Hypothesis / aims of study
Theoretical models of bladder contraction, based on the Hill equation, predict the relationship between the detrusor pressure and flow rate [1]. This is known as the Bladder Output Relation, BOR. It is, however, difficult to validate as urethral resistance must be controlled in order to vary the flow rate. Normally, $p_{\text{det}}$ and $Q_{\text{max}}$ can be measured, as well as $p_{\text{det,isv}}$ during a stop test, but these only plot two points on the curve and provide limited opportunity to validate the theoretical model.

We used an inflatable penile cuff to reduce flow to zero by increasing urethral resistance, whilst simultaneously measuring detrusor pressure ($p_{\text{det}}$) and flow rate ($Q$), to obtain an experimental measure of BOR which was then compared to the theoretically predicted BOR.

Study design, materials and methods
150 men undergoing invasive PFS for investigation of LUTS gave informed consent to have a cuff test after their routine assessment. After PFS, the bladder was refilled until urge to void and the cuff test was performed with catheters in place. On detection of flow, the cuff was inflated at 10cmH$_2$O until flow was interrupted or 200cmH$_2$O reached and then rapidly deflated. This was repeated until the end of the void. For each patient, the inflation with the highest interruption pressure was analysed.

Voided volume and filled volume were used to infer bladder volume. The Watts factor equation [2] was used to predict the $p_{\text{det}}$ from the measured flow rate and bladder volume. Using detrusor contraction strength (WF) calculated from $p_{\text{det,ijy}}$ and assumed to be constant, and published values for the constants ‘$a$’ (corresponding to maximum isovolumetric pressure) and ‘$b$’ (corresponding to maximum shortening velocity) [2] the experimental and theoretical BOR ($p_{\text{det}}$ vs $Q$) were plotted. The prediction was compared to the measured values by evaluating the r.m.s. differences between the two.

In order to improve the fit of the predicted theoretical BOR to the experimentally obtained BOR, the constants $a$ and $b$ were optimised for each patient using a least squares method.

Results

Fig 1. Pressure-flow data: Black: experimental BOR; Green: predicted BOR (using standard $a$ and $b$); Red: ‘best fit’ BOR (using calculated $a$ and $b$ for each patient)

Results were obtained in 104 men, with representative traces plotted in Fig 1. Approximately a third of men fell into each category (Good, Average, Poor) according to r.m.s. value.

The values of $a$ and $b$ which produced the ‘best fit’ are plotted in Fig 2 below. This shows very little agreement between the ‘standard’ values of $a$ and $b$ and the best fit values. The majority of calculated values of $a$ are negative.
Interpretation of results

In theory, the curves should tend towards zero pressure for higher values of flow rate, but this was not the case in many of the patients. In these patients, where $\text{BOR}_{\text{exp}}$ did not agree with $\text{BOR}_{\text{theory}}$, the curve appears to level out at a positive pressure. Changing $a$ and $b$ to give a ‘best fit’ BOR yielded good fits, but many of the values of $a$ were negative. This reflects the tendency of the curves to level out at a positive pressure, but is unphysiological according to the Hill equation.

The large spread of ‘best fit’ values of $a$ and $b$ suggests that these parameters differ substantially between individuals, and it would be inappropriate to use them to calculate a new average $a$ and $b$.

A possible reason for disagreement between the results and the theory may be inhibition of the detrusor contraction during inflation of the cuff; however, previous studies have shown that using the penile cuff to interrupt the flow does not inhibit detrusor contraction [3]. Collection of data midstream, where the isovolumetric pressure is highest and the contraction strength is assumed to be stable, supports that we are making a representative measure of the BOR.

Concluding message

This method of using measurement of detrusor pressure whilst a cuff is being inflated to interrupt flow mid-void allows experimental BOR data to be obtained. The data we have collected, however, is not consistent with the WF equation based on the Hill equation. Further work and possibly further development of the theoretical model is required to explain our results.

References

1. Neurourol Urodyn (1985) 4:77-87