Analysis of pressure-flow data in terms of computer-derived urethral resistance parameters

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Summary. The simultaneous measurement of detrusor pressure and flow rate during voiding is at present the only way to measure or grade infravesical obstruction objectively. Numerous methods have been introduced to analyze the resulting data. These methods differ in aim (measurement of urethral resistance and/or diagnosis of obstruction), method (manual versus computerized data processing), theory or model used, and resolution (continuously variable parameters or a limited number of classes, the so-called nomogram). In this paper, some aspects of these fundamental differences are discussed and illustrated. Subsequently, the properties and clinical performance of two computer-based methods for deriving continuous urethral resistance parameters are treated.

Consensus exists that infravesical obstruction can be diagnosed urodynamically only from simultaneous measurements of the detrusor pressure and flow rate during voiding, a pressure-flow study. In extreme cases the diagnosis is straightforward. If patients have a very high maximal flow rate and a very low detrusor pressure, they are obviously unobstructed. If they have a very low flow rate and a very high detrusor pressure the patients are obstructed [2]. In the great majority of cases, i.e., patients with moderate flow rates and/or moderate pressures, patients with low flow rates and/or low pressures, or patients with high flow rates and high pressures, such a simple, direct diagnosis is not possible. In such cases, methods of quantifying or grading the urethral resistance, or the degree of obstruction, of the patient can favorably be used.

Several different kinds of such methods have been developed. All these methods are based on pressure-flow data that are somehow manipulated to derive one or more parameters that represent urethral resistance and/or classify the pressure/flow data into one of a limited number of classes. The methods differ in a number of aspects: they are based on different models and/or on different data-processing techniques (automatic/computerized versus manual), have different aims (e.g., measurement of urethral resistance and/or diagnosis of obstruction), and have a different resolution, i.e., the smallest change in urethral resistance that can be detected is different.

In this article, some introductory remarks are made on the different models that are used, on urethral resistance factors, and on the required resolution for different aims. Subsequently, two methods for deriving urethral resistance factors and some examples of the clinical application of these methods are discussed in detail. Both of the methods imply computerized data processing. Finally, some statistics are applied to the criteria for selection of patients for pressure-flow studies.

Models used for calculating urethral resistance parameters

Most simply, the bladder outlet during voiding can be modeled as a hole in the urinary bladder [21]. In such an oversimplified case the relation between the detrusor pressure and the flow rate through the hole during voiding would be quadratic. The "classic" urethral resistance factor p/Q^2 [14] is based on this theoretical relation. Practical measurements, however, hardly ever show a simple quadratic curve. Figure 1 shows a typical example of a pressure-flow plot. The lowest pressure values at each flow rate represent the most relaxed state of the urethra and, thus, the best estimate for the degree of "anatomical" obstruction. Hereafter, these lowest values are referred to simply as the pressure flow data or the pressure-flow plot.

A simple quadratic curve is not applicable to the data shown in Fig. 1, as the curve does not pass through the origin [12]. This is the case because the urethra is not a hole in the bladder wall but a complicated structure that must be described as a flexible collapsible tube. A certain minimal pressure is needed to open this collapsed tube and keep it open during voiding. The terminology used for this minimal pressure is very confusing. Throughout this paper it will be called the theoretical urethral opening pressure, and in Fig. 1 it is in the order of 30 cmH₂O. Taking into account a nonzero theoretical urethral opening pressure, a theoretical pressure-flow relationship can be derived as shown fitted to the data in Fig. 1. This has been called the passive urethral resistance relation (PURR)
Fig. 1. A typical example of a pressure-flow plot, fitted with a quadratic pressure-flow relation with additive theoretical urethral opening pressure.

Fig. 2. An example of a pressure-flow plot that cannot adequately be described by a quadratic pressure-flow relation.

[20]. Although this relation accounts for opening of the urethra, it is nonetheless based on rigid pipe hydrodynamics: as long as the urethra is open, it has a constant cross-sectional area. In reality this is usually not the case. The urethra is an elastic structure, and its cross-sectional area depends to some degree on the pressure. As a consequence, pressure-flow plots often have a shape that cannot adequately be described by the quadratic relation shown in Fig. 1. Figure 2 shows an example.

Taking a pressure-dependent change in the cross-sectional area of the urethra into account, it is possible to model the urethra as an elastic collapsible tube [3]. Such a model results in a pressure-flow relationship that is not quadratic but has a variable shape depending on the elasticity of the urethra [23]. In a subsequent section of this article we demonstrate that for the determination of one practical, combined urethral resistance parameter this model has drawbacks as a result of its statistical properties. Therefore, an alternative model with favorable statistical properties has also been proposed, an orthogonal polynomial model [7]. Using this model it was found that on average, pressure-flow plots can best be modeled in terms of the average height (of the lowest pressure values at each flow rate) and the average slope (of these values). Figure 3 shows a straight line based on these values superimposed on the data. This line does not ideally "fit" the data (as compared with other possible curves) but represents the only two properties (average slope and height) that can reliably be determined in the average patient.

Urethral resistance parameters

When the mathematical relations or models described in the previous section are used to characterize the pressure-flow data measured in patients, a number of parameters result that define the fitted curve. The quadratic PURR curve (Fig. 1) is defined by two parameters: the theoretical urethral opening pressure, or the pressure at which the fitted curve intersects the pressure axis, and its steepness (in the references cited, only the theoretical urethral opening pressure is used as a parameter). The collapsible tube model [23] is defined by a comparable theoretical urethral opening pressure, a steepness, and a shape factor, or exponent m. The orthogonal polynomial model is defined by a number of parameters, depending on the number of terms included in the model; in Fig. 3, two terms were used, resulting in a curve defined by its average height and average slope.

In theory, the parameters listed for the various models can directly be used as urethral resistance parameters. A problem is that it is unclear how patient measurements should be compared and how, for instance, improvement or deterioration should be concluded if urethral resistance is defined in terms of a set of parameters. This can be illustrated using the study described below [13].

Application of the orthogonal polynomial model to alpha-blocker data

In 32 patients, 3 pressure-flow studies were done before treatment and 3 studies were conducted after 4 weeks of treatment; 16 patients were treated daily with 4 mg of an alpha-blocker, doxazosin, and 16 patients received a placebo. The study was randomized and double-blind. The digitally stored pressure-flow data were processed using the software packages MATLAB, QPRO, PARADOX,