Chapter 1
Urodynamic Studies: Types and Indications

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Introduction

The origin of the word "urodynamics" dates back to 1954, when David Davis used this term while presenting work on upper tract pressure and renal injury [1]. Since that time our understanding of the urinary tract, the equipment used to test, and even the definition of urodynamics (UDS) has expanded significantly. Now "urodynamics" refers to a collection of tests that aim to provide the clinician information about the lower urinary tract during bladder filling/storage and emptying [2].

There are numerous conditions and diseases that affect the lower urinary tract and disrupt the storage and/or evacuation of urine. This can lead to bothersome symptoms (e.g., urinary incontinence or pain from failure to empty) or, in some cases, potentially harmful sequela. Depending on the complexity of the symptoms, condition, or patient, varying degrees of precision may be required to assess urine storage and emptying to optimally treat patients. UDS is the dynamic study of the transport, storage, and evacuation of urine. It is comprised of a number of tests that individually or collectively can be used to gain information about urine storage and evacuation. UDS involves the assessment of the function and dysfunction of the urinary tract and includes the actual tests that are performed (UDS studies) and the observations during the testing (UDS observations) [3, 4]. The actual UDS studies chosen will depend on the amount of information and degree of precision required to comfortably treat a patient.

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UDS are considered an interactive diagnostic study of the lower urinary tract [5]. The clinician should be using these "tests" to answer a specific question (or questions) about normal function and/or dysfunction. The clinician needs to first understand the tools that make up UDS, so that the appropriate evaluation can take place. We follow three important rules before starting the UDS evaluation [6]:

1. Decide on questions to be answered before starting a study.
2. Design the study to answer these questions.
3. Customize the study as necessary.

Before the clinician can know what test to perform, a clear history and focused physical examination are needed. The more salient information the clinician has prior to testing, the more effective they can be at tailoring tests toward an individual patient. Frequency–volume charts or bladder diaries are very useful tools that help ensure that other urodynamic tests provide meaningful information. A bladder diary provides useful real life information of how often a patient voids, what his/her functional bladder capacity is, and on the volume of fluid intake and urine output. Correlation of UDS findings with a bladder diary can help to avoid errors of interpretation. This is especially important when one considers that UDS is preformed in an "artificial" environment where we try to obtain "real life" information.

There are three critical "good urodynamic practice elements" [7]:

1. Have a clear indication for, and appropriate selection of, relevant test measurements and procedures.
2. Ensure precise measurement with data quality control and complete documentation.
3. Accurately analyze and critically report results. *This includes interpreting UDS in the context of a patient's history and symptoms*.

It is important that the staff involved with patient preparation for UDS (especially invasive testing) is well trained, attentive, and supportive. The person performing the actual study, if different from the clinician ordering the study, should have a clear understanding of why the tests are being performed and what critical information is necessary. Finally, patients should be properly prepared and told why the test is being done, how the results may affect treatment, and what to expect during the actual UDS test.

Components of UDS

Post Void Residual

Post void residual (PVR) refers to the volume of urine left in the bladder immediately after voiding. It is one of the most basic and widely used urodynamic tests [8]. The PVR value can be obtained by ultrasound (bladder scan) and/or catheterization. The advantage of ultrasound is that it is less invasive and can usually be done promptly to avoid additional input from the upper urinary tract that occurs if there is a delay prior to obtaining a catheterized specimen [9]. The bladder scan has been shown to correlate well with urine volume obtained from catheterization in many, but not all patients [10]. A PVR should ideally be obtained immediately after a "normal" void. Forced voids (i.e., when a patient does not have a desire to void) can lead to falsely elevated PVR. There are some situations where obtaining or interpreting bladder scans can be difficult (i.e., significant abdominal ascites, obesity, large fibroids) and a catheterized PVR is favored.

Elevated PVR is suggestive of detrusor underactivity, bladder outlet obstruction, or a combination of both [5]. PVR alone cannot differentiate between the two. However, knowing that a patient does not empty completely may prompt further testing (see below), when it is important to determine the cause of the incomplete emptying. It is often difficult to determine what a "significant" PVR is and even the recently published AUA/SUFU UDS Guideline states that a definition of exactly what constitutes an elevated PVR has not been agreed upon [5]. However, urologists generally agree that in some patients, an elevated PVR may be harmful. Therefore, when considering what an elevated PVR is and whether or not it is significant, it must be considered in the context of a particular patient and his/her clinical presentation. Unfortunately, there is not a lot of high-level evidence that correlates PVR with treatment outcomes. PVR can be falsely elevated in some patients who may not empty completely in the clinic setting or who were asked to void without a normal desire. PVR may vary in the same patient and an elevated PVR should be confirmed with a second measurement, especially if treatment is being considered based on the elevation.

Uroflowmetry

Uroflowmetry, or uroflow is an objective way of "observing" the act of micturition [11]. Uroflow assesses the rate of urine flow over time. When possible this test should be done free of any catheters, in a private room at a time when the patient feels the "normal" desire to void [8]. This allows for the clinician to assess a "normal" void. Patients should also be asked if the void was representative of their usual toileting [12].

There are multiple data points that can be reported from non-invasive uroflowmetry. These include:

Voided volume (VV—mL)
Flow rate (Q—mL/s)
Maximum flow rate (Q_{Max}—mL/s)
Average flow rate (Q_{ave}—mL/s)
Voiding time (total time during micturition—s)
Flow Time (the time during which flow occurred—s)
Time to maximum flow (onset of flow to Q_{max}—s)

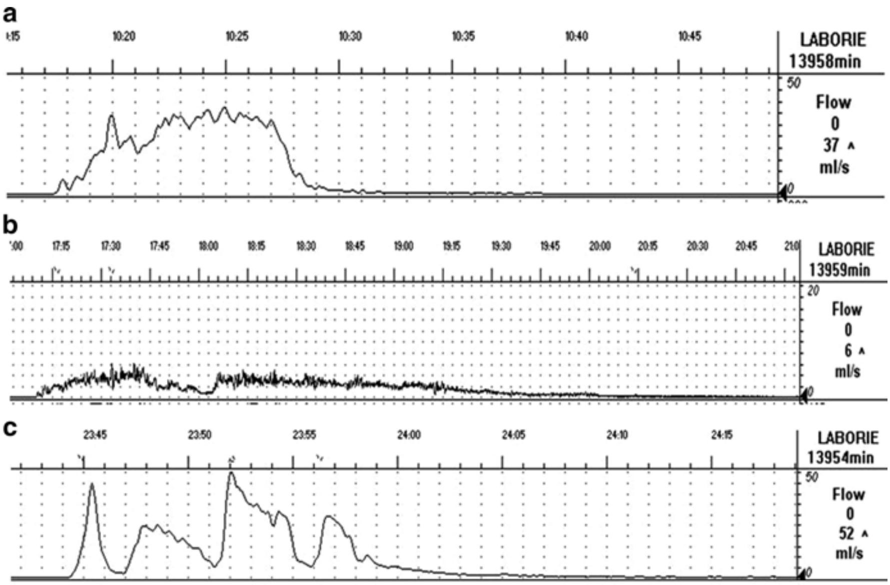

Fig. 1.1 Three examples of uroflow patterns: (**a**) Normal bell-shaped. (**b**) Obstructive pattern. (**c**) Straining pattern

In addition to these objective measurements, it is also important to observe the pattern or shape of the uroflow curve. A normal uroflow curve is bell-shaped (Fig. 1.1). Uroflow curve interpretation is somewhat subjective because of difficulty in qualitatively judging a pattern [11]. While certain patterns are suggestive of certain voiding dynamics (e.g., an interrupted or straining pattern with detrusor underactivity and a flattened pattern with a fixed obstruction) one cannot definitively identify specific underlying abnormalities without detrusor pressure data (see invasive pressure-flow UDS below).

It is helpful to obtain a PVR after completion of uroflowmetry in order to fully understand bladder emptying. In addition, bladder-emptying efficiency can be calculated using the formula: VV/(VV + PVR). Voided volume will have a large impact on flow rate and can lead to variability in an individual patient. It has been suggested that maximum flow rates are not meaningful at voided volumes of less than 150 mL because of the hyperbolic relationship that exists in men between the two variables (maximum flow rate and voided volume) [12]. However for patients who cannot hold 150 mL, obtaining an "accurate" uroflow can be impossible. In some patients uroflow with voided volumes of <150 mL may not have to be discounted, but interpreted with caution.

Today, most uroflowmetry equipment utilizes one of two transducer types. The first is based on weight. After setting the density of urine, the voided weight is measured and as this changes with time a flow rate is determined. The urine is voided into a container that sits on top of the weight transducer. The other method relies on a rotating disk. Here the voided urine is directed toward a spinning disk and alterations of the disk's speed (and the electrical energy needed to keep the disc spinning at a constant rate) are converted into electrical signals that represent flow rate [13]. Other methods of uroflow data collection are also available, but may have more limited practical application [14].

Abnormalities in non-invasive uroflow indicate that voiding phase dysfunction may exist. Figure 1.1 shows examples of an abnormal elongated flow curve and an interrupted/straining that suggest voiding phase dysfunction. However, uroflowmetry, like PVR, does not allow the clinician to determine the cause of an abnormality (e.g., if slow flow is secondary to outlet obstruction, detrusor underactivity, or a combination of both).

Electromyography

Pelvic floor muscles and the striated urethral sphincter both have a critical role in bladder storage and emptying. Electromyography (EMG) is the test that best evaluates these muscles. EMG is the study of electrical potentials generated by the depolarization of muscles [15]. In the setting of UDS, EMG is recording the motor unit action potential; this is the depolarization of the striated muscle fiber that occurs when the muscle is activated by the anterior horn nerve cell. Needle electrodes or surface electrodes can record the action potential. The quality of EMG has often been cited as variable or problematic because of a poor signal source. Needle electrodes are thought to be superior, however are often avoided because of patient discomfort and logistical difficulty [16]. The more commonly used surface EMG was described in 1980 to determine relaxation of the pelvic floor as an indirect measure of the simultaneous relaxation for the external sphincter [17].

EMG testing can be performed in isolation, however this test is usually combined with other UDS tests. As an isolated test, EMG can allow the clinician to assess the voluntary contraction of pelvic floor muscles, confirming that the corticospinal tract is intact and the cortical function required to initiate the contraction of the external sphincter is working.

Passive continence does not require external sphincter activity in most cases. However, there does exist a somatic passive guarding reflex that causes sphincter activity to increase as the bladder fills. Accurate measure with needle electrodes will often show a gradual increase in EMG activity with filling until a voluntary void is initiated. When using surface electrodes, one may not always see this pattern and may rather see a consistent signal. The EMG signal, assuming appropriate recording, should transiently increase if the patient performs a stress maneuver, i.e., straining or coughing (Fig. 1.2). When a voluntary void is initiated the first UDS evidence of this is relaxation of the external sphincter and a decrease in EMG activity (Fig. 1.2). This is then followed by an increase in detrusor pressure and initiation of flow. In a neurologically normal person, failure of the external sphincter to relax will result in inhibition of a detrusor contraction.

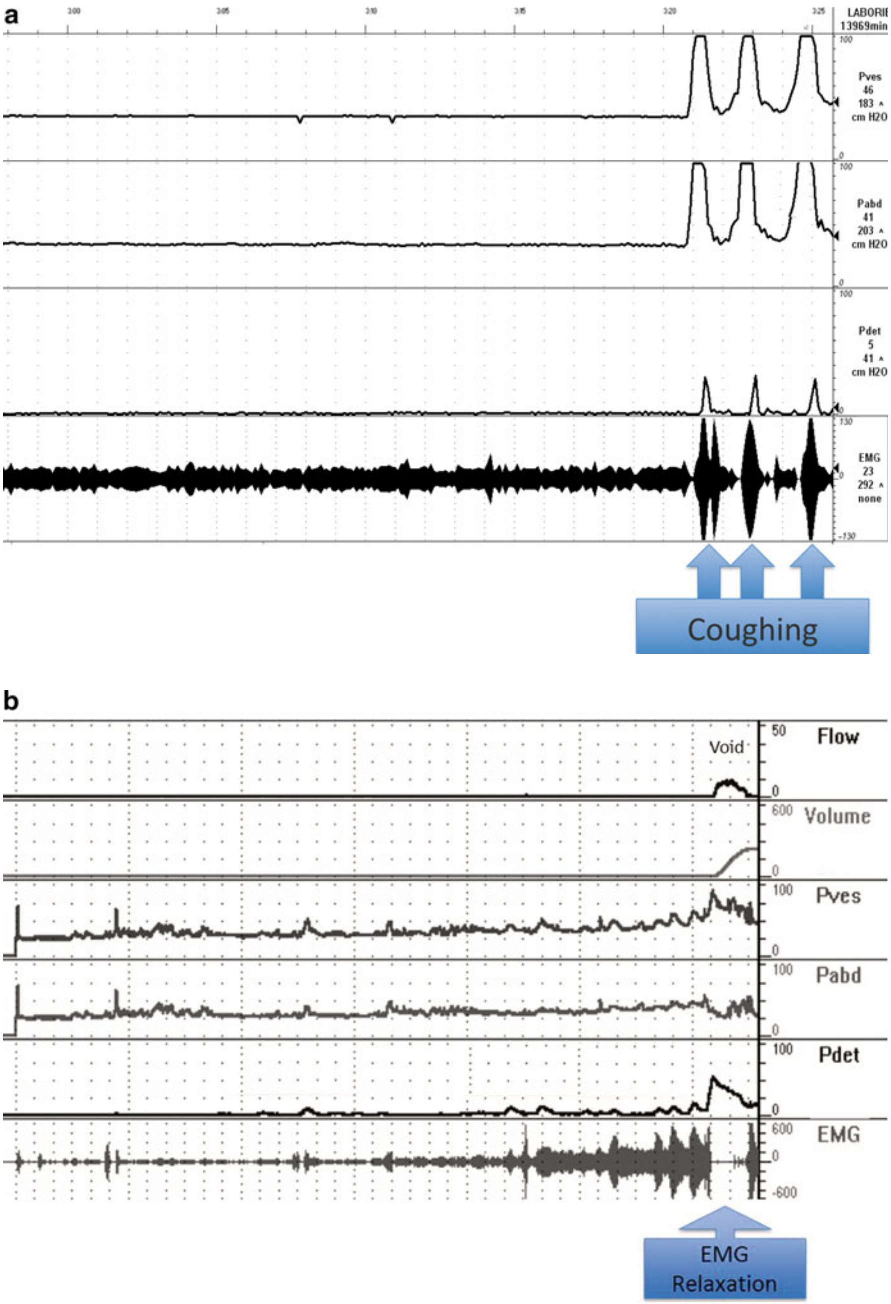

Fig. 1.2 Three examples of EMG activity: (**a**) Normal activity with increase due to coughing. (**b**) Appropriate relaxation of the EMG signal with voluntary voiding. (**c**) Increase of the external sphincter activity with voiding

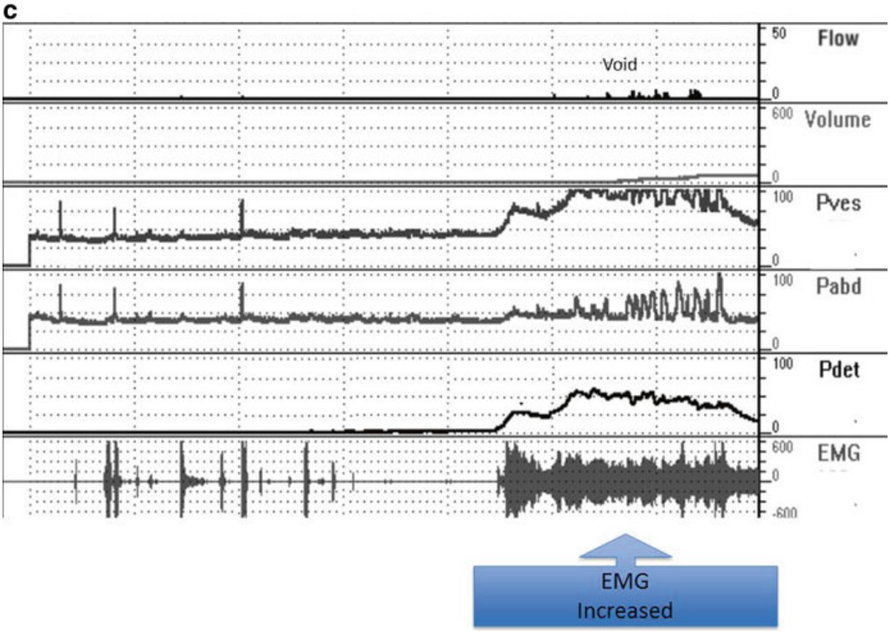

Fig. 1.2 (continued)

Normal EMG studies can lead to the exclusion of some diagnoses. However, the diagnostic utility is seen best in cases where it confirms neurological or functional causes of voiding phase dysfunction [5]. When not attributed to artifact, inappropriately increased EMG activity during the voiding phase is known as detrusor-external sphincter dyssynergia (DESD), when a neurologic lesion that can explain the dyssynergia exists (typically a suprasacral spinal cord lesion) (Fig. 1.2). When there is no underlying relevant neurologic lesion, the failure of external sphincter relaxation (or increasing EMG) leads to a diagnosis of dysfunctional voiding (a learned behavior of failed external sphincter relaxation during voiding). It is difficult to accurately predict when EMG information is going to be needed to explain voiding abnormalities. Thus, because of the relatively easy methodology and low morbidity of obtaining a surface EMG, EMG is often included as a channel in multichannel pressure-flow UDS studies [18].

EMG activity can also be increased during micturition because of external factors or artifact, sometimes called "pseudo-dyssynergia." This includes abdominal straining, movement, guarding reflex, painful urination due to the presence of a urethral catheter, and wet or dislodged electrodes [19]. The interpretation of the study therefore should include all other available information. For example, if fluoroscopy (discussed below) is obtained during voiding on studies where EMG contains artifacts, it may be used to discriminate between voiding patterns that would otherwise be differentiated by their EMG signals, i.e., dysfunctional voiding

(EMG activity is expected to be increased during voiding) and primary bladder neck obstruction (PBNO) (where EMG signal is expected to be quiescent) [7, 16]. Also, a completely normal uroflow (Q_{max}, Q_{ave}, and pattern) usually will exclude significant sphincter activity during voiding. EMG and/or uroflow abnormalities seen on invasive UDS should be confirmed with non-invasive uroflow.

Cystometry

The cystometrogram (CMG) assesses the bladder's response to filling. The CMG can measure filling pressure, sensation, involuntary contractions, compliance, and capacity. Sensation is the part of cystometry that is truly subjective and therefore requires an alert and attentive patient and clinician. The filling phase starts when filling commences and ends when the patient and urodynamicist decide that "permission to void" has been given. The CMG is ideally started with an empty bladder. The bladder pressure (P_{ves}) is monitored and fluid is infused into the bladder. This can be achieved using two separate catheters, or more commonly, a dual lumen catheter (usually 6–8 French) usually placed transurethrally (or much less commonly via a suprapubic stab incision). Guidelines exist regarding the technical specification of these catheters [7]. It is important to note that changes in bladder pressure can represent a change in detrusor pressure (P_{det}), for example from a bladder contraction voluntary or involuntary, or a change in abdominal pressure (P_{abd}), for example from movement, Valsalva, etc. Though single channel studies that monitor only P_{ves} can provide information about bladder function, the recommended method to measure bladder pressure includes simultaneously measuring P_{abd}, usually by placing a balloon catheter in the rectum or vagina. When both P_{ves} and P_{abd} are measured, the P_{det} can be calculated by using the equation: $P_{det} = P_{ves} - P_{abd}$.

In addition to recording pressures during filling, the CMG study also should record the volume infused into the bladder during filling. Filling rates [1], fluid temperature [7], and fluid type [8] all need to be considered. Today most cystometry is done with liquid (most commonly saline or radiographic contrast in cases where fluoroscopy will be used). The practice of gas CMG was historically described [20–22], and is rarely performed any longer as it does not allow for studying the voiding phase.

Normally detrusor pressure should remain near zero during the entire filling cycle until voluntary voiding is initiated. That means baseline pressure stays constant (and low) and there are no involuntary detrusor contractions (Fig. 1.3a). Involuntary bladder contractions can occur with filling and are seen as a rise in P_{ves} in the absence of a rise in $P_{abd.}$ Urodynamically, this phenomenon is known as detrusor overactivity (DO). DO may be accompanied by a feeling of urgency or even loss of urine (Fig. 1.3b). Another important parameter that the CMG measures is bladder compliance, the relationship between change in bladder volume and detrusor pressure. Normally the bladder is highly compliant and stores increasing volumes of urine at low pressure. However certain conditions may cause the bladder

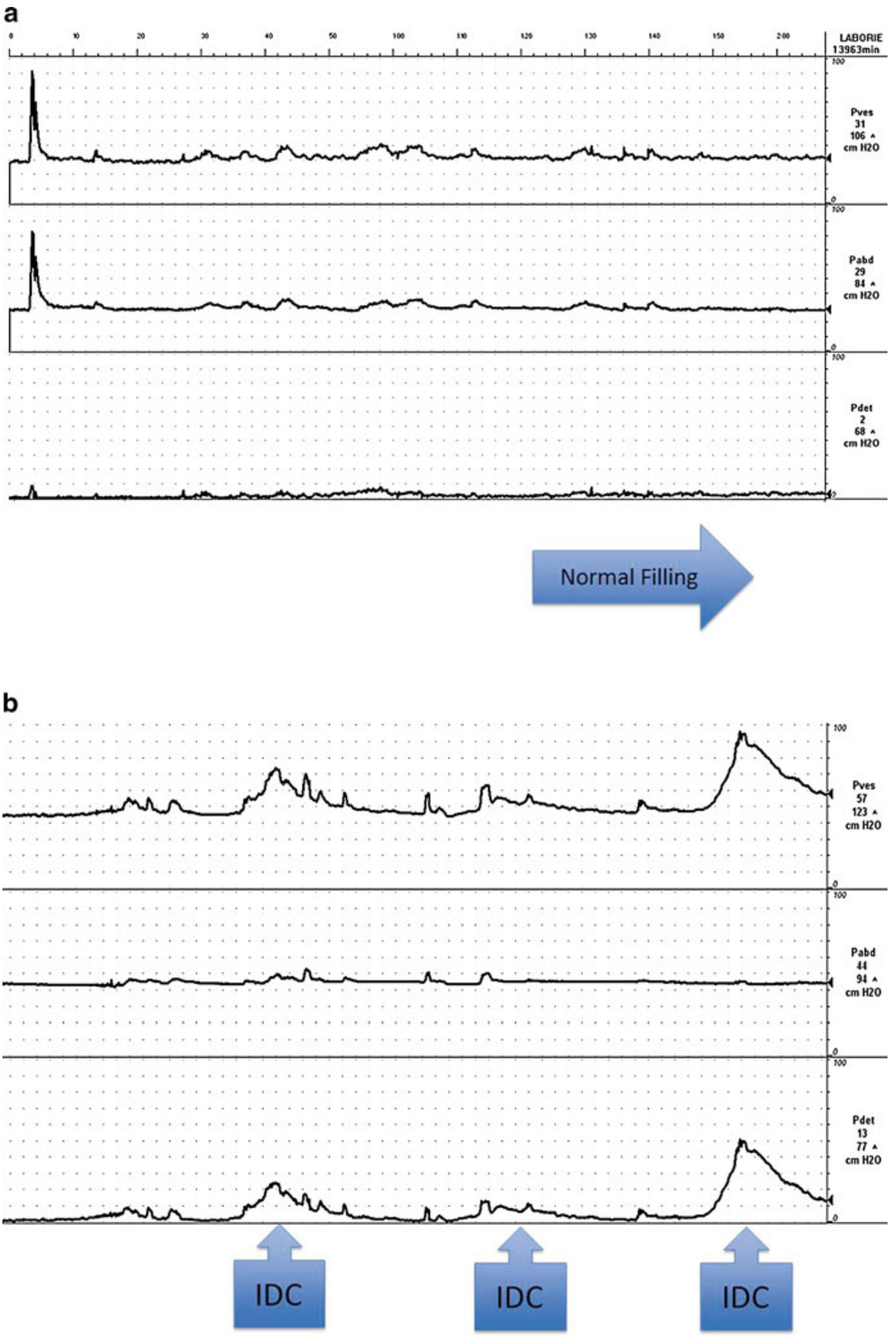

Fig. 1.3 Cystometrogram. (**a**) Normal low pressure filling. (**b**) Involuntary detrusor contraction (detrusor overactivity), there is a rise in P_{ves}, but not P_{abd}. (**c**) Impaired or low bladder compliance, with end filling pressure of over 40 cm H_2O

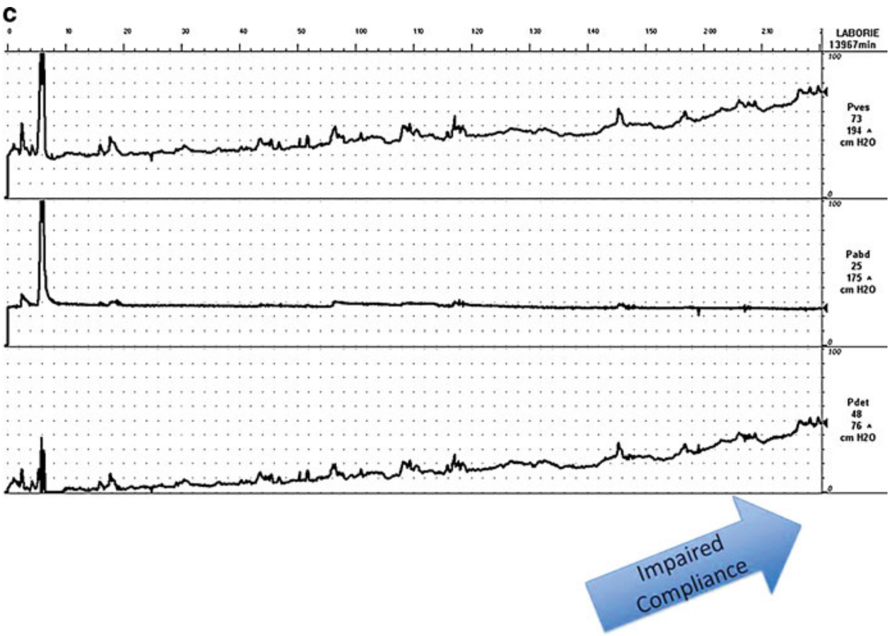

Fig. 1.3 (continued)

pressure to rise in the absence of a distinct detrusor contraction. This is known as impaired compliance (Fig. 1.3c) and can pose danger to the kidneys when this pressure is transferred to the upper urinary tracts. It is difficult to define what "normal compliance" is in terms of mL/cm H_2O. In the literature mean values for normal compliance in healthy subjects range from 46 to 124 mL/cm H_2O [23–25]. Various definitions of impaired compliance have been used (i.e., between 10 and 20 mL/cm H_2O), however there is not a consistent definition based on mL/cm H_2O. Stohrer et al. have suggested that a value of less than 20 mL/cm H_2O is consistent with impaired compliance and implies a poorly accommodating bladder [26]. However, examples can be cited (i.e., small cystometric capacity) where this may not be the case. Therefore, in practical terms, absolute pressure is probably more useful than a "compliance number" or value. For example, it has been shown that storage >40 cm H_2O are associated with harmful effects on the upper tracts [27].

For patients who have incontinence, provocative maneuvers can be performed during CMG to assess urethral competence and diagnose stress urinary incontinence (SUI). Patients can be asked to Valsalva or cough during filling. The abdominal leak point pressure (ALPP) is a measure of sphincteric strength or the ability of the sphincter to resist changes in abdominal pressure [28]. ALPP is defined as the intravesical pressure at which urine leakage occurs due to increased abdominal pressure in the absence of a detrusor contraction [1]. This measure of intrinsic urethral function is applicable to patients with stress incontinence. An ALPP can only be demonstrated in a patient with SUI. Conceptually the lower the ALPP, the weaker the sphincter.

In addition to providing information of filling pressures, the CMG can assess coarse bladder sensation and capacity. The International Continence Society (ICS) defines the following measures of sensation during bladder filling [1]:

First sensation of bladder filling is the feeling the patient has, during filling cystometry, when he/she first becomes aware of the bladder filling.

First desire to void is the feeling, during filling cystometry, that would lead the patient to pass urine at the next convenient moment, but voiding can be delayed if necessary.

Strong desire to void is defined, during filling cystometry, as a persistent desire to void without the fear of leakage.

Urgency is a sudden compelling desire to void.

Maximum cystometric capacity, in patients with normal sensation, is the volume at which the patient feels he/she can no longer delay micturition (has a strong desire to void).

Various methods exist, but ensuring quality control and adhering to standardized practices and interpretation guidelines can achieve good inter-rater reliability [29].

Voiding Pressure-Flow Study

Once the bladder is filled to cystometric capacity, the voiding portion of the pressure-flow study can begin. This examines the emptying phase of micturition. The same bladder and rectal (or vaginal catheter in women) catheters are used while simultaneously collecting pressure data along with uroflowmetry (Fig. 1.4). Ideally, such a study should assess a voluntary void. When there is flow of urine during an involuntary detrusor contraction patients may contract the pelvic floor to prevent leakage. Such an event should be annotated on study. In addition, some subjects may have a difficult time voiding on demand in a public setting and with invasive monitoring in place. These stressors and the artificial environment of the testing need to be accounted for when interpreting the test. For example, some patients cannot voluntarily void during an urodynamic study due to discomfort or psychogenic inhibition. Therefore the lack of a voluntary voiding bladder contraction during UDS does not always indicate that a patient has a truly a contractile bladder. Such a finding needs to be placed in the context of other parameters (i.e., non-invasive flows, history, PVR, etc.) to determine if it is, in fact, testing artifact. Remember that in order to answer a clinical question, the symptom(s) should be reproduced during the study. For example if a man has a complaint of a slow urinary stream, and his pressure-flow study reproduced the slow stream which occurs with a high pressure detrusor contraction, this is assumed to be an accurate depiction of an obstructive process.

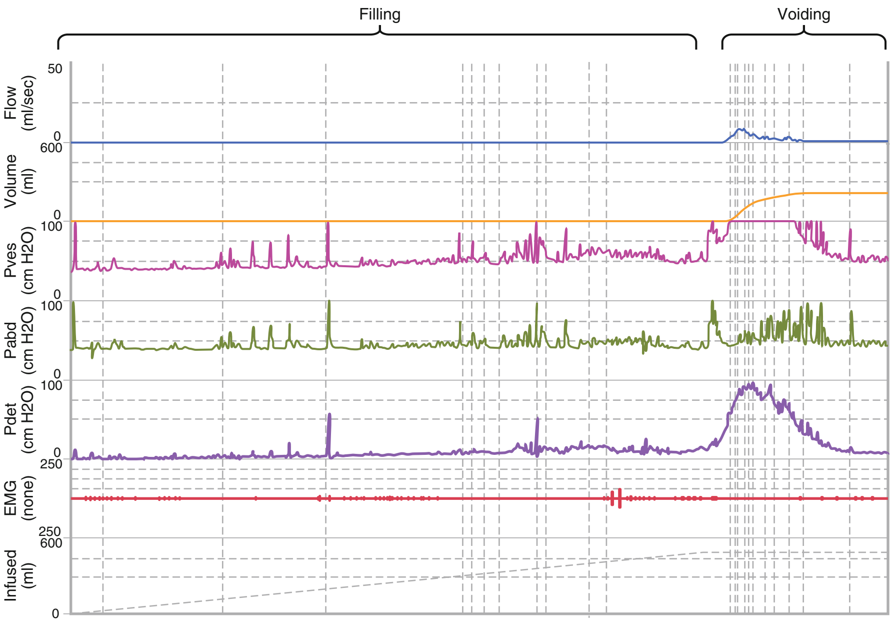

Fig. 1.4 This image shows a printout of a multichannel urodynamic study. The channels are labels and the filling and voiding phases are labeled

However, if a woman, who complains of urinary incontinence and has no reported difficulty with voiding and a low PVR, is unable to generate a voluntary detrusor contraction, it is less likely to have clinical significance. In these cases a poor flow rate can be confirmed or refuted with a non-invasive uroflow done in a private setting.

The voiding phase of a pressure-flow study helps assess two critical parameters related to the bladder and bladder outlet: detrusor contractility (normal vs. impaired) and outlet resistance (obstructed vs. unobstructed) [30]. Combinations of these two features will be discussed in Chap. 2 as contractility, coordination, complete emptying and clinical obstruction. In general the pressure-flow study can identify three fundamental conditions [30]:

1. Low (or normal) detrusor pressure and high (or normal) flow rate (normal, unobstructed voiding).
2. High detrusor pressure and low (or normal) flow rate (obstruction).
3. Low detrusor pressure with low flow rate (impaired contractility).

The most widespread application of pressure-flow studies has been to determine the presence of bladder outlet obstruction, most commonly in men. Starting in the early 1960s [24] nomograms were developed to standardize the definitions of obstruction and bladder contractility [31–33]. These nomograms are well established and broadly accepted in men (because of a single highly prevalent condition, benign prostatic obstruction—BPO). However pressure-flow nomograms are less widely agreed upon for use in women (due to the lack of a single highly prevalent condition causing obstruction) and as such have not gained widespread utilization in clinical practice [34–38].

Not all pressure-flow studies fall neatly into the three fundamental conditions. An example is a man with a poorly contractile bladder from long-term outlet obstruction. His bladder may not be able to generate a sufficient pressure to have his condition classified as obstruction, even though it is a progression of a process that occurred as a result of BPO. In such cases, it is once again important to consider all aspects of the patient's evaluation and come to a consistent clinical conclusion.

Urethral Pressure Profilometry

Urethral pressure profilometry (UPP) was popularized by Brown and Wickman [39] as a method to determine resistance provided by the urethra. Using a small catheter with lateral apertures through which fluid is continuously infused, simultaneous bladder and urethral pressure is measured as the catheter is slowly withdrawn along the course of the urethra. The urethral pressure transducer measures the fluid pressure required to lift the urethral wall off the catheter side holes and thus evaluates the circumferential and radial stresses induced by the presence of the catheter in the urethra and the slow urethral perfusion. Thus, urethral pressure is defined as the fluid pressure needed to just open a closed urethra [1].

Several parameters can be obtained from the UPP:

The urethral closure pressure profile (*UCP*) is given by the subtraction of intravesical pressure from urethral pressure.

Maximum urethral pressure (*MUP*) is the highest pressure measured along the UPP.

Maximum urethral closure pressure (*MUCP*) is the maximum difference between the urethral pressure and the intravesical pressure.

Functional profile length is the length of the urethra along which the urethral pressure exceeds intravesical pressure in women.

UPP has been mostly used as a measure of urethral resistance in women with SUI. Despite an abundant literature on urethral profilometry, its clinical relevance is controversial. Many urologists do not routinely perform urethral profilometry. In 2002, the ICS standardization sub-committee concluded that the clinical utility of urethral pressure measurement is unclear [40]. Furthermore, there are no urethral pressure measurements that (1) discriminate urethral incompetence from other disorders; (2) provide a measure of the severity of the condition; (3) provide a reliable indicator to surgical success, and return to normal after surgical intervention [40].

Videourodynamics

Videourodynamics (VUDS) consists of the simultaneous measurement of UDS parameters and imaging of the lower urinary tract. It provides the most precise evaluation of voiding function and dysfunction. VUDS are particularly useful when anatomic structure in relation to lower urinary tract function is important, for example in localizing bladder outlet obstruction (particular in women) or in assessing vesico-ureteral reflux in relation to storage and/or voiding pressures. VUDS can be performed using a variety of different methods. Most commonly fluoroscopy is employed using a C-arm that gives the most flexibility for patient positioning. However a fixed unit with fluoroscopy table that can move from 90° to 180° may also be used. It is important that the patient be able to be positioned properly to evaluate the desired function and anatomy.

The technique of obtaining fluoroscopic imaging during multichannel UDS was popularized in the United States by Tanagho et al. [41] and in Europe by Turner-Warwick [42]. Over the years, the value of adding this functional and anatomical picture to multichannel UDS studies has been described in various situations [35, 43–45].

In isolation, pressure-flow UDS can identify if obstruction is present, but cannot determine where in the lower urinary tract the obstruction is located. Simultaneous fluoroscopy can provide that information. Another benefit of fluoroscopy is the identification of vesico-ureteral reflux (Fig. 1.5). The detection of VUR can be critical in patients with high storage pressures such as certain types of neurogenic bladder as well as other conditions that can lead to impaired bladder compliance. During bladder filling, storage pressures may appear low (a safe situation), but poor compliance and high bladder filling pressures may be masked by a "pop-off" valve due to reflux into a dilated upper urinary tract. This is a situation that is accurately diagnosed with VUDS. Compared to a voiding cystourethrogram alone, the simultaneous pressure and volume readings during VUDS provide information about the pressure and volume at which reflux occurs, which can direct management.

Fluoroscopic imaging can also have a role in the diagnosis of urinary incontinence. Images can help identify small amounts of urinary leakage [46]. The level of continence is also assessed during bladder filling (e.g., open or closed bladder neck at rest or straining). Furthermore, the function of the bladder neck and external urethral sphincter can also be assessed during the voiding phase. This can be especially important in cases where EMG readings are difficult to interpret. Finally, in some cases of voiding dysfunction in women, the fluoroscopic images can be used to define as well as localize obstruction [35].

Other Urodynamic Tests

This chapter is not meant to be an exhaustive list of all technology used or investigated in the evaluation and management of disorders of the urinary tract. However, similar to all fields of diagnostic testing, there is never a shortage of attempts to improve the tools and techniques that have been used in the past.

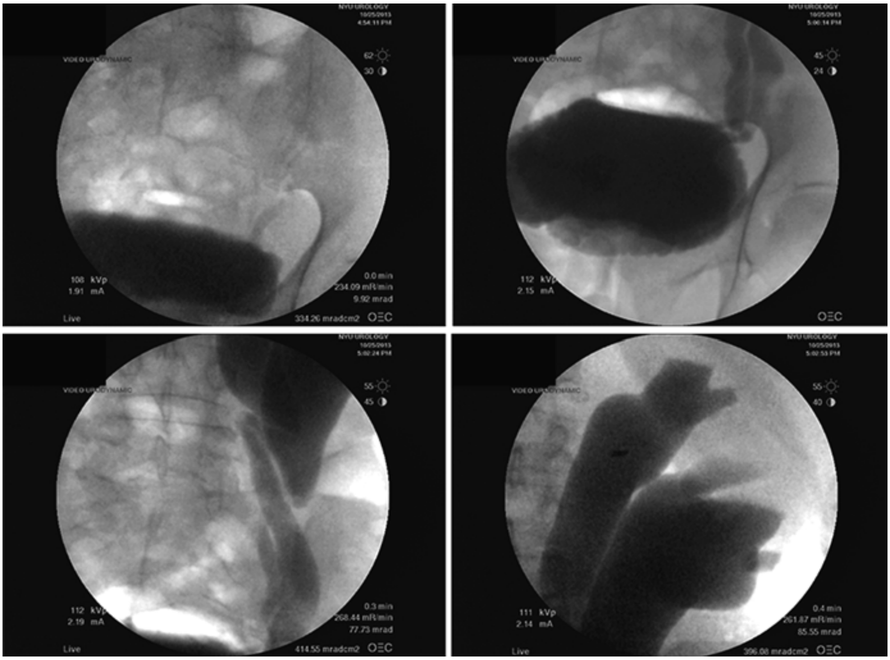

Fig. 1.5 The presence of reflux is noted on this fluoroscopic image obtained during filling CMG. The true bladder compliance may actually be less than what is measured on CMG because of the "pop-off" mechanism provided by the *left upper tract*

Though invasive testing has been shown to be well tolerated [47] newer technology attempts to improve the patient experience and minimize associated morbidity. However, if the technology is going to replace older methods, it must not sacrifice diagnostic ability.

Imaging studies have been investigated in the diagnosis of lower urinary tract disorders. Though not a new concept, researchers continue to look at resistive index from color flow Doppler of the prostate in men with Benign Prostatic Hyperpertrophy to assess bladder outlet obstruction [48]. Many different measurements of the prostate anatomy by ultrasound imaging have also been investigated, but still remain difficult to reproduce and practically apply [49]. Ultrasound technology has also been used in order to determine estimated bladder weight and bladder wall thickness, but has had mixed results [50, 51].

Near infrared spectrometry (NIRS) is another technique that has now been applied to investigate for the presence or absence of bladder outlet obstruction [52]. This is based on the premise that during voiding when bladder outlet obstruction exists, the detrusor contraction will be excessive as compared to unobstructed patients. This increased contraction results in a decrease in total hemoglobin and oxyhemoglobin concentrations. NIRS is able to monitor these changes. This technology is intriguing, but technical limitation and reproducibility remain issues.

UDS in Clinical Practice

Although UDS has been used as part of clinical practice for decades, clear-cut, level 1 evidenced-based "indications" for its use in many conditions are lacking. There are a number of reasons for this lack of evidence. It is difficult to conduct proper randomized controlled trials on UDS for conditions where lesser levels of evidence and expert opinion strongly suggest clinical utility and where "empiric treatment" is potentially harmful or even life-threatening (e.g., neurogenic voiding dysfunction). Additionally, symptoms can be caused by a number of different conditions, and it is difficult to study pure or homogeneous patient populations [53]. Recently the American Urological Association (AUA) and the Society of Urodynamics, Female Pelvic Medicine and Urogenital Reconstruction (SUFU) published the AUA/SUFU Urodynamic Guidelines [5]. The purpose of that guideline was not to present an exhaustive review of the "indications" for UDS, but rather to review the literature regarding urodynamic testing in common lower urinary tract conditions and assist clinicians in the proper selection and application of urodynamic tests, following an appropriate evaluation and symptom characterization. When it comes to "indications" for UDS for any condition, the most important factors are that the clinician has clear-cut reason(s) for performing the study, and that the information obtained will be used to guide treatment of the patient. Therefore it is probably more useful to describe the role of UDS in clinical practice rather than precise "indications" for its use.

In practical terms, UDS is most useful when history, physical exam, and simple tests are not sufficient to make an accurate diagnosis and/or institute treatment [53]. This has clinical applicability in two general scenarios:

1. To obtain information needed to make an accurate diagnosis for what condition(s) is causing symptoms (i.e., lower urinary tract symptoms (LUTS) or incontinence).
2. To determine the impact of a disease that has the potential to cause serious and irreversible damage to the upper and lower urinary tract (i.e., neurological diseases like spinal cord injury and multiple sclerosis, radiation cystitis). Sometimes profound abnormalities can be found in the relative absence of symptoms.

As with most diagnostic studies in medicine, understanding the results of the test is only part of a much broader picture. It is equally important to understand those results in the context of a specific clinical condition or situation. Another important consideration is the understanding of when to order the given test. Indiscriminate testing leads to unnecessary cost, subjects patients to risk, and can even complicate the diagnosis when these results are misinterpreted.

The information that follows is obviously not exhaustive, but begins to explore the process of choosing the "right test." This will be within the framework of the current AUA/SUFU Urodynamic guideline document [5]. These guidelines also include the level of evidence and the strength of the recommendation made by the committee.

Stress Urinary Incontinence

UDS in SUI, like in many other conditions, should be performed if the results will have a significant impact on patient management or counseling. This is most often applicable to pre-surgical UDS testing or cases where the diagnosis of SUI is in doubt or when SUI appears to co-exist with other conditions that could affect management (i.e., detrusor overactivity of bladder outlet obstruction). Recently, a large multi-center randomized controlled trial to determine the value of UDS prior to surgery for women with SUI concluded that UDS is not needed prior to the surgical treatment of women with "straight forward" SUI who have demonstrable clinical SUI with no significant overactive bladder symptoms and normal emptying [54]. We would agree with this for patients and clinicians who would not change the type of surgery based on the results of UDS testing. However some surgeons may alter the type of procedure done based on a measure of urethral resistance, such as ALPP. In such cases, it would seem reasonable for that particular surgeon to consider UDS. It is also important to remember that if one chooses not to do UDS prior to SUI surgery in women it is critical that SUI be demonstrated on physical exam, that storage symptoms are adequately characterized and that emptying is assessed (symptoms and measurement of PVR).

We believe that the recommendations from the AUA/SUFU Guideline for the utility of Urodynamic studies in adult women with SUI and pelvic organ prolapse [5] provide useful information for the clinician. Please note that these "guidelines" do not specifically say when or on whom to perform UDS, but rather provide information based on the literature and expert opinion/clinical principles. Ultimately the decision to perform UDS on a given patient should be based on certainty of diagnosis and whether or not the results will affect treatment or counseling.

Key points from AUA/SUFU Guideline Statements [5]:

1. When diagnosing stress incontinence on UDS, clinicians should assess urethral function.
2. If considering invasive therapy to treat SUI, surgeons should assess PVR urine volume.
3. Multichannel UDS may be performed in patients with both symptoms and physical findings of SUI if considering "invasive, potentially morbid, or irreversible treatments."
4. If SUI is suspected, but not demonstrated on UDS with a catheter in place, repeat stress testing with the urethral catheter removed should be performed.
5. Stress testing with reduction of POP (high-grade) should be performed in women without the symptom of SUI (if the presence of SUI will alter the surgical treatment plan). Multichannel UDS may be used for this assessment of SUI with reduction of prolapse and detrusor dysfunction in women with associated LUTS.

Urgency Urinary Incontinence

Urgency urinary incontinence (UUI) is another common condition that is often evaluated with UDS. For patients with UUI, UDS is most applicable when the diagnosis is in doubt (i.e., when significant portion of incontinence may be caused by urethral insufficiency), when a concomitant problem such as bladder outlet obstruction can co-exist or even be the cause of bladder overactivity, and in certain conditions (neurological conditions, radiation cystitis, or chronic outlet obstruction) where high pressure storage and impaired bladder compliance can co-exist. The recommendations from the AUA/SUFU Guideline for the utility of Urodynamic studies in adults with UUI [5] provide useful information for the clinician and consider all of these possibilities. Again the "guidelines" do not specifically say when or on whom to perform UDS, but rather provide information based on the literature and expert opinion/clinical principles:

1. If it is important to determine if compliance is altered, detrusor overactivity (DO) is present, or other urodynamic abnormalities exist (or not) multichannel filling cystometry may be performed in patients with UUI when considering "invasive, potentially morbid, or irreversible treatments."
2. In patients with UUI after procedures on the bladder outlet, PFS may be performed to evaluate for bladder outlet obstruction.
3. Absence of detrusor overactivity on an urodynamic study does not mean that it may not still be a *causative agent* for symptoms of UUI and mixed urinary incontinence.

Neurogenic Bladder

UDS probably has its most important role in the diagnosis and management of patients with neuropathic voiding dysfunction. This is because certain conditions can have a profound impact on the lower urinary tract that can affect upper tract (kidney) function. In such cases management is not driven by symptoms, but rather by the need to preserve renal function. The term "neurogenic" encompasses a broad spectrum of diseases that can result in bladder storage and bladder-emptying dysfunction. Here too, a clear understanding of the underlying neurogenic process and its effect on the lower urinary tract should help guide appropriate selection of urodynamic testing. Patients who are at risk for upper tract decompensation are those with high storage pressure and incomplete bladder emptying. This most frequently occurs in cases of detrusor-sphincter dyssynergia (suprasacral spinal cord lesions). In such patients VUDS can be particularly useful to evaluate for the presence of vesico-ureteral reflux (see above). For patients with neurological disease not at risk for upper tract decompensation (i.e., women post-cerebral vascular accident) UDS has its greatest utility when patients have failed appropriate empiric therapy. The recommendations from the AUA/SUFU Guideline for the utility of UDS in adults with Neurogenic Bladder [5] *offer appropriate* "guidelines" based on the literature and expert opinion/clinical principles:

1. PVR measurements should be assessed, as part of complete urodynamic study or as a separate test, during evaluation of patients with "relevant neurological disease" (i.e., spinal cord injury, myelomeningocele). The PVR should also be measured in follow-up when appropriate.
2. Complex CMG should be performed during initial urological evaluation of patients with "relevant neurological conditions" regardless of the presence (or absence) of symptoms. Complex CMG should also be performed as part of the continued follow-up in appropriate situations. In the urologic evaluation of patients with other neurologic diseases, CMG may be considered as an option to evaluate LUTS.
3. Pressure-flow analysis should be performed in patients with "relevant neurologic disease" regardless of the presence (or absence) of symptoms. Pressure-flow analysis should also be performed in cases of patients with other neurologic disease that have an elevated PVR or urinary symptoms.
4. Fluoroscopy (if available) may be done at the time of UDS (VUDS) in patients with "relevant neurologic disease at risk for NGB." The same is true for patients with other neurologic disease who have an elevated PVR or urinary symptoms.
5. Clinicians should perform EMG along with CMG and with pressure-flow studies (if performed) in patients with "relevant neurologic disease at risk for NGB." EMG should also be carried out with the aforementioned studies in cases of other neurologic disease where patients have an elevated PVR or urinary symptoms.

Voiding Dysfunction/LUTS

UDS is often used to assist in the evaluation of men and women with storage and voiding LUTS. We have found UDS most useful in patients with LUTS who: have failed empiric treatment; have multiple symptoms that cannot be easily differentiated; have mixed storage and voiding symptoms, especially when surgery for the relief of obstruction is being considered; or have underlying conditions that can affect lower urinary tract function (i.e., prior pelvic surgery or radiation). Often a clinician's own treatment algorithm, comfort with diagnosis, and expertise will determine at what stage UDS are introduced. In many patients with LUTS, a stepwise use of tests seems to be most appropriate. The evaluation of bladder emptying can be of critical importance. Therefore, it is common to utilize non-invasive uroflow and/or PVR determination early in the evaluation. History and physical exam alone or in combination with these simple tests are often all that is needed to initiate therapy. However, when initial therapy fails, or when uroflow and PVR results are concerning, more comprehensive UDS testing may be employed. There is also evidence to support the use of UDS prior to surgical intervention for suspected benign prostatic obstruction with LUTS, to document the presence of obstruction. In women and young men with LUTS and suspected outlet obstruction, we have found VUDS to be particularly helpful in aiding in the diagnosis and localization of obstruction [35, 55]. Again the recommendations from the AUA/SUFU Guideline for the utility of UDS in adults with LUTS [5] provide useful information for the clinician without a presentation of absolute indications for any specific patient.

1. During the initial evaluation (and follow-up) of patients with LUTS measurement of PVR may be used as a "safety measure" to rule out significant retention of urine.
2. During the initial (and follow-up) evaluation of male patients with LUTS that suggest abnormal voiding/emptying, Uroflow may be used.
3. Multichannel filling cystometry may be used if "it is important to determine DO or other abnormalities of bladder filling/urine storage" exist in patients with LUTS. This has may have more importance when "invasive, potentially morbid, or irreversible treatments are considered."
4. If it is "important to determine if urodynamic obstruction is present in men with LUTS" clinicians should perform PFS. This may be particularly important when "invasive, potentially morbid, or irreversible treatments are considered."
5. In female patients if it is "important to determine if obstruction is present," PFS may be performed.
6. VUDS may be carried out in "properly selected patients" where localization of the level of obstruction is particularly important. For example to diagnose PBNO.

Summary

UDS consists of a number of different tests that evaluate lower urinary tract function. These tests can be employed individually or in combination depending on a specific clinical scenario to aid the clinician in diagnosing and treating patients with LUTS other conditions that affect the lower urinary tract function. UDS is most useful when performed for specific reasons to obtain specific information to guide management (treatment or no treatment). We would caution that the indiscriminate use of UDS is not appropriate and can be counterproductive, or even harmful. However, when used appropriately, these tests can be invaluable.

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