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# The Calculation and Comparison of the Detrusor Contractility Parameter ( $v_{CE}$ ) and Watts Factor

## Abstract

**Aims.** To test the significance between a validated index of detrusor contractility,  $v_{CE}$ , the Watts Factor, Bladder Outlet Obstruction Index (BOOI), and the Detrusor Contractility Parameter,  $t_{20-80}$ ; and to test whether  $t_{20-80}$  depends on outflow tract resistance.

**Methods.** Thirty-seven pressure-flow traces from 20 male and 17 female patients were analysed and forms of the Watts Factor,  $t_{20-80}$  and BOOI were compared with  $v_{CE}$ .

**Results.** The Detrusor Contractility Parameter,  $t_{20-80}$ , is significantly associated with  $v_{CE}$  for both women and men without a high degree of bladder outlet obstruction. The Watts Factor only had a significant association with  $v_{CE}$  at the point of maximum flow in women.

**Conclusions.** The detrusor contractility parameter, DCP ( $t_{20-80}$ ), can be measured easily from the pressure flow curves of a urodynamic test. The Watts Factor at maximum urine flow,  $WF_{Q_{max}}$ , can be readily calculated, but is only applicable to women. In both women and men without a high degree of bladder outlet obstruction, DCP is better associated with true detrusor contractility than any Watts Factor analysis.

General point:

Throughout WF is used for example with  $WF_{Q_{max}}$ . However, it is only W for  $W_{max}$  or  $W^*_{max}$ .

Is this standard nomenclature?

## Introduction

Contractility is a term generally used in a broad sense in urology to indicate strength of contraction. However, a change of contractility specifically reflects a fundamental alteration to excitation-contraction coupling in muscle tension development. Thus, contractility will be independent of: the resting muscle fibre length; innervation of the detrusor; and the composition of bladder wall tissues (e.g. detrusor vs connective tissue proportion)<sup>1,2</sup>. A further complication is that intravesical pressure is often inappropriately used as a surrogate for muscle force (wall tension), yet pressure and tension are proportional only when bladder volume and shape remain constant<sup>1</sup>. However, detrusor contractility is normally assessed during emptying, when changes to bladder volume and outflow tract resistance impact on pressure development. These confounding factors must either be accounted for when measuring pressures or deemed insignificant. The concept of contractility was initially developed with respect to cardiac function as a change of stroke work at constant fibre length (end-diastolic volume<sup>3</sup>) and this has been applied to estimates of detrusor contractility here.

Several urodynamic parameters have been proposed to estimate detrusor contractile function. These include: a linearised passive urethral resistance relation, linPURR<sup>4</sup>; a bladder contractility index, BCI<sup>5</sup>; a projected isovolumic pressure (PIP)<sup>4,6</sup> and a maximum Watts Factor,  $W_{\max}$ <sup>7-9</sup>. The first three are inter-related and a recent comparative study in men found the expected excellent agreement<sup>10</sup>. The Watts Factor estimates power generated by the bladder during a contraction, based on the Hill equation, and the maximum value is an estimate of contractility. Agreement between linPURR and  $W_{\max}$  is weaker<sup>10</sup> and reflects their different derivations. All these urodynamic parameters suffer the disadvantage that their calculation depends on urine flow and hence can be affected by outflow resistance.

An alternative estimate of detrusor contractility was derived from the isovolumic phase of bladder contraction (i.e. before flow was initiated) by deriving a Hill plot from this period to

extrapolate to maximum velocity of muscle element shortening,  $v_{CE}$ <sup>2</sup>. The approach originated from a definition of cardiac contractility derived from the isovolumic phase of left ventricular contraction<sup>11</sup> and translated to define altered detrusor contractility<sup>12,13</sup>. In view of the more complex analysis required, an empirical surrogate measurement from standard urodynamic recordings was also sought. The most suitable was the time taken for pressure to rise from 20 to 80% of its maximum value,  $t_{20-80}$ , during the same isovolumic period of detrusor contraction used to estimate  $v_{CE}$ , and was proposed as an alternative index of true detrusor contractility in both men and women: a Detrusor Contractility Parameter (DCP)<sup>2</sup>. DCP was compared with BCI,  $Q_{max}$  and age, but not with  $W_{max}$ . The use of  $t_{20-80}$ , whilst convenient, may be criticised<sup>14</sup> as it could be dependent on outflow tract opening pressure and resistance, which if increased would prolong the isovolumic phase. This study therefore aimed: to test the association between  $v_{CE}$  and the Watts Factor; and to test whether  $t_{20-80}$  depends on outflow tract resistance. The null hypotheses were that there were no significant associations between either pair of variables.

## Materials and methods

### *Patient data:*

Thirty-seven pressure-flow traces from 20 male and 17 female patients previously analysed to estimate  $v_{CE}$  and  $t_{20-80}$ <sup>2</sup> were used for Watts Factor (WF) calculations. Inclusion criteria were patients listed for routine or video urodynamics and with voided volumes greater than 100 ml. Exclusion criteria were: evidence of a bladder diverticulum, which would prevent a constant-volume contraction, and traces with poor quality subtraction during voiding, which would affect the reliability of the calculations. All traces were obtained using urodynamic equipment (Aquarius software version 12, Laborie Medical Systems, Mississauga, Canada) at a single tertiary level hospital. Urodynamic tests were carried out according to International Continence Society Good Urodynamic Practices<sup>15</sup>. Ethical approval was not required, as the study involved anonymised, historical data.

### *Calculation of the Watts Factor (WF).*

WF values were calculated as described by Griffiths *et al.*<sup>16</sup>:

$$WF = \frac{[(P_{det}+a)(v_{det}+b)-ab]}{2\pi} \quad \text{- Equation 1}$$

where

$$v_{det} = Q/2 \left[ \frac{3(V+V_t)}{4\pi} \right]^{2/3}$$

where  $P_{det}$  is detrusor pressure, cmH<sub>2</sub>O;  $v_{det}$  is velocity of detrusor muscle contraction, cm.s<sup>-1</sup>;  $V$  is instantaneous bladder volume, ml;  $Q$  is flow rate, ml.s<sup>-1</sup> at each  $V$ . The bladder is modelled as a thick-walled sphere of lumen volume  $V$  and a volume,  $V_t$ , (10 ml) of non-contractile tissue surrounded by contracting detrusor. Standard values of  $a$  (25 cmH<sub>2</sub>O) and  $b$  (0.6 cm.s<sup>-1</sup>) have been verified for the bladder<sup>17</sup>. Combination of the above equations and these standard values gives the simpler relation:

$$WF = (P_{det} + 25) \cdot \left( \frac{0.207Q}{(V+10)^{\frac{2}{3}}} + 0.0955 \right) - 2.39. \quad \text{- Equation 2}$$

Lumen volume,  $V$ , was calculated by the urodynamic software from the flow trace plus any post-void residual volume. The maximum value of WF,  $W_{\max}$ , was obtained by two methods (Figure 1): i) the value given automatically by the urodynamic software; ii) a value obtained by smoothing artefacts from the automated WF graph, referred to here as  $W^*_{\max}$ . Smoothing was accomplished by reducing the WF graph empirically to a second-order curve, and reading off the maximum value, illustrated by the horizontal line in Figure 1. Values were reported to the nearest integer value.  $WF_{Q_{\max}}$ , the value of WF at  $Q_{\max}$ , the point of maximum flow, was also calculated as a further comparison, using values taken from the urodynamic traces inserted into Equation 2.

*Calculation of the Detrusor Contractility Parameter (DCP,  $t_{20-80}$ ) and Bladder Outlet Obstruction Index (BOOI).*

Figure 2 shows a urodynamic trace used to estimate the maximum velocity of muscle element shortening,  $v_{CE}$ , along with the associated variable  $t_{20-80}$ ; DCP. The initial increase of  $P_{\det}$  for a voiding contraction is shown along with the start of the flow trace (part A) and  $t_{20-80}$  is shown as the interval between  $P_{\det}$  rising from 20% to 80% of the value when flow starts. This isovolumic region of the rise of  $P_{\det}$  was transformed to a plot (part B) that allows  $v_{CE}$  to be estimated from a fit of a hyperbolic function to the data<sup>2</sup>.

Bladder outlet obstruction index (BOOI)<sup>5</sup> was calculated as  $BOOI = P_{\det} @ Q_{\max} - 2 \cdot Q_{\max}$ .

*Data analysis and curve-fitting.*

Data are medians [25,75% interquartiles] and associations between different variables tested with a Spearman's rank test to obtain a correlation coefficient,  $\rho$ , with related  $p$ -value for significance of association from  $n$  patients (PSPP v.0.10.2; Free Software Foundation, Boston). Curve-fitting of data to estimate  $v_{CE}$  values used an iterative procedure (KaleidaGraph, Synergy, USA, v.4.5). The null hypothesis was rejected at  $p < 0.05$ .

## Results

*Watts Factor values and contractility variables.*

The different Watts Factor values, as well as values of  $v_{CE}$  and  $t_{20-80}$  are given in Table 1 for all data ( $n=37$ ), and also for female ( $n=17$ ) and male ( $n=20$ ) subsets. For the whole data set and the two subsets,  $W_{max}$ , as reported by the urodynamic system, was significantly greater than both the empirically smoothed value ( $W^*_{max}$ ) and also the calculated  $WF$  at  $Q_{max}$  ( $WF_{Qmax}$ ). However,  $W^*_{max}$  and  $WF_{Qmax}$  were not significantly different from each other. There were no differences for any variable between the male and female subsets.  $W_{max}$  values will not be commented on further due to the evident influence on values from measurement artefacts.

The relationships between  $v_{CE}$  and  $W^*_{max}$  or  $WF_{Qmax}$ , as well as with  $t_{20-80}$ , are shown in Figure 3A. Values of the Spearman correlation coefficient,  $\rho$ , and the statistical significance of these values are in Table 1.  $v_{CE}$  was very significantly associated with  $t_{20-80}$ , as reported previously<sup>2</sup>, with a greater degree of significance within female data. However, there was no significant association between  $v_{CE}$  and  $W^*_{max}$ , nor  $WF_{Qmax}$ , except for an association between  $v_{CE}$  and  $WF_{Qmax}$  in the female subset.

The value of  $t_{20-80}$  has been proposed as a surrogate measure of  $v_{CE}$  that may be more readily obtained from urodynamic traces<sup>2</sup>, as observed by the high correlation index between the two variables (Table 1, Figure 3A). Figure 3B shows the relationships between  $t_{20-80}$  and  $W^*_{max}$  or  $WF_{Qmax}$ . For the whole data set there was no significant relationship between  $t_{20-80}$  and  $W^*_{max}$  or  $WF_{Qmax}$ , and the same was true for the male subset. However, for the female subset,  $WF_{Qmax}$  was significantly associated with  $t_{20-80}$ , as it was with  $v_{CE}$ .

*Factors influencing  $t_{20-80}$ .*

The usefulness of  $t_{20-80}$  as a surrogate estimate of detrusor contractility,  $v_{CE}$ , depends on a lack of influence of other urodynamic variables on its value. There is a potential dependence of  $t_{20-80}$  on the magnitude of the outflow resistance, because the isovolumic increase of  $P_{det}$  will be greater with raised outflow opening pressure<sup>14</sup>. This in turn would prolong the isovolumic period of  $P_{det}$  increase: this would be especially significant in men. If this was a significant confounder,  $t_{20-80}$  should be a positive function of the BOOI. In the male population BOOI varied between -39 and 129 units and there was a significant relationship between BOOI and  $t_{20-80}$  ( $p=0.015$ ,  $n=20$ ). Three BOOI values were greater than 95 units and if these were discounted there was no significant relationship between BOOI and  $t_{20-80}$  ( $p=0.220$ ,  $n=17$ ). However, the value of  $v_{CE}$  itself was independent of BOOI for all values of the latter ( $p=0.257$ ,  $n=20$ ). One female patient, with bladder outlet obstruction, had a very high value of  $t_{20-80}$  (19.5s).



## Discussion

### *Detrusor contractility in men and women.*

The measurement of bladder contractility is an important part of the assessment of bladder function, particularly in patients with voiding symptoms such as poor stream and incomplete bladder emptying. If poor contractility can be reliably diagnosed, then an operation on the bladder outlet will be unlikely to lead to symptomatic improvement, and the patient can be spared unnecessary surgery. Also, a poor prognosis for adequate voiding after stress incontinence surgery in women with poor contractility could be predicted.  $v_{CE}$ , the maximum contraction velocity of muscle element, has long been proposed<sup>7,18</sup> as the best way to assess detrusor contractility. There was a lack of significant association between  $v_{CE}$  and either  $W_{max}$ ,  $W_{max}^*$  or  $WF_{Qmax}$ , except for the latter in the female subset (Table 1). This poor general association may result from the fact that Watts Factor is measured during flow and is thus affected by the state of the bladder outlet. This is a less frequent problem for women than for men, and indeed a significant positive relationship between BOOI and  $WF_{Qmax}$  was observed in men ( $\rho=0.499$ ,  $p=0.025$ ,  $n=20$ ). A larger study than this pilot will confirm if  $WF_{Qmax}$  is a useful index of detrusor contractility in women, whilst for men there is from these data no evidence to support its utility.

### *DCP and outflow resistance*

The value of  $t_{20-80}$ , in the isovolumic phase of the rise of  $P_{det}$  during a voiding contraction, was suggested as a surrogate of  $v_{CE}$  due to the excellent association between the two in both men and women<sup>2</sup>, and labelled the detrusor contractility parameter (DCP). It has been pointed out that  $t_{20-80}$  can be influenced by outflow resistance<sup>14</sup> and this should be particularly so in men, for whom prostatic obstruction is a common problem. This is supported by the less significant association of  $v_{CE}$  and  $t_{20-80}$  in men (Table 1) and also by the positive association between BOOI

and  $t_{20-80}$ . The latter observation was true only if greater values of BOOI (>95 units) were included, but if they were not, then variations in BOOI did not impact on  $t_{20-80}$ . In addition, the one female patient with outflow obstruction also had a much higher DCP value than other women. However, it is appreciated that this small pilot study requires a larger population to identify a more accurate cut-off value of BOOI. Indeed, Oelke *et al.*<sup>19</sup> show that  $W_{max}$  tends to rise with BOOI in men. A definitive association will only be discernible when the DCP variable is measured in the same patients before and after treatment, for instance in male patients before and after prostate surgery.

#### *Clinical usefulness of DCP*

Overall, if  $v_{CE}$  is used as the gold standard to define detrusor contractility, the value of DCP,  $t_{20-80}$ , is a useful and simple urodynamic measure that will substitute. This is particularly so in women, unless clearly obstructed, whereas in men, higher values of BOOI will falsely increase the value (and so decrease the contractility estimate). For similar reasons,  $WF_{Qmax}$  may also be a useful estimate of detrusor contractility in women, since obstruction occurs less frequently than in men, although it has no utility in men due to the significantly positive relationship between BOOI and  $WF_{Qmax}$ . The association between  $WF_{Qmax}$  and  $v_{CE}$  was less significant than for  $t_{20-80}$  (Table 1), so the usefulness of  $WF_{Qmax}$  is limited compared to DCP.

#### *Practical aspects of calculating Watts Factor.*

##### *a) Resting pressure*

Since the resting  $P_{det}$  at the start of filling is not always 0 cmH<sub>2</sub>O, it is advisable to take this offset into account when considering  $P_{det}$  values during voiding<sup>15</sup>. However, the urodynamic system calculates WF using the raw  $P_{det}$  value without this adjustment, giving an error. In our data set, the change in  $WF_{Qmax}$  value by omitting resting  $P_{det}$  led to an average error of 3%

(range 0–21%) in  $WF_{Q_{max}}$ . This error will vary according to local urodynamic practice regarding starting pressures. Additionally, similar errors will occur when adjusting  $P_{det}$  at  $Q_{max}$  for any drop in abdominal pressure during voiding.

*b) Bladder volume measurement*

Errors in volume estimation can occur if the bladder is not fully emptied at the start of the test, or due to urine production adding to the volume infused during the test. This can be mitigated by measuring the post-void residual (PVR) bladder volume after the urodynamic study, but this is rarely done in practice, especially if the voided volume is greater than the volume infused, when zero residual is normally assumed, perhaps erroneously in some cases. In our data set, the error that could occur when ignoring residual was on average 9% (range 0–69%).

*c) WF artefacts*

The fact that  $W_{max}$  values change so radically when smoothing the WF curves to obtain  $W^*_{max}$  shows that automatically generated variables cannot be relied upon, as artefacts may greatly raise the values. The urodynamicist recording WF will therefore always need to scrutinise the WF trace, and adjust the  $W_{max}$  value accordingly, if contractility is being measured. This will necessarily result in approximate values for  $W_{max}$ , which we have analysed above as  $W^*_{max}$ . The appropriate smoothing filter for this process has yet to be determined. Oelke *et al.*<sup>19</sup> refer to elimination of measurement artefacts, but do not specify the protocol for this. It would therefore seem advisable, if using WF in women, to use  $WF_{Q_{max}}$  instead, since the  $Q_{max}$  point is routinely moved away from artefacts by the user, and can be easily and precisely calculated from the data table produced by urodynamic equipment, without the need for a WF trace at all. Indeed,  $WF_{Q_{max}}$  was the parameter used by Griffiths *et al.* in their 1989 study<sup>8</sup> and was held to be more useful than  $W_{max}$  in the original paper<sup>16</sup>, although our data from this study suggests neither is a reliable indicator of true contractility in men.

d)  $W_{max}$ , filtering and  $WF_{Qmax}$

A recent exchange of letters<sup>20,21</sup> questioned whether  $W_{max}$  and  $WF_{Qmax}$  could be assumed to be occurring at the same volume. Griffiths *et al.*<sup>16</sup> state this is unlikely, and our data confirm this, especially given the artefacts noted. The median (upper, lower quartiles) of volumes at  $W_{max}$  was 60 (18, 146) ml and at  $WF_{Qmax}$  was 153 (123, 253) ml. The difference between the pairs of volume data had a mean of 85 ml (SD 140,  $p=0.001$ ). The difference between actual values of  $W_{max}$  and  $WF_{Qmax}$  had a mean of 15.4 W/m<sup>2</sup> (SD 18.7,  $p<0.001$ ), *contra* Bray and Drinnan<sup>22</sup>, who reported a difference of only 1 W/m<sup>2</sup> in 33 male patients. However, the concordance of  $W_{max}^*$  with  $WF_{Qmax}$  values was much closer to Bray and Drinnan's results (our data had mean difference of 1.6 W/m<sup>2</sup>, SD 3.7,  $p=0.014$ ), implying that they had filtered out artefacts to record  $W_{max}$ , as we effectively did to obtain  $W_{max}^*$ . Alternatively, they may have simply disregarded artefacts occurring below a certain volume, as WF spikes tend to occur at that stage. Removal of artefacts from the WF graph is a vital requirement, but note again that no filtering regime has been standardised, even though it would be preferable to subjective smoothing.

e) *Units of measurement*

In the original WF paper<sup>16</sup>, the constant  $b$  included with  $v_{det}$  in Equation 1 above is stated to be 6 mm/s. However, since the units of volume are ml (i.e. cm<sup>3</sup>), other parameters in equation 2 must be consistent with this and use 0.6 (in cm/s) as the constant  $b$ . The urodynamic system used for this study follows this practice. Another issue concerning units is that WF is stated to be in W/m<sup>2</sup> (or  $\mu$ W/mm<sup>2</sup>, which is equivalent). However, there is a small (2%) error in using this unit, as 1 cmH<sub>2</sub>O of pressure is actually 98 N/m<sup>2</sup>, not 100 N/m<sup>2</sup>, but if practice is consistent, this will not be significant.

It is therefore necessary to correct for resting  $P_{det}$ , PVR volume and artefactual variations if calculating WF.

### *Limitations of this study*

The clinical application of DCP has yet to be tested with large numbers of data. An issue, raised in the original DCP publication<sup>2</sup>, will affect this, namely the time delay set by the urodynamic equipment on the pressure signal. This is routinely added to ensure synchronous measurement of pressure and flow, since urine takes a finite time to reach the flowmeter. This time delay, however, depends on urine flow rate, patient position and equipment setup, so the value of  $P_{det}$  at the start of flow will be affected by this unknown variation. Another factor needing investigation is the effect of bladder shape on this parameter. The assumption of continual spherical shape is unlikely to be true<sup>14</sup>, and the resultant effect on the DCP is unknown and should be quantified. Additionally, for many patients, there is negligible rise time, or even negligible  $P_{det}$  rise, before flow starts, so DCP cannot be used in their case.

### Conclusions

The detrusor contractility parameter, DCP ( $t_{20-80}$ ), can be measured easily from the pressure flow curves of a urodynamic test, as shown in Figure 1. The Watts Factor at maximum urine flow,  $WF_{Qmax}$ , can be readily calculated from figures obtained during a urodynamic test, using Equation 2, and avoids the artefactually high values that are automatically generated by software, but is only applicable to women. In both women and men without a high degree of bladder outlet obstruction, DCP is better associated with true detrusor contractility than any Watts Factor analysis.

### **Legends**

Table 1. Values of detrusor contractility indices  $v_{CE}$  and  $t_{20-80}$  and their comparison with three Watts Factor (WF) derivatives:  $W_{max}$ : maximum Watts Factor from the urodynamic system;  $W^*_{max}$ : maximum value of empirically smoothed WF;  $WF_{Qmax}$ : calculated value of WF at point of maximum urine flow rate. Shown also are the Spearman correlation coefficients,  $\rho$ , for the association of each variable with  $v_{CE}$  and the significance,  $p$ , of  $\rho$ , values of  $p < 0.05$  are shown in **boldface type**. Data are from the whole data set ( $n=37$ ) and from female ( $n=17$ ) and male ( $n=20$ ) subsets. Data are medians [25%, 75% interquartiles]. Additional comparisons for  $W^*_{max}$  or  $WF_{Qmax}$  vs  $W_{max}$  are signified by #  $p < 0.05$ , ##  $p < 0.01$ , ###  $p < 0.001$ .

Figure 1. **Estimation of Watts factor parameters.** The trace shows a continuous calculation of the Watts Factor, WF, from the urodynamic system, contraction starts at bottom right. The example shows an artefact in the later stages of contraction that is reported by the system as the maximum value of WF,  $W_{max}$ , i.e.  $47.6 \text{ W/m}^2$ . The dotted line shows a smoothed fit to the data to yield a smaller value of WF,  $W^*_{max}$ , i.e.  $17 \text{ W/m}^2$ . The volume at maximum flow,  $Q_{max}$ , is also indicated, where  $WF_{Qmax}$  is  $14 \text{ W/m}^2$ .

Figure 2. **Estimation of contractility variables,  $v_{CE}$  and  $t_{20-80}$ .** A: the initial stages of the rise of detrusor pressure,  $P_{det}$ , during a voiding contraction. The isovolumic phase is terminated at the beginning of flow.  $t_{20-80}$  is shown as the interval between 20 and 80% of the isovolumic increase of  $P_{det}$ ,  $\Delta P_{det, isovol}$ . B: Estimation of  $v_{CE}$ , the maximum velocity of contractile element shortening from a derivative plot of the isovolumic rise of  $P_{det}$ .

Steps to calculate  $t_{20-80}$ :

- Mark beginning and end of isovolumic pressure rise
- Mark 20% and 80% of maximum pressure within that rise
- DCP is the time between those 20% and 80% marks

Figure 3. **The association between different contractility variables.** A: the association between  $v_{CE}$  and  $t_{20-80}$  (left),  $W^*_{max}$  (centre) and  $WF_{Qmax}$  (right). B: the association between  $t_{20-80}$  and  $W^*_{max}$  (left) and  $WF_{Qmax}$  (right). Data are for female (black squares) and male (white squares) participants. See Table 1 for values of correlation coefficients.

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Figure 1

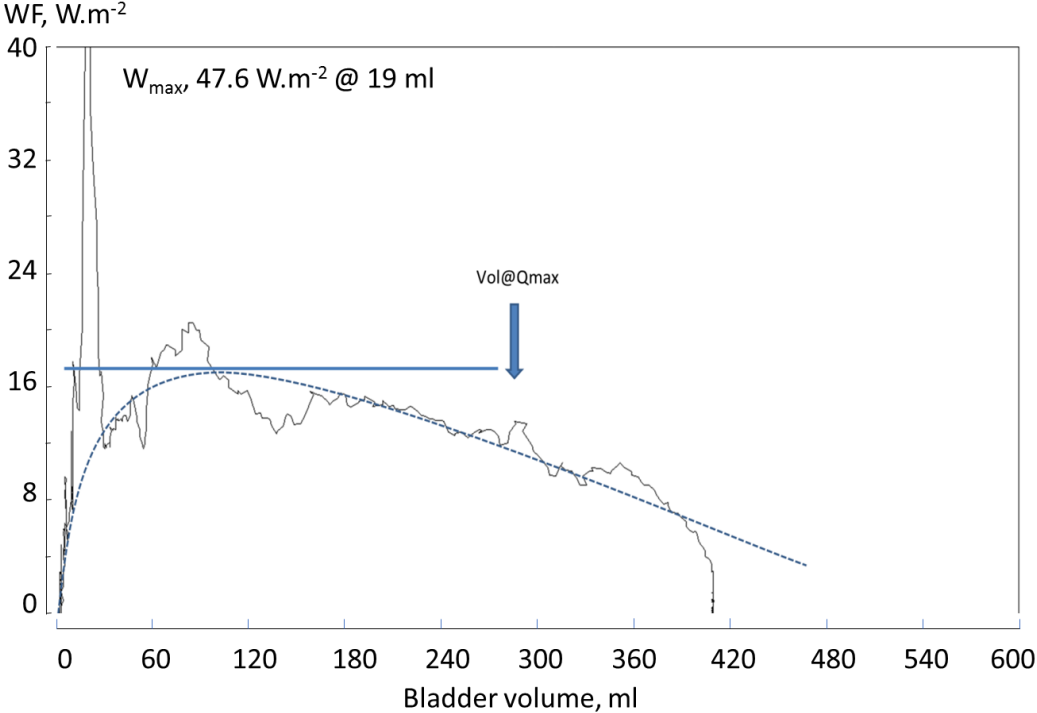
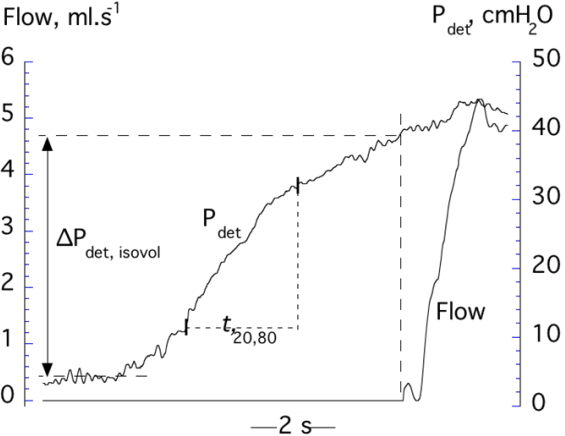


Figure 2

A



B

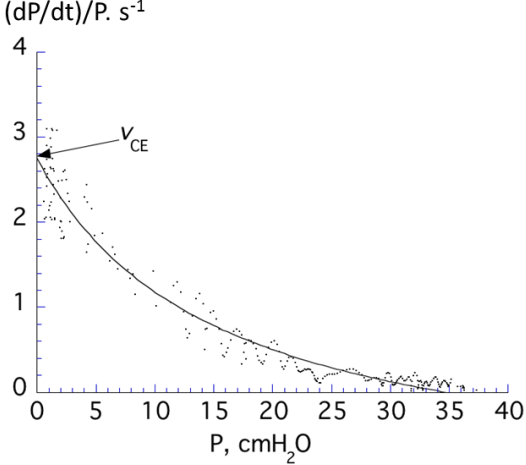
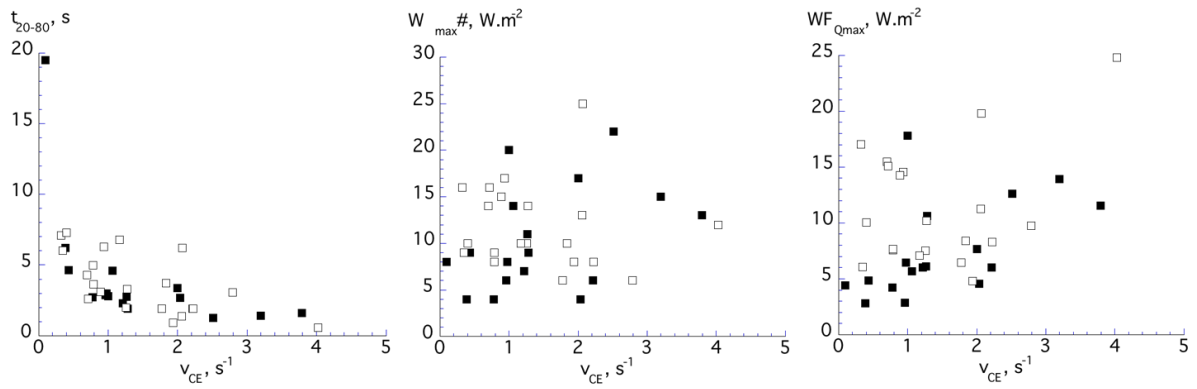


Figure 3

A



B

