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Review Article

Urodynamics of the Lower Urinary Tract

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Summary. The principles and techniques of uroflowmetry, cystometry, pressure-flow studies and urethral pressure profilometry are reviewed. The interpretation of urodynamic tests depends on the methodology used and whether the patients usual voiding symptoms during the examination. The more complicated urodynamic tests may require computer assistance both for data storage but also for test interpretation. One of the main challenge in future urodynamic is to transform these tests to clinical usable tools.

Key words: Urodynamic – Lower urinary tract – Techniques – Methodology

Table 1. Techniques for urine volume and flow rate measurement

Principle	Manufacturer
Balance (weight)	Browne, Life, Siemens
Dipstick (galvanic)	Ely, Wolf, Lectromed
Rotating disc	Dantec
Air displacement	Neomedix
Hot wire	
Drop spectrometry	
Radioisotope clearance	
Electromagnetic	
Hydrostatic pressure	

Introduction

Urodynamic studies are employed to measure and record events during a voiding cycle to gain information about the pathophysiology of micturition. This broad definition encompasses all the various tests available such as uroflowmetry, cystometry, urethral pressure profilometry, pressure-flow study, electromyography (EMG) and voiding cysto-urethrography. A full review of these tests and their interpretation in the different pathological states is beyond the scope of this paper. We will focus on a description of the techniques and equipment used in uroflowmetry, cystometry, pressure-flow studies, and urethral pressure profilometry since these are the routinely used screening procedures. The problems of correlating test results to clinical practice will be discussed. The urodynamic definitions and terms as proposed by the International Continence Society [9] will be followed.

Uroflowmetry

Drake constructed the first uroflowmeter in 1948 [21], but uroflowmeters were not commercially available until the early 1960's. Nine different methods for measurement of the voided volume and flow rate have been described but the commercially available flowmeters are based on only 4 of these principles; rotating disc, galvanic dipstick, balance weight and air displacement (Table 1). However, some of the other methods deserve comment since they are interesting from an experimental viewpoint.

Early Flowmeter Models

Zinner et al. [53] developed the drop spectrometer based on the observation that the urine stream is split up in droplets shortly after leaving the external urethral meatus [54]. Two systems, each consisting of a light source and a photosensitive receiver composed of several photo cells, were placed horizontally 1 cm apart. A recording system was connected to the photo cells. When a stream was directed into the light rays the velocity of a drop falling the distance between the two light beams could be calculated by the time difference between the first and the second pass. The volume was calculated by computing the size of each individual drop measured by the number of photo cells activated during passage. Despite the theoretical advantages of this equipment such as precise dynamic interpretation of urination, its clinical use is limited since the technique involved requires methiculous calibration.

Flow measurement by the hot wire method relied on the electrical power needed per unit time to keep a coil which heats a wire at a constant temperature. The patient urinates in a container and as the urine level rises the hot wire will gradually be submerged and lose heat to the fluid. The electrical energy necessary to keep the temperature of the wire constant at a certain preset level indirectly gives the volume voided and the flow rate. The electromagnetic method is similar to the hot wire principle but instead of change in heat a change in conductivity caused by passage of variable volumes of urine containing electrolytes is measured. However, neither of these techniques became popular probably because they are less accurate and prone to error from improper calibration.

Winter described a method for estimating uroflow and voided volume by using a dilution principle based on radioisotopes injected intravenously or given orally [49]. A counter chamber was placed over the sacral bone corresponding to the posterior aspect of the bladder and by counting the decrease in radioactive intensity, as the bladder emptied, flow rate and voided volume could be calculated. One major disadvantage was the lack of a flow tracing and the need for special equipment such as a counter chamber and associated electronic recorder. In the hydrostatic technique the pressure increase in a fluid column connected to the collecting container is measured and correlated to flow and volume voided [48].

Modern Flowmeters

Three different principles, weight transducers, capacitance dipsticks and rotating discs, are used in the most popular flowmeters available today.

The weight transducer is the most widely employed. This transducer is placed in the bottom of a collecting container. The patient urinates into a funnel and the weight of the urine is calculated to give total volume voided and volume change per second equal to flow rate. These flowmeters have high durability and accuracy. In flowmeters using a rotating disc the decrease in rotational speed caused by the patient urinating on the disc correlates to the flow. The output from the motor rotating the disc is computed to give flow and voided volume. The capacitance dipstick method is based on the principle that the capacitance of a capacitor (metal strip) changes if it gets wet. The dipstick with a capacitor is placed on the inside of a container and as the patient voids the metal strip is gradually covered with urine. This decreases the capacitance which correlates to voided volume. Flow rate is calculated by differentiation over time. In addition to flow rate and voided volume, additional information such as voiding time, time to maximum flow rate, mean flow rate and total flow time may be displayed.

The accuracy of these flowmeters are in the range ± 1% to ± 5% which is sufficient for clinical use. However, most flowmeters have a time delay in recording the flow, averaging 1 second caused by the funnel collecting the urine [6, 23]. This may be of importance in pressure-flow studies where accurate timing of the flow/pressure events are crucial. The distortion of the stream as it hits the funnel will vary during voiding and the recorded flow pattern will be an approximation to the true flow [52]. Ask et al. [6] constucted a short-time-delay flow meter based on a rotating disc and weight transducer. A funnel was omitted and a delay of maximal 0.25 s was obtained resulting in a decrease in the distortion of the flow pattern. Likewise, the accuracy of flow rate and volume determination was improved in a flowmeter described by Best et al. [10]. The collecting bottle was connected to a pressure transducer through an air filled sidearm on the bottle. An accuracy of 1% was achieved.

Technique of Flow Rate Measurement

Ideally a flow rate determination should be a spontaneous voiding event in environs resembling the place where the patient usually urinates. This is seldom possible. Home flowmeters, where the patient is instructed to measure the voided volume and estimate a flow rate during 5 s [13], can only serve as a rough screening test but may be helpful in evaluating the patient's bladder-urethral function.

The importance of the voided urine volume for reliable and reproducible flow rate measurements has been known for several years. A correlation between these parameters was established by Siroky et al. [44] and a voided volume of at least 150 ml is generally considered necessary for obtaining an accurate measure of flow. It is tempting to catheterize and fill the bladder in those patients who are unable to void or who urinate insufficient volumes. If cystometry is done, it would be convenient to obtain a flow following this examination. However, after cystometry where the bladder is filled to capacity a decrease in mean flow of 48% was found in 1/3 of patients studied [33]. This may be explained by decreased bladder contraction on repeated filling either because of rapid filling rates in low-complicance bladders or because of over-stretching of the detrusor during cystometry [27]. Likewise, the size of the catheter used for filling the bladder may have an influence on the flow rate especially in patients with bladder outlet obstruction, while patients with no apparent obstruction might show no change in flow rate [39].

It is difficult to list normal values for maximum flow rates for various age groups because limited information is available especially in the older age groups (Table 2). The data published by Siroky et al. [44], which formed the basis for construction of the flow nomogram, was derived from 30 normal males aged 21–45 years while Drach et al. [20] study included only 7 males. In a study of 93 men, aged 50–92 years, with no symptoms suggestive of prostatism, the maximum flow rate showed a clear age-related decrease [30]. The use of a rigid lower limit for maximum flow rate e.g. 15 ml/s regardless of age (and volume voided) should be abandoned.

Table 2. Normal values for maximum urine flow rates for different agegroups of men [20, 30, 44]

Age (years)	Urine flow rate (ml/s)
< 40	> 22
40–60	> 18
61–70	> 14
71–75	> 12
76–80	> 10
⩾ 81	> 6

Table 3. CO_2-cystometry. Advantages and disadvantages

Advantages	Disadvantages
Fast, complete examination takes 2–3 min	Unphysiologic since pressure is exerted uniformly to the whole bladder
Clean	Gas leakage from tubings and urethra hard to recognize
	CO_2 local irritant of the urothelium
	Poor accommodation of the bladder volume to sudden fast filling
	Slow contractions of the bladder can go undetected due to damping

An isolated flow rate determination will seldom solve a diagnostic problem and the value of this investigation as opposed to clinical examination and symptom analysis in patients with bladder outlet obstruction has been debated [28, 29]. However, as a screening procedure prior to further urodynamic testing, a urine flow determination is an important preliminary investigation [2].

Cystometry

Several different techniques for simultaneous recording of bladder pressure and volume have been described and may complicate test interpretation. Comparison between results from various studies is made easier by the standardization proposed by the International Continence Society [9]. Four factors of special importance for the interpretation of cystometry include the position of the patient during the examination, the medium used for bladder filling, the rate and mode of filling, and the recording equipment employed.

In the clinical setting the patient is usually examined in the supine position and transurethrally catheterized. Unfortunately, this is unphysiological due to absence of the weight of the abdominal viscera on the bladder, and an examination with the patient standing or sitting should be included. This might be of special importance in female patients if cystometry is indicated to differentiate between stress and urge incontinence [5, 36]. If changing of position during the examination is impossible, repeated coughing, Valsalva or straining should be performed. A catheter in the urethra introduces a second substantial artifact.

The choice between water and gas (CO_2) cystometry should not be difficult to make. Several factors speak in disfavor of CO_2 cystometry (Table 3). First, CO_2 is compressible and important pressure rises caused by uninhibited detrusor contractions may be lost [22]. Typically, a gas cystometry tracing is blunted compared to water cystometry due to damping of the response. If one is aware of the limitations of gas cystometry, it may serve as a fast screening procedure to find patients that need more refined diagnostics by water-fill cystometry.

Three filling rates; slow (< 10 ml/min), medium (between 10 and 100 ml/min) and fast (> 100 ml/min) can be used in cystometry. Slow filling or even physiological filling of the bladder (allowing the urine to fill the bladder) [38] is, at least theoretically, a sound principle but impractical in a clinical setting. Usually a medium filling rate between 50–80 ml/min is chosen and the results obtained by using the lower and upper limit of this range of filling rates compare favorably in one study to another [27, 38]. Rapid filling cystometry has been used experimentally and in a few clinical studies [35, 36] but to date the indications for its use have not been established. We found a poor correlation between medium and rapid filling cystometry in diagnosing uninhibited detrusor contractions in men with prostatism [35].

Like the rate, the mode of bladder filling (incremental or continuous) may impact on cystometry interpretation. Incremental filling of the baldder usually implies that the bladder pressure is allowed to stabilize between each partial filling. Low et al. [34] compared rapid rate incremental filling to medium rate continuous filling cystometry in 52 patients with unstable bladders. The continuous infusion was more sensitive than the incremental filling, the latter failing to diagnose unhibited detrusor contractions in 65% of the patients. This discrepancy might be explained by a greater ability of the detrusor to adjust to the increased volume between the fillings, thus decreasing the tendency for spontaneous, involuntary contractions. However, different recording systems were used during the two cystometry measurements so direct comparison is only possible with some restrictions. That bladder contractility changes after repeated cystometrography with filling rates < 90 ml/min was found in a study by Jensen [27], and a minimum period of 20 min between fillings was established as necessary to obtain reproducible and reliable cystometrograms.

The usual transurethral route for bladder filling and pressure measurement during water cysteometry may influence the recording in several ways. Specially designed two- or three-way urodynamic catheters are available but often a Foley catheter is used for filling and a small diameter plastic tube (5–8 F) for pressure recording. The distal 2–3 cm of the pressure catheter should preferably have multiple side holes to prevent false recordings due to obliteration of the holes by bladder mucosa or lubricant. The reference point during cystometry is, by definition, the superior edge of pubic symphysis. Even after calibrating the pressure transducer using this reference point, a false reading caused by inappropriate positioning of the pressure catheter in the proximal urethra may invalidate the examination. A 2-way catheter with an inflatable balloon may prevent this bias by keeping the catheter tip in the bladder. However, this introduces another potential source of error since an inflated catheter balloon may trigger uninhibited detrusor contractions if the investigator pulls the catheter balloon tight against the bladder neck. Colstrup et al. [17] found a 70% incidence of detrusor instability when the balloon on a Foley catheter used for filling was inflated while the incidence fell to 43% when the balloon was deflated. Suprapubic insertion of catheters for clinical cystometry is rarely used in the United States but has the advantages of avoiding stimulation of the urethra-bladder neck region and allowing urination through a non-catheterized urethra, thus obtaining physiologic pressure-flow studies.

Water-filled tubes connecting the bladder to the pressure transducer can cause artifacts and false reading due to breakage, leakage, kinking, and movement of the tubes. Air bubbles in the pressure lines damp the pressure transmission as do long tubes, tubes other than high pressure tubes, and differences in lumen between pressure catheters. Microtip transducer catheters offer some advantages especially if a transducer catheter with a lumen for bladder filling is used since only one catheterization is necessary to obtain a cystometrogram. While sharing none of the potential sources of artifacts described for the water-filled pressure lines, the positions of the tip transducer in the bladder is a source of error. If the tip is placed in the top of a full bladder, a lower pressure will be recorded than if the tip is in the bottom of the bladder, typically a difference of 5–10 cm water. However, the major disadvantages are the high price, the relative fragile construction and the fact that calibration of the transducer should be done using 37 °C warm fluid because the response of the transducer is temperature dependent. Another type of microtip transducer, the fiberoptic transducer, is less susceptible to damage [32]. These transducers are made of two fiberoptic bundles connected at the tip by a pressure-sensitive membrane. Light is directed against the reflecting backside of the membrane through one bundle and due to deformation by pressure the membrane will change the direction of the light rays. This light deflection is transmitted through the other fiberoptic cable and electronically transformed to give a pressure reading. Though described 5 years ago the fiberoptic transducers have not gained widespread popularity.

Pressure-Flow-Studies

The indication for and interpretation of simultaneously registration of intravesical pressure and flow rate is still a matter of much debate probably because of earlier attempts which applied numerous mechanical principles in explaining the bladder urethra relationship [14, 45]. Calculation of a urethral resistance coefficient based on the assumption that the urethra acts like a rigid tube is a case in point [16]. Griffiths [24] and Schäfer [43] analyzed the complex relationship between pressure and flow and concluded that a simple equation with a static expression of urethral resistance has little physiologic correlation. Of special interest in this discussion, is the data on the effect of different calibers of transurethral catheters on the pressure-flow recording. Ryall found only small reductions in flow rates using a 6 F transurethral catheter [42], while Anikwe reported no changes [4]. However, most authors agree that a transurethral catheter above the diameter of 6–7 F does influence the flow rate [40, 49, 50]. This seems to be an important cause of error but Griffiths found that the decrease in flow rate caused by a transurethral catheter could be used to find patients with a subtle bladder outlet obstruction [24]. In fact, by using a suprapubic access for pressure recording when doing pressure flow studies, important information may be lost.

There is no general agreement on the interpretation of the pressure rise when partly or completely obstructing the baldder outflow at maximum flow rate. This peak pressure termed P_{iso} for isometric bladder contraction reaches high levels in patients with hypersensitive bladders and in bedwetters and may represent irritability of the bladder. Usually P_{iso} is measured during a voluntary interruption of the stream, but it can be approximated as a stop test by pulling down on an inflated catheter balloon to the bladder neck level [19]. However, this stimulation of the bladder neck area may in itself cause artifacts [17].

Urethral Pressure Profilometry

The International Continence Society defines urethral pressure profilometry as the intraluminar pressure along the length of the urethra with the bladder at rest. The classical method for obtaining a pressure profile is the procedure described by Brown and Wickham in 1969 [15]. In this technique an 8 F catheter with 2 side holes 5–10 cm apart is retracted at a constant speed of 0.5 cm/s while perfusing the catheter with 1.66 ml/min of 0.9% saline. The patient is examined in the supine position with an empty bladder. Like all other urodynamic tests, several modifications have been described. Transducer catheters like a 6 F double transducer catheter, 1 situated in the bladder, the other at the external sphincter [10], or a 10 F triple lumen catheter where the extra lumen can be used for bladder filling [12], or 8 F water-filled double lumen catheter connected to external pressure transducers [7] have been employed. Perfusion of the urethra has been performed at inconsistent rates; e.g. 0.7 ml/min [47], 1 ml/min [7] or 2 ml/min [36]. In addition, the speed of catheter retraction is subject to wide variation from manual pullout at „low speed“ [31] through withdrawal machines set at 0.5 cm/s [15] and 1 cm/s [37] to gradual pull through at 1/2 cm intervals, pausing for pressure stabilization. It is difficult to evaluate the importance of these differences in methodology on the test results because comparative studies are lacking, but is seems important to keep rate of withdrawal below 0.5 cm/s and perfusion rate above 1 ml/s; otherwise the reproducibility and accuracy of the test is low. A saw-tooth appearance of the profile is typical if withdrawal speed is higher and perfusion rate lower than these parameters [1]. Besides the classical Brown and Wickham technique or the perfusion method, 2 other techniques of static urethral pressure profilometry; the balloon catheter and the tip transducer can be used. Both give comparable, reliable results but the calibration of the balloon catheter and the orientation of the transducer membrane are potential sources of error.

An urethral pressure profile performed during stress gives more information about the closure mechanism of the urethra [3]. A transducer catheter with 2 transducers spaced sufficiently apart so that simultaneous bladder and urethral pressure will be recorded, can be employed. Usually a slow-pull-through speed of 0.1 cm/s is chosen to allow accurate recording of the pressure changes. Urethral pressure measurement during bladder filling and voiding, the dynamic urethral pressure profile, has provided additional information on the physiology of voiding [8, 41] but recommendations on the interpretation of the test vary.

First of all, a proper understanding of the relationship between dimension of the urethra and the pressure is needed. Colstrup [18] used a specially designed catheter which allowed for variation of the lumen of the urethra and simultaneously recording of the intraurethral pressure at 0.5 cm intervals. In the resting female urethra a zone with high pressure and low capability for contraction could be differentiated from a low pressure zone with high contractibility. The application of this information to female incontinence is interesting but the technique is not yet available for clinical use.

Urodynamic Test Interpretation

The tendency to use more sophisticated urodynamic tests bears the risk of obtaining results that either are difficult to understand and explain or have no clinical value [25]. Katz and Blaivas [31] clinically evaluated 425 patients, and divided them in 3 groups according to type of voiding dysfunction. Following extensive urodynamic testing, including synchronous video/pressure/flow/electromyography, the authors found correlation between clinical and urodynamic diagnosis in 53% of the patients. The poorest correlation (46%) was found in patients with storage and emptying problems while patients with emptying problems showed correlation between clinical and urodynamic diagnosis in 75% of the cases. However, some of this descrepancy between history and urodynamics can be explained by the fact that among patients with acute urinary retention, 1/3 of the patients do not give a history of prior obstructive symptoms.

The importance of reproducing the patients usual symptoms during the urodynamic investigation has been stressed by several authors [31, 25], but it can be difficult to obtain an impression of the bladder-urethra function in the urodynamic laboratory when the patient has 1–2 transurethral catheters inserted in the bladder, a pressure catheter in the rectum, EMG electrodes in the anal sphincter and surrounded by high-tech equipment and an examiner. Attempts have been made to reproduce the physiological situation by natural test circumstances using continuous monitoring of bladder and urethral pressure by telemetry [11, 26]. Unfortunately, 1 important factor is lacking; the person who will do the interpretation is not present during the test thereby decreasing the chance of correct evaluation.

The amount of information gathered during more extensive urodynamic testing is impressive and has nourished the idea of employing data storage and processing on computer files [10, 39]. Especially when comparison between, for example, pre- and posttreatment examinations is warranted, easy access to the data is available.

Clinical urodynamic study is a discipline where a growing number of more complex techniques are periodically introduced. Despite this only a limited number of clinicians utilize these studies and believe that useful information is provided by them. To change that conception is the greater challenge facing urodynamic advocates.

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