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The Assessment of Prostatic Obstruction from Urodynamic Measurements and from Residual Urine

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Summary—One hundred and seventeen males over the age of 55 were investigated for possible prostatic obstruction. About half of the cases in this series could have been objectively classified as unobstructed or obstructed from the maximum flow rate alone.

In about two-thirds of the cases obstruction could be satisfactorily assessed from the maximum flow rate together with the detrusor pressure at maximum flow. It was not helpful to combine these 2 measurements into a single urethral resistance factor.

In the remaining one-third of the cases, obstruction could be objectively assessed only from a plot of detrusor pressure against flow rate throughout micturition. In many of these cases both the pressure and the flow rate were low and the main peculiarity was that the contractile power of the bladder was weak.

Residual urine is a sign of an abnormality of bladder function rather than the direct result of urethral obstruction.

Measurements of bladder pressure and flow rate during micturition make it possible, in principle, to distinguish objectively between an obstructed and unobstructed urethra. It is not clear, however, what criteria should be used for the most reliable assessment. Often the maximum flow rate and either the intravesical or the detrusor pressure at that flow rate are used as criteria; sometimes these are combined into a single urethral resistance factor (Smith, 1968). It has been suggested that a plot of detrusor pressure against flow rate throughout micturition should be a useful way of detecting obstruction (Griffiths, 1973, 1974; Bates *et al.*, 1975).

In this paper it is first shown that such pressure/flow plots are a sensitive and reproducible test of prostatic obstruction, both before and after prostatectomy. A series of patients is then classified according to the pressure/flow plots and it is argued (i) that the majority can in fact be objectively classified as clearly obstructed or unobstructed by simpler methods, but that there is a substantial borderline group in which obstruction can be assessed only by the pressure/flow plot; (ii) that in the borderline group there are both unobstructed and obstructed patients whose main urodynamic peculiarity is a reduced contractile power of the bladder; (iii) that residual urine is a sign of an abnormality of bladder function and not the direct, mechanical result of urethral obstruction.

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Patients and Methods

The series consisted of 117 males of 55 years and over who, apart from a few exclusions for technical reasons, were taken without selection from those in this age group referred to the Unit for investigation of possible prostatic obstruction. Fifteen of these patients were examined again about 3 months after prostatectomy (either retropubic or transurethral). In 8 of the patients 2 pressure/flow plots were obtained before any operation, either (a) on the same occasion or (b) on 2 occasions separated by an interval of about 6 months, during which they received either a placebo or a drug that proved to have no detectable urodynamic effect (Abrams, 1977a).

After measurement of the urethral closure pressure profile and filling cystometry, the patient micturated, seated and with a transurethral epidural catheter (Portex 100/380/300) in place, while intravesical and rectal pressures and the

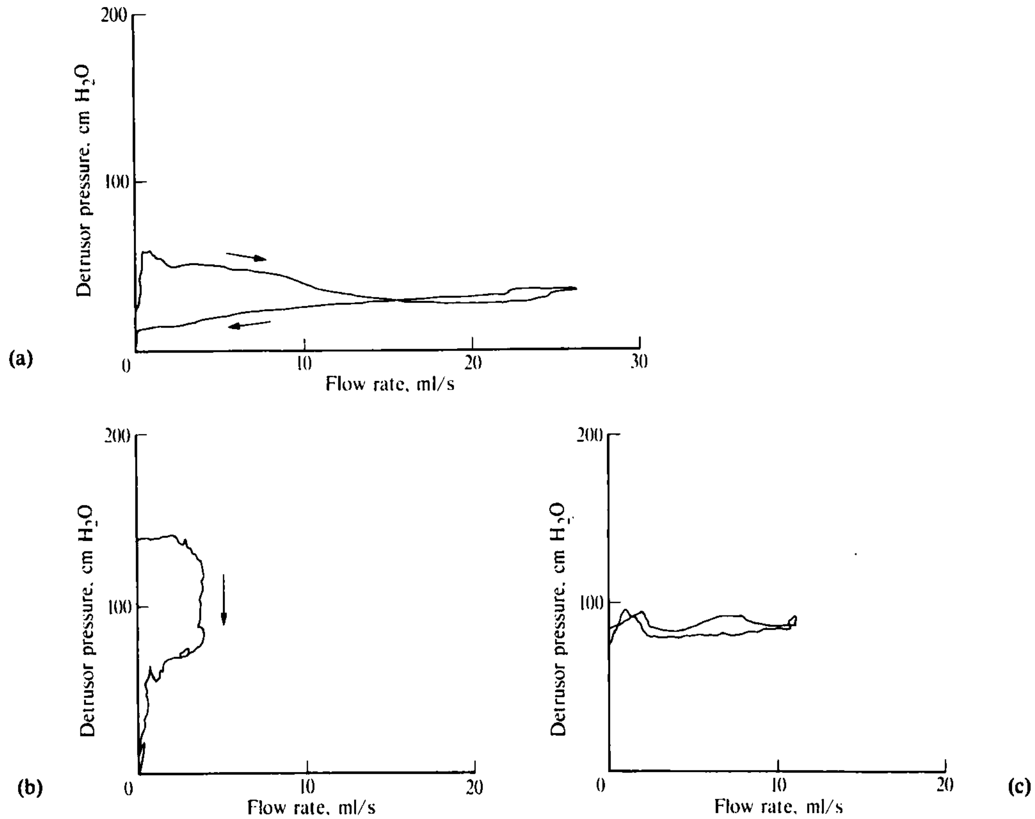

Fig. 1 Pressure/flow plots for micturition of 3 different unoperated patients: (a) unobstructed pattern A: characteristics are that plot is nearly horizontal (*i.e.* mean slope is small) and pressure at end of voiding is low; (b) obstructed pattern B: main characteristic is that plot is not horizontal, so that mean slope (after fast initial rise of flow rate) is large; also plot is often curved, as here; (c) obstructed pattern C: plot is nearly horizontal but pressure at end of voiding is high. 1 cm H_2O is approximately 100 Pa, the S.I. unit of pressure.

volume voided were measured (Siemens-Elema EMT 34 and 435 transducers). Detrusor pressure (= intravesical pressure—rectal pressure) and volume flow rate were calculated electronically. All 5 variables were recorded on a chart recorder (Siemens-Elema M81) and on tape (Ampex PR 500 recorder). Residual urine was estimated by subtracting the voided volume from the volume previously introduced into the empty bladder, or was measured by catheterisation.

The magnetic tapes were played back to an x-y recorder (Bryans 26000/A4), with some smoothing to reduce noise artefacts, so that detrusor pressure was plotted against flow rate throughout each micturition as illustrated in Figure 1. No account was taken of the unavoidable time lag of about 1 s in the measurement of the flow rate.

Urethral obstruction was also assessed clinically by one of the authors (P.H.A.), prior to and independently of the work described here. The criteria and further details of the methods used have been described elsewhere (Abrams, 1976, 1977b; Abrams *et al.*, 1977).

Results

Illustrative Results

Figure 1 shows 3 representative pressure/flow plots, which are respectively (a) unobstructed, pattern A, and (b) and (c), obstructed patterns B and C. Pattern B is the commoner obstructed pattern. Pattern C is similar to A but is displaced to much higher pressures; it is uncommon. The criteria for classification are discussed below.

Figures 2i and ii show how a severely obstructed pattern is changed into an unobstructed pattern A by successful prostatectomy.

Figures 3a and b show 2 pre-operative plots from the same patient, separated by 6 months without intervening surgery. The pattern is an

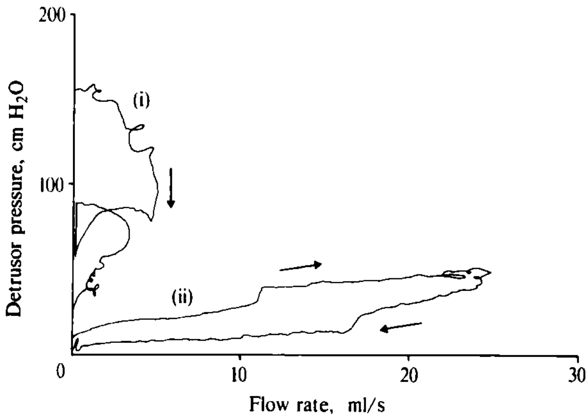

Fig. 2 Pressure/flow plots for 2 micturitions of one patient. (i) before prostatectomy: obstructed, pattern B; (ii) after prostatectomy (TUR): unobstructed, pattern A.

obstructed one (B) on both occasions, although there are small quantitative changes.

Classification

Previous experience (Griffiths, 1973; Bates *et al.*, 1975) suggests that, in unobstructed cases, the mean slope of the pressure/flow plot (after the fast initial rise in flow rate) is less than 2 cm H_2O/ml s^{-1} and the detrusor pressure as flow ceases at the end of voiding is 40 cm H_2O or less. Plots satisfying these 2 criteria have been classified as unobstructed, pattern A. Plots with mean slope greater than 2 cm H_2O/ml s^{-1} have been classified as obstructed, pattern B, and those with mean slope less than 2 cm H_2O/ml s^{-1} but detrusor pressure at the end of voiding greater than 40 cm H_2O have been classified as obstructed, pattern C. Plots with pattern B are often curved (Figs. 1-3), so that the mean slope can only be roughly estimated. However, this leads to very little ambiguity since, in fact, such curvature is helpful in classifying the pattern as obstructed, type B.

Of the 117 unoperated patients, 21 showed an unobstructed pattern A and 91 showed obstructed patterns; 3 could not be unambiguously classified; 85 of the 91 obstructed patterns were of type B and only 6 of type C.

Of the 15 patients examined before and after prostatectomy, 14 had plots of pattern B and 1 of pattern C before operation. After operation 13 showed the unobstructed pattern A and 2 showed evidence of slight residual obstruction, pattern B.

Comparison with Clinical Assessment

These pre-operative and post-operative results are compared graphically in Figure 4 with the clinical assessment, which is based on symptoms, signs and urodynamic criteria different from those described here (Abrams, 1976, 1977b; Abrams *et al.*, 1977). For each patient's micturition (selected arbitrarily, if there was more than one similar micturition) a point is plotted showing the maximum flow rate and the detrusor pressure at maximum flow. The symbols show whether the 2 assessments agree that there is obstruction (triangles) or no obstruction (circles), or whether there is doubt in either assessment or disagreement between them (squares). As one would expect, there is agreement in virtually all the clear-cut cases (high pressure with low flow rate or low pressure with high flow rate), and nearly all the doubtful cases fall in a borderline region of moderate to low detrusor pressures and flow rates.

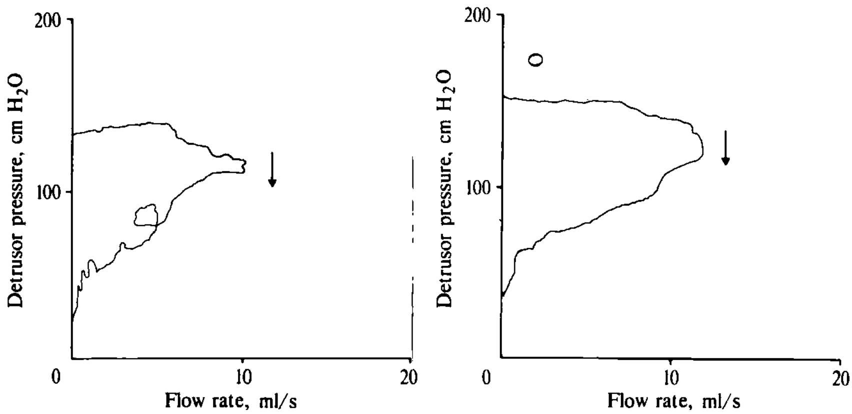

Fig. 3 Pressure/flow plots for 2 micturitions of one patient. (a) before treatment; (b) 6 months later, with no intervening surgery. Both plots show the obstructed pattern B.

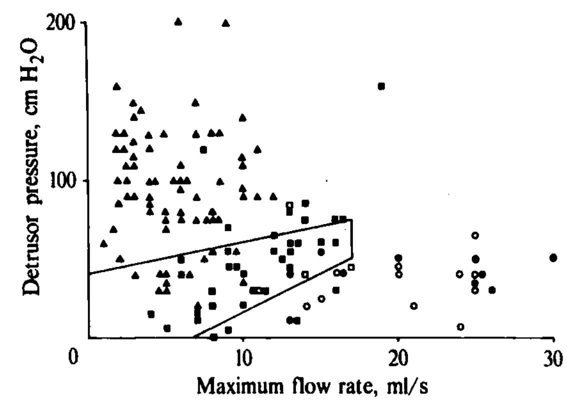

Fig. 4 Comparison between the assessments of obstruction by 2 independent means, namely clinically and from the pressure/flow plots, for pre-operative micturitions of 102 males and for pre-operative and post-operative micturitions of 15 males. Each micturition is represented by a point showing the maximum flow.

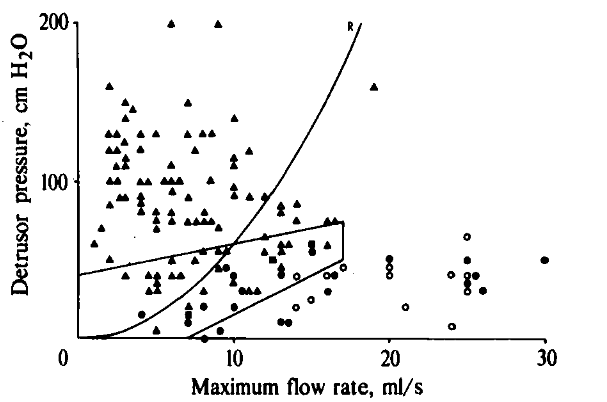

Fig. 5 The result of assessing obstruction by the pressure/flow plots alone, for the same micturitions as in Figure 4. The region enclosed by straight lines is a borderline region where obstructed and unobstructed cases are, or could in principle be, intermingled. All points falling on the curve labelled R have a urethral resistance factor (p_{det}/Q_{max}^2) of 0.6 cm $H_2O/ml^2\ s^{-2}$.

When the results of the urodynamic assessment of the pressure/flow plots are plotted without reference to the clinical assessment (Fig. 5), the number of "doubtful" cases is much reduced. A borderline region is still apparent, however, as an area on the graph where obstructed and unobstructed cases are mingled. The borderline region outlined in Figure 5 includes both this area and also, on the higher-pressure side, an area where mingling could in principle occur, according to the criteria used to classify the pressure/flow plots.

Discussion

Objective Assessment of Obstruction by Simple Criteria

Figures 4 and 5 show that many cases can be assessed reliably from a simple measurement of maximum flow rate (Q_{max}) alone. For example, if all cases with $Q_{max}=20$ ml/s or more are taken as unobstructed, and all with $Q_{max}=6$ ml/s or less are taken as obstructed, 49% of the unoperated results and 53% of the post-operative results can be classified. This classification agrees with that deduced from the pressure/flow plot in every case except one (98%).

If the detrusor pressure p_{det} at maximum flow is taken into account also, all the cases which fall outside the borderline region outlined in Figure 5 can be classified; that is, about two-thirds of the unoperated results and nearly all of the post-operative results. This still leaves a substantial proportion of cases unclassified, however, and these can only be assessed objectively from the complete pressure/flow plot.

It is common to combine Q_{max} and p_{det} into a single urethral resistance factor, e.g. p_{det}/Q_{max}^2 (Smith, 1968). In Figure 5, a curve corresponding to a constant urethral resistance factor of 0.6 cm $H_2O/ml^2\ s^{-2}$, calculated according to this formula, is shown. Obviously it separates the clearly obstructed from the clearly unobstructed patient. However, the resistance factor cannot distinguish between cases in the borderline region. Moreover, it fails to show whether a case falls in the borderline region or not, and so confuses clear-cut and doubtful cases. For example, among the cases in Figure 5 with a urethral resistance factor near 0.6 cm $H_2O/ml^2\ s^{-2}$, there are some outside the borderline region which are certainly obstructed and some within the borderline region which are not obstructed, as well as some which are. Resistance factors calculated from other formulae have similar disadvantages. Therefore they are not helpful in practice, just as they are not valid in theory (Griffiths, 1973). It is better to assess obstruction from the maximum flow rate and the detrusor pressure at maximum flow separately, perhaps by plotting them graphically as in Figure 5, in order to see whether they fall in the obstructed, unobstructed or borderline regions.

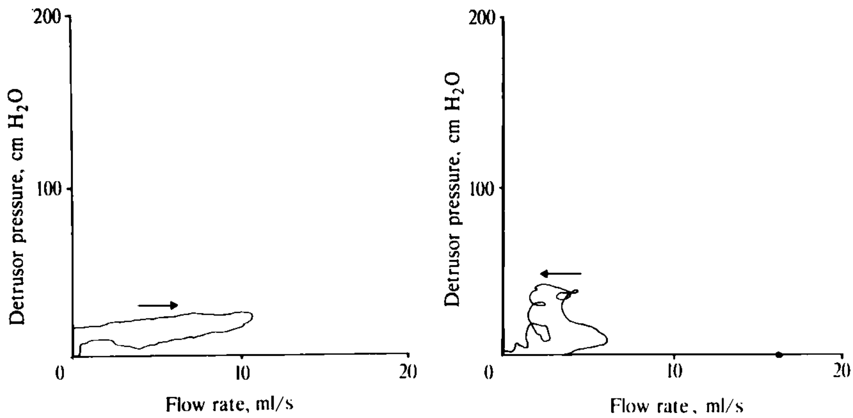

Fig. 6 Pressure/flow plots for 2 different unoperated males in the borderline region of Figure 5. Both have low pressures and low flow rates, yet (a) has the unobstructed pattern A, while (b) has the obstructed pattern B.

Cases in the borderline region can then be looked at more carefully, by means of the pressure/flow plot.

Low-Pressure, Low-Flow Cases in the Borderline Region

Figures 6a and b show the pressure/flow plots of 2 unoperated cases falling in the borderline region of Figure 5. They are not readily distinguishable on the basis of Q_{max} and p_{det} but, as judged from their patterns, Figure 6b is obstructed and Figure 6a is not. In both cases the voided volume was sufficient to ensure that the low flow rate was not unrepresentative, and this is known also from a preliminary flow-rate check before the urodynamic examination. Presumably the low flow rate in Figure 6a is due to a reduced contractile power of the bladder muscle. In Figure 6b the low flow rate again occurs at relatively low pressure, despite the evidence of obstruction, again suggesting a reduced bladder contractile power. A measure of the mechanical power developed by the bladder at maximum flow is $Q_{max} \times p_{det}$. For example, a normal flow rate of 25 ml/s at a normal detrusor pressure of 40 cm H_2O would correspond to a power of 1000 cm H_2O ml/s, *i.e.* 100 mW.

Six of the cases which fell in the borderline region before operation were examined again after operation. Post-operatively all had increased maximum flow rates. The average power at maximum flow was 17 mW pre-operatively, while it rose to 57 mW after operation, an increase of 240%. Individually the changes in power ranged from −20 to +1400%.

Nine cases which before operation were definitely obstructed, not in the borderline region, were examined again post-operatively. All were urodynamically improved by operation as judged from their pressure/flow plots (cf. Fig. 2). For these the average power at maximum flow changed from 70 mW before to 80 mW after operation, an increase of only 14%. Individually the changes ranged from −60 to +170%.

It therefore appears that prostatectomy has a relatively small effect on the bladder power in clearly obstructed cases, but that in the borderline low-pressure, low-flow cases its main effect is, paradoxically, to raise the bladder power to a more normal value.

Residual Urine

The observation of residual urine is commonly taken as a sign of obstruction. Of the 117 unoperated cases examined, 77 (66%) had residual urine of 50 ml or more (mean value used if more than one measurement). The average residual urine was 116 ml. These figures are much higher than those for the normal population (Hinman and Cox, 1967), apparently confirming the association of residual urine with obstruction. However, among the 21 unoperated cases classified urodynamically as unobstructed, 11 (52%) had residual urine of 50 ml or more and the average volume was 74 ml. In this series, therefore, the association with obstruction is rather weak, as was found also by Turner-Warwick *et al.* (1973).

One may therefore ask: is the urethral obstruction the immediate cause of the residual urine? That is, is the detrusor pressure demanded by the obstructed urethra so high that a normally functioning bladder could not empty through it? Or is the cause an abnormality of bladder function, possibly secondary to urethral obstruction? The residual urine is left in the bladder at the end of voiding and therefore, if the high pressure demanded by the urethra is its immediate cause, it is the detrusor pressure at that moment that should be examined. Many obstructed patients have pressure/flow plots of pattern B (Fig. 1b) in which the detrusor pressure at the end of voiding is much lower than that at maximum flow. The pressure and urethral resistance at this moment in fact differ little from those in an unobstructed case (Fig. 1a). Therefore a normally functioning non-decompensating bladder could certainly empty to completion through these obstructed urethras.

In order to confirm this observation quantitively, the association between the volume of residual urine and the detrusor pressure measured as flow ceases at the end of voiding has been examined. A significant positive correlation would provide evidence that the pressure demanded by the urethra was important in determining the volume of residual urine. In fact, for the 117 unoperated patients, the correlation coefficient was only 0.15, which was not significantly different from zero at the 5% level. (For comparison, the coefficient of correlation between the volume of residual urine and the maximum flow rate is −0.45, significant at the 1% level.)

This evidence implies that residual urine is not the direct, mechanical result of urethral obstruction but is the sign of an abnormality of bladder function, such that the bladder ceases contracting adequately before it is empty (decompensates). This view is consistent with that of Turner-Warwick *et al.* (1973) that residual urine can be a sign of bladder failure, secondary to outlet obstruction. However, it sometimes occurs in the absence of outlet obstruction.

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