusor contractility power more than 10.85 watts per
m.2. In the unobstructed group the mean voided volume at
maximum detrusor contractility power was larger (333 ml.
versus 104 ml.), which is also reflected in the larger voiding
percentage at maximum detrusor contractility power in the
unobstructed group.

When patients with low and high maximum contraction
powers are compared, it appears that the difference between
the post-void residual urines is statistically significant (low
127 ml. versus high 87 ml.) but the difference between the
voiding percentage values is not (low 72% versus high 74%,
table 2). The results of correlation analysis of post-void res­
idual urine, voiding percentage and maximum detrusor con­
tractility power with the bladder outlet obstruction para­
eters are shown in table 3.

### Table 2. Comparison of mean (plus or minus standard deviation) values of patients without and with obstruction (urethral resistance factor less than 28 versus greater than 28 cm. water), and with and without low maximum detrusor contractility power (less than 10.85 versus greater than 10.85)

<table>
<thead>
<tr>
<th>Obstruction</th>
<th>Maximum Contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>No (86 pts.)</td>
<td>Yes (154 pts.)</td>
</tr>
<tr>
<td>Max flow rate (ml/sec.)</td>
<td>10.9 (4.8)</td>
</tr>
<tr>
<td>Post-void residual vol. (ml.)</td>
<td>79 (126)</td>
</tr>
<tr>
<td>Voids %</td>
<td>86 (22)</td>
</tr>
<tr>
<td>Max detrusor contractility power (watts/m.²)</td>
<td>10.2 (6.3)</td>
</tr>
<tr>
<td>Voids vol. at max detrusor contractility power (ml)</td>
<td>233 (149)</td>
</tr>
<tr>
<td>Voids % at max detrusor contractility power</td>
<td>52 (30)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum flow rate (ml/sec.)</th>
<th>Detrusor pressure at max flow rate (cm. water)</th>
<th>Minimal pressure during voiding (cm. water)</th>
<th>Urethral resistance factor (cm. water)</th>
<th>Flow time (secs.)</th>
<th>Max detrusor contractility power (watts/m.²)</th>
<th>Post-Void Residual (ml.)</th>
<th>Voids %</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.448*</td>
<td>0.121*</td>
<td>0.134*</td>
<td>0.357*</td>
<td>0.208*</td>
<td>-0.192*</td>
<td>0.537*</td>
<td></td>
</tr>
<tr>
<td>-0.213*</td>
<td></td>
<td></td>
<td></td>
<td>-0.069</td>
<td></td>
<td>0.626</td>
<td></td>
</tr>
</tbody>
</table>

In table 3, the correlation matrix of absolute (post-void residual urine) and relative (voiding percent) amount of residual urine is shown. The results of correlation analysis of post-void residual urine, voiding percentage and maximum detrusor contractility power with the bladder outlet obstruction parameters are shown in table 3.

#### DISCUSSION

Incomplete bladder emptying during micturition was noted
in many of our patients. Of all patients 44% emptied less
than an arbitrary limit of 75% of the bladder contents, or 62%
of all patients had a post-void residual urine of more than 50
ml. A post-void residual urine of less than 50 ml. can be
regarded as clinically insignificant. Large amounts of post­
void residual urine ("greater than a certain threshold") will
be inconvenient for the patient and will be considered harm­
ful or even dangerous by many practitioners.

Although these patients were unselected at our clinic, they
are not a random group from the population. The patients
were selected because of the fact that they were symptomatic
and able to urinate during urodynamic investigation. The
incidence of retention in our patient population was low
(approximately 1% unable to void during the urodynamic
investigation and/or approximately 5% presenting with reten­
tion) but it is impossible to generalize the observations
that we made and to interpret the results in a longitudinal
manner as being a description of the time-related changes of
the detrusor in relation to bladder outlet obstruction.

Complete bladder emptying (with a normal interval) is the
aim of micturition. The efficiency of voiding is, therefore,
an important outcome in the urodynamic analysis of mictur­i­
tion. In our patients we observed an association of incom­
plete bladder emptying with the grade of obstruction but a
low correlation of the efficiency of micturition with the max­
imum contractility as defined by maximum detrusor contractility
power. Furthermore, the correlation of maximum detrusor
contractility power with the grade of obstruction was signif­i­
cant and positive. The high maximum detrusor contractility
power in patients with bladder outlet obstruction is associ­
ated with a lesser voided volume at the moment of maximum
detrusor contractility power. This fact seems to be the pre­
dominant cause of incomplete emptying because the voided
percentage during cessation of the contraction is fairly con­
stant. Therefore, the increase in the maximum contraction
power can be interpreted as a sign of the detrusor reacting

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**Table 3. Correlation matrix of absolute (post-void residual urine) and relative (voiding percent) amount of residual urine**

<table>
<thead>
<tr>
<th></th>
<th>Post-Void Residual (ml)</th>
<th>Voids %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum flow rate (ml/sec.)</td>
<td>-0.448*</td>
<td>0.537*</td>
</tr>
<tr>
<td>Detrusor pressure at max flow rate (cm. water)</td>
<td>0.121*</td>
<td>-0.213*</td>
</tr>
<tr>
<td>Minimal pressure during voiding (cm. water)</td>
<td>0.134*</td>
<td>-0.251*</td>
</tr>
<tr>
<td>Urethral resistance factor (cm. water)</td>
<td>0.357*</td>
<td>-0.493*</td>
</tr>
<tr>
<td>Flow time (secs.)</td>
<td>0.208*</td>
<td>-0.069</td>
</tr>
<tr>
<td>Maximum detrusor contractility power (watts/m²)</td>
<td>-0.192*</td>
<td>-0.177*</td>
</tr>
</tbody>
</table>

*p < 0.001.  \( p < 0.010.\)
against the increased bladder outlet obstruction. Thus, our hypothesis is that the compensation is instantaneous. We assume on this urodynamic basis that there exists a certain amount of built-in compensation or spare energy in the detrusor muscle that is consumed when (acute or chronic) bladder outlet obstruction develops.

Because the efficiency of micturition is the most important qualification for normal micturition or normal detrusor contractility, we related maximum detrusor contractility power with parameters that quantify the efficiency of voiding. We observed no difference in the efficiency of voiding between patients with a high or low maximum detrusor contractility power when the limit of 10.85 watts per m.² was used in the total group (with all grades of obstruction). This finding indicates that it is impossible to apply a single maximum detrusor contractility power value to classify patients with bladder outlet obstruction as having detrusor underactivity or normal detrusor contractility. We determined the lower maximum detrusor contractility power limits for effective micturition in relation to the various levels of bladder outlet obstruction.

Figure 3, A shows the relationship of maximum detrusor contractility power with urethral resistance factor for the patients with and without a post-void residual urine volume of more than 50 ml. A lower border for both groups of patients can be noted. When no bladder outlet obstruction was present (102 patients), the maximum detrusor contractility power value of more than 8.0 watts per m.² showed a specificity of 67.4% and a sensitivity of 84.3% for complete emptying (post-void residual urine less than 50 ml). A maximum detrusor contractility power value of more than 10.0 watts per m.² in the 108 patients with moderate bladder outlet obstruction showed a specificity of 66.4% and a sensitivity of 55.4% for complete emptying. Of 32 patients with severe bladder outlet obstruction only 4 had a post-void residual urine less than 50 ml. The minimal maximum detrusor contractility power value in these patients was 11.0 watts per m.². The specificity for complete emptying was 60.7% with a maximum detrusor contractility power value of more than 15.0 watts per m.² and the sensitivity was then 100%. When the limit for complete emptying is set as "emptied more than 75% of cystometric capacity," the aforementioned lower limits resulted in a sensitivity of 70% and a specificity of 64.5% in the patients without bladder outlet obstruction, versus 85.7% and 44.9%, respectively, in those with moderate bladder outlet obstruction, and 80% and 50%, respectively, in the severe bladder outlet obstruction group. The bladder outlet obstruction classes are based on the 3 methods of analysis (linear passive urethral resistance relation, urethral resistance factor and passive urethral resistance relation), which overall showed similar results. For comparison, the sensitivity of the maximum detrusor contractility power value of 10.85 watts per m.² for incomplete emptying was 57.0%, with a specificity of 63.0% in the complete group.

Figure 3, B shows the observed means and standard deviation of maximum detrusor contractility power in every linear passive urethral resistance relation class. The bold line represents the lower limit of maximum detrusor contractility power in relation to effective emptying in every linear passive urethral resistance relation class.

CONCLUSIONS

Maximum spontaneous contraction during micturition is affected by the grade of bladder outlet obstruction, which confirms clinical impression and sense of logic. Urodynamic evidence, however, was not yet provided in this regard and a clinical description of the mechanics of detrusor contractility is scarce. A clinically meaningful interpretation of maximum contractility power should consider the grade of obstruction. Based on our analysis, we present minimal outflow obstruction corrected limits of maximum detrusor contractility power that show a better correlation with incomplete emptying, compared to a single limit for all patients. Therefore, these new limits are more in accordance with the definitions of detrusor function during micturition.

REFERENCES

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