Chapter 3
Practical Interpretation and Application of Urodynamic Findings

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Abstract Proper reading and interpretation of a pressure flow urodynamic tracing should be performed in a systematic fashion. Unfortunately, there is no universally agreed upon approach to the interpretation of a pressure flow urodynamic study. Using the functional classification of voiding dysfunction as a framework, the pressure-flow tracing can be dissected into a filling/storage portion and an emptying portion. Important aspects of the urodynamic study can sub-classified within each of these phases. Conveniently, each of these aspects can be titled with a "C" thus providing the 9 "C's" of pressure-flow urodynamics interpretation and reporting. Such a scheme allows a complete and uniform approach to the interpretation of the urodynamic tracing. This chapter will provide a framework with which the practitioner can approach and interpret the pressure-flow urodynamic (PFUD) study.

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Introduction

Urodynamics (UDS) are the dynamic study of the transport, storage and evacuation of urine [1]. UDS consists of a number of studies including uroflowmetry, post void residual measurement, filling and voiding cystometry, and sometimes urethral pressure measurement. Fluoroscopy is sometimes used concurrently to evaluate the dynamic anatomy of urinary tract in which case the study is termed "video-urodynamics". These tests measure and assess various processes, intrinsic and extrinsic to the lower urinary tract. UDS can assist in the diagnosis, prognosis, and treatment regimens related to a variety of lower urinary tract conditions. The term "urodynamics" was first coined by Dr. David Davis in 1954 [16]. Since then, there has been an exponential increase in the utilization of UDS by healthcare practitioners including urologists.

The amount of information produced during a routine PFUD study can be imposing to fully comprehend, understand and properly interpret. For a given study, the modern electronic multichannel pressure flow urodynamic machine produces a large amount of data in a graphical display usually supplemented with other information. The format varies depending on the type of urodynamic equipment, the specific study, and the end-user customization. Nevertheless, in most instances, the various channels on the graph represent a set of continuous variables over time including vesical and abdominal pressure recordings, urine flow rate and volume, infused volume and potentially other signals as well. An event summary, annotations, nomograms and other features now commonly found on commercially available urodynamics equipment add to the tremendous set of data available from a routine pressure-flow urodynamic (PFUD) study.

In the same manner in which radiologists interpret their imaging studies, it is crucial to be systematic and organized in approaching the PFUD tracing in order to properly and completely distil the optimal amount of information from the study. It is quite possible to overlook salient and relevant features of a PFUD tracing especially in those cases where there exists one single overwhelming abnormality. Like the astute radiologist, the expert urodynamicist will not be dissuaded from completely interpreting the study even in the setting of a distracting feature so that other, subtler findings can be noted as well. Such nuances can be crucial in formulating an accurate interpretation of the study and should not be overlooked.

The 9 "C's" of PFUD are a method of organizing and interpreting the PFUD study in a simple, reliable and practical manner [19]. In doing so, this system minimizes the potential for "missing" an important and relevant finding on the tracing. This framework is easy to understand, remember, and applicable to all PFUD studies for virtually all lower urinary conditions.

The "9 C's" of Urodynamics

In the functional classification as popularized by Wein the micturition cycle consists of two phases: (1) bladder filling/urinary storage, and (2) bladder emptying. All voiding dysfunctions therefore can be categorized as abnormalities of one or both of these phases. This classification system also provides a useful framework for organizing the 9 "C's".

The 9 "C's" represent the nine essential features of the PFUDs tracing that represent a minimum interpretive data set. Each of the features begins with the letter "C." (Table 3.1):

- in the filling phase, the "C's" consist of <u>c</u>ontractions (involuntary), <u>c</u>ompliance, <u>c</u>ontinence, <u>c</u>apacity and <u>c</u>oarse sensation.
- in the emptying phase <u>c</u>ontractility, <u>c</u>omplete emptying, <u>c</u>oordination and <u>c</u>linical obstruction are evaluated.

The "C's" are not specific for all types urinary dysfunction nor all urodynamic abnormalities. Nevertheless, by organizing and interpreting a study within this framework, it provides an

Table 3.1 9 "C's" of PFUD

Filling and storage	Emptying
Coarse sensation	Contractility
Compliance	Coordination
Contractions (involuntary detrusor)	Complete emptying
Continence	Clinical obstruction
Cystometric capacity	

organizing thread from which to formulate a diagnosis and begin to assemble a management plan.

Of course all PFUD tracings should be interpreted in the context of the patient's history, physical examination and other relevant studies. Additionally, reproducing the patient's symptoms or at least notating whether this was achieved during the study is also important in order to properly interpret the tracing and any abnormalities seen. Notwithstanding these limitations, it remains that a systematic and organized approach to interpretation of the PFUD tracing is likely to yield the most useful and complete set of data and optimize clinical care and outcomes.

Simply reviewing a UDS tracing is not sufficient to generate an accurate interpretation. The filling and voiding phases of the study are dynamic processes that are influenced by patient understanding of testing instructions (i.e. waiting for permission to void), and artifact (i.e. movement of uroflow detector during the test). Therefore, it is important that the person interpreting the UDS tracing is involved with the actual UDS study as knowledge of the testing environment will help differentiate artifacts from true findings.

Filling and Storage Phase

The filling phase starts with the initiation of instillation of saline (or contrast if a video urodynamic study is being performed) and ends with the instruction to void or "permission to void". Prior to giving permission to void the provider performing the UDS needs to ensure that all questions regarding the filling and storage phase have been addressed. Once permission to void has been given, the emptying phase begins. It is helpful to have a recent voiding diary available prior to the UDS. The voiding diary will help assess how the UDS tracing reflects their voided volumes in a non-clinical environment.

Coarse Sensation

The sensation of bladder filling experienced by the patient is variable but absence of normal sensation, or delayed sensation of bladder may be indicative of neurological abnormalities. Furthermore, hypersensitivity, lack of sensation during detrusor overactivity, sensation of extreme pain, or low bladder capacity overall due to sensation of fullness may be indicative of other lower urinary tract pathology.

It is important to begin the study with an empty bladder. Thus, most often patients are catheterized prior to the start of the study. This will help ensure that the infused volumes at which sensations are recorded are accurate. It is also important to ensure that the recorded infused amount accurately reflects the actual infused amount. Such calibrations should be done regularly and periodically as routine maintenance of the urodynamic equipment. Bladder coarse sensation can be delayed in patients with poorly controlled diabetes and HIV. Sensation can be absent in patients with spinal cord injuries. Hypersensitivity at low volumes may be indicative of interstitial cystitis (Painful bladder syndrome), UTI or other disorders.

Patients should be informed of the study objectives prior to beginning testing and this is especially relevant when assessing sensation. They should be prompted to inform the person performing the study of several events in the study [1]:

1. first sensation of bladder filling (during filling cystometry, the sensation when he/she first becomes aware of bladder filling)

2. first desire to void (the feeling, during filling cystometry, that the patient would desire to pass urine and the next convenient moment, but voiding can be delayed if necessary),
3. strong desire to void (during filling cystometry, as a persistent desire to void without the fear of leakage),
4. 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)).
5. Urgency (during filling cystometry, the sudden compelling desire to void) at any time during the UDS.

Filling sensations are very subjective and as such there are not a universally accepted set of normative values hence the term “coarse sensation” is utilized. Typical ranges are: first sensation ~170–200 mL, first desire to void ~250 mL, strong desire to void ~400 mL and Maximum capacity ~480 mL [17]. Reviewing a recent voiding diary may be helpful. Sensation is affected by the placement of a catheter in the bladder, which may cause irritation, and/or pain, which may be erroneously interpreted as a sensation to void. Overly warm, cold, or too rapidly infused fluid can also affect bladder sensation. When documenting the interpretation of the UDS tracing coarse sensation is usually reported as absent, reduced or increased [9].

Compliance

Compliance reflects the passive viscoelastic properties of the bladder and is defined as the relationship between change in bladder volume and change in detrusor pressure [1]. Compliance is calculated by mathematically dividing the volume change of the bladder just prior to volitional micturition or the first involuntary bladder contraction by the detrusor pressure at that same point [1]. In a normally compliant bladder and in the absence of detrusor overactivity, the detrusor pressure should remain essentially unchanged during filling.

Decreased bladder compliance is generally acknowledged as a risk factor for upper tract deterioration.

Despite the importance of this data point, there exists no universally accepted normative value. Compliance of less than 20 mL/cm H_2O is commonly used as the threshold below which is considered abnormal [22]. Occasionally, a prolonged involuntary bladder contraction (detrusor overactivity or DO) can be confused with true abnormal compliance. One way to differentiate between these is to stop infusing fluid and observe for a few minutes. Typically, pressures will return to baseline after a few minutes with DO whereas pressures will remain high in abnormal compliance. Video urodynamics/VCUG can be helpful as high-grade reflux and large bladder diverticulum can act as a "pop off" masking underlying abnormal compliance.

Testing of the detrusor leak point pressure (DLPP) in patients with abnormal compliance can be helpful in risk assessment of future upper tract deterioration. DLPP is defined as "lowest value of the detrusor pressure at which leakage is observed in the absence of abdominal strain or detrusor contraction" [12]. A DLPP of greater than 40 is considered deleterious to the upper tracts [13]. However, in certain individuals; a DLPP of less than 40 may also put the upper tracts at risk (Fig. 3.1).

Pelvic radiation, denervation from radical pelvic surgery, neurogenic bladder and chronically indwelling Foley catheters are common etiologies of abnormal bladder compliance. Patients, who have abnormal compliance with a chronic indwelling Foley, should be converted to a short period of CIC to allow for bladder cycling if feasible. Often, in these patients without a high suspicion of true poor compliance, normal compliance will be noted after a short period of CIC and/or bladder cycling.

When documenting the interpretation of the UDS tracing, compliance is usually reported as normal or abnormal or can be listed as a calculated value as noted previously. It is important to recognize that an artifactual decrease in the P_{abd} (P_2) transducer can misinterpreted as decreased compliance, but in fact this is due to artifact or repositioning of the abdominal pressure transducer during the study (Fig. 3.2).

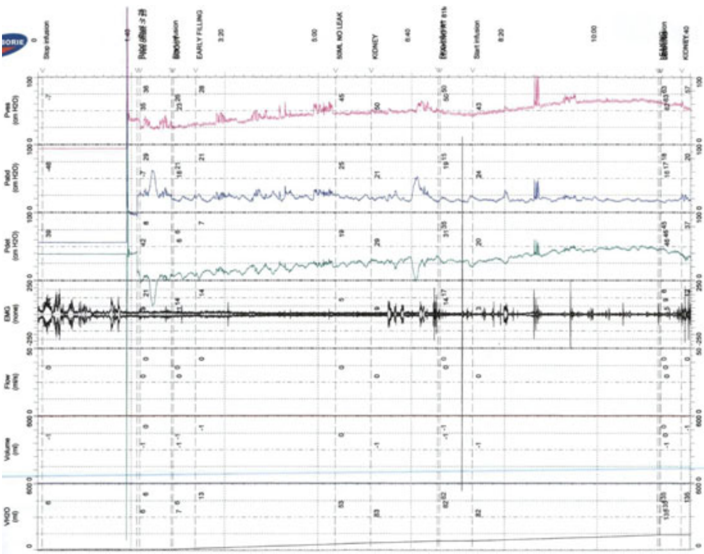

FIGURE 3.1 Decreased compliance. Note the change in detrusor pressure of 6–46 cm H_2O during instillation of 135 ml of fluid volume. Change in P_{det} is 46–6 = 40 cm H_2O with a change in volume of 135 mL. Compliance = (ΔVolume/ΔP_{det}) = 135 mL/40 cm = 3.375 mL/cm H_2O

Contractions, Involuntary (Detrusor Overactivity)

Detrusor overactivity (DO) is defined as a urodynamic observation characterized by involuntary detrusor contractions (IDC) during the filling phase which may be spontaneous or provoked. If there is a relevant neurologic lesion it is deemed neurogenic DO. If there is no relevant neurologic lesion it is deemed idiopathic DO [1]. It is important to ensure than any suspected detrusor overactivity is in fact accurate and not artifact. True detrusor overactivity is noted as a wavelike form on the P_{det} tracing along with a similar wave like form on P_{ves} in the absence of "permission to void". Additionally, the interpreter must ensure that there is not drop out from the rectal/abdominal catheter (P_{abd}) that may artificially simulate a rise in detrusor pressure.

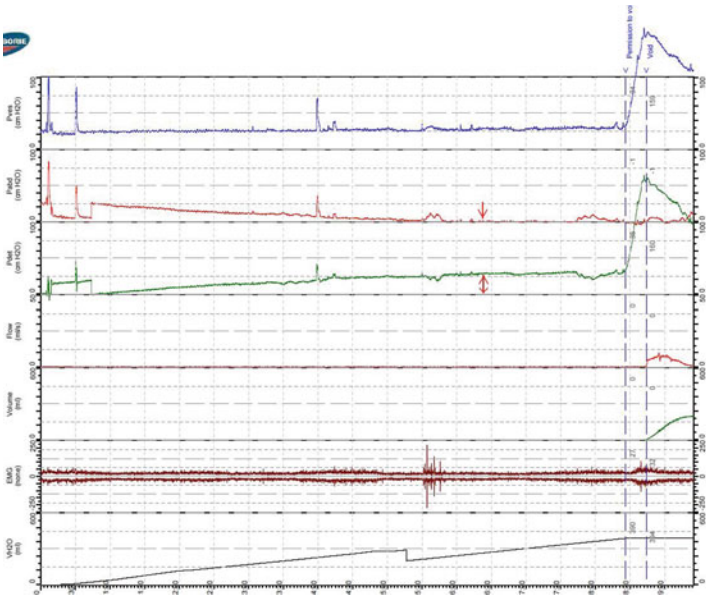

FIGURE 3.2 The apparent rise in P_{det} is artifactual and secondary to a change in position and signal drop out of P_{abd} which can be mistaken for decreased compliance

Often, patients will report an unintended or sudden urge to urinate, which may or may not correlate with an IDC. It is key for the interpreter of the UDS tracing to be involved in the study as this helps identify artifact from true detrusor overactivity and can confirm if the DO replicates the patients presenting symptoms. Additionally, DO can be “stress induced” by strain or cough so it is important to be aware of potential precipitating events both during the study and at home.

When documenting the interpretation of the UDS tracing, detrusor contractions during the filling phase are usually reported as absent (“stable filling”), present and suppressible, present with resulting detrusor overactivity incontinence, or terminal DO (DO related incontinence resulting in emptying of the bladder) (Fig. 3.3). DO which occurs at cystometric

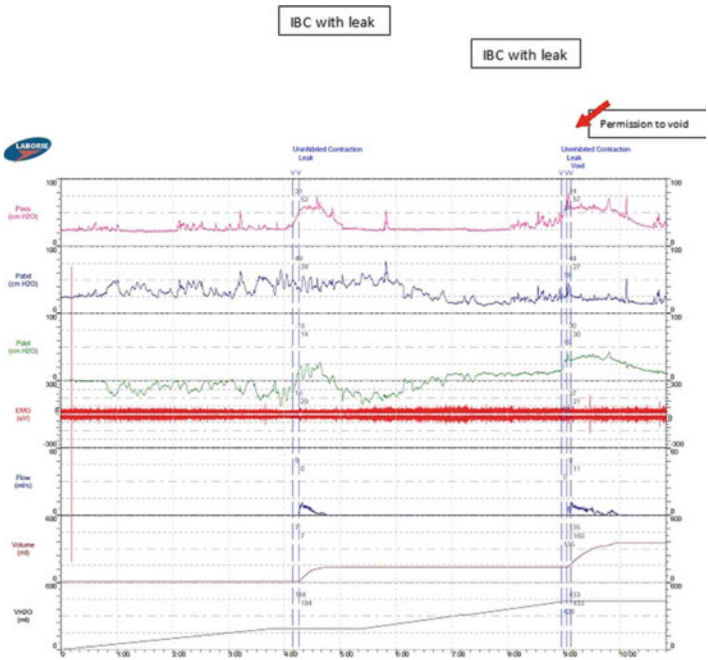

FIGURE 3.3 Detrusor overactivity with associated urinary urge incontinence. Note while there is some artifact from $P_{abd,}$ the waveform of P_{ves} correlates to P_{det}. In both sequences there is an involuntary detrusor contraction (IDC) followed by involuntary flow of urine. During the second IDC the patient is give permission to void (3rd mark). It is important to notate events in real time as this tracing could be mistaken for a normal voiding pattern if patient were given permission to void prior to increased detrusor pressure

capacity and results in bladder emptying is referred to as "terminal detrusor overactivity". An after-contraction (Fig. 3.4) is a large amplitude rise in P_{det} occurring after the cessation of voiding. The clinical significance of this finding is unclear as it may represent catheter artifact or a true abnormality. While there is no defined high/low limit of rise in P_{det} to be considered DO, the definitive interpretation of low amplitude DO (less than 5 cm H_2O) requires a high quality UDS study [1].

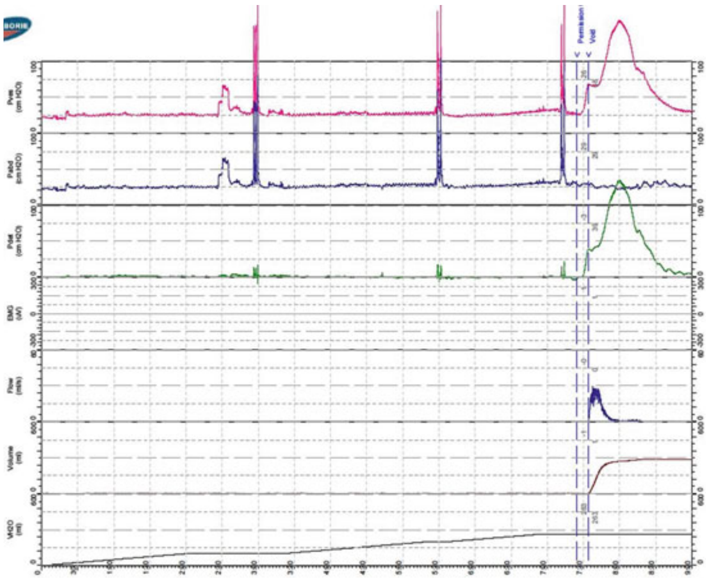

FIGURE 3.4 Normal detrusor contractility. This is a female patient with complaints of mixed urinary incontinence. Stress incontinence was tested multiple times throughout study at increasing bladder volumes. Filling was stable with no evidence of detrusor overactivity. Note the rise in detrusor pressure with permission to void followed by an aftercontraction of the detrusor muscle denoted by the arrow (See section "Contractility (Detrusor Overactivity)")

Cystometric Capacity

Cystometric capacity is the volume in which "patients with *normal* sensation can no longer delay micturition" [1]. Cystometric capacity should not be confused with functional bladder capacity, which is obtained from a voiding diary in conjunction with a post void residual. Cystometric capacity is typically less than the functional bladder capacity. There is no universally defined normal cystometric capacity, but typical values range from 370 to 540 mL ± 100 cc [18]. Of note, the provider performing the UDS should ensure the patient is not experiencing an involuntary detrusor contraction which is generating the sensation such that they cannot delay micturition. Extremely large bladder capacity, due to impaired sensation of bladder filling, may result from peripheral or central (spinal) neurological disease. Small bladder capacity may be secondary to sensory disorders of the lower urinary tract such as painful bladder syndrome.

The filling rate of the bladder can also affect the cystometric capacity. Generally, a filling rate of 50–70 mL/min is used in adults [3]. This filling range allows for the test to be completed in a reasonable amount of time, yet minimizes the artifacts related to overly rapid bladder filling [20]. A voiding diary suggestive of large/small bladder capacity can assist in determining if a faster/slower fill rate is more appropriate. When documenting the interpretation of the UDS tracing, cystometric capacity is usually reported in cc or mL.

Continence

Continence refers to the presence or absence of urinary leakage during the UDS. The abdominal leak point pressure (ALPP), also performed as cough leak point pressure or Valsalva leak point pressure is defined as the lowest intravesical pressure at which urine leakage occurs because of increased abdominal pressure in the absence of a detrusor contraction [1]. While there is no universally accepted method to test ALPP it is important to ensure that the leakage of urine reproduces the patient's symptoms and that the test is performed in the same manner in the urodynamics laboratory for each patient allowing for consistent interpretation of results.

If unable to reproduce a patient's symptomatic stress incontinence, provocative maneuvers (i.e., moving from sitting to standing) can be attempted. UDS can help differentiate stress induced detrusor overactivity (Fig. 3.5) from true stress incontinence (Fig. 3.6). Having the patient cough or Valsalva may demonstrate stress induced DO as their true

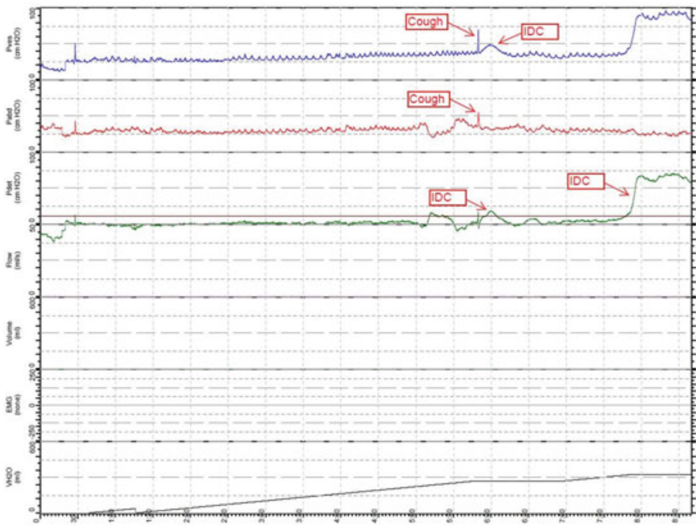

FIGURE 3.5 Stress induced detrusor overactivity. Notice the patient's cough which is recorded as an increase in P_{abd} and P_{ves} followed by a rise in detrusor pressure (IDC) recorded on P_{ves} and P_{det}

etiology of incontinence. ALPP testing should not be performed during an involuntary detrusor contraction.

It is important to note that despite the small size of the urethral catheter it can obstruct the bladder outlet masking clinical urinary incontinence. In patients with suspected stress urinary incontinence that is unable to be reproduced during the UDS study it has been suggested that the urethral catheter be removed and stress maneuvers repeated [11, 21]. Patients with advanced prolapse may have their prolapse reduced to rule out occult stress urinary incontinence, which may be masked by urethral kinking from prolapsed [5]. Lastly, it should be noted whether the urinary incontinence on the study reproduced the patients presenting symptoms as the artificial circumstances of the UDS laboratory may result in spurious findings and thus erroneous interventions. When documenting the interpretation of

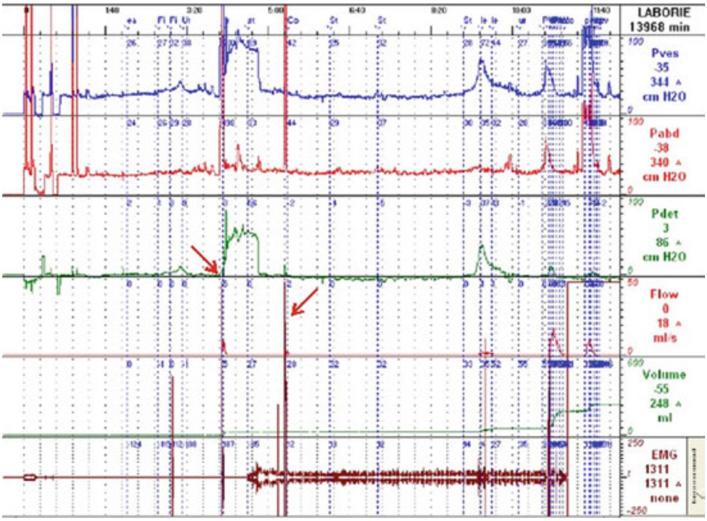

FIGURE 3.6 Stress urinary incontinence and stress induced detrusor overactivity. Note the two cough and strain provocative maneuvers with resultant urinary incontinence (*arrows*). The first arrow is cough followed by an IDC with incontinence representing stress induced detrusor overactivity. The second arrow marks leakage of urine with cough without associated IDC and represents a true leak point pressure

the UDS tracing incontinence is usually reported as absent (normal), present- stress incontinence, present – detrusor over activity incontinence.

Emptying Phase

The emptying phase begins when the bladder is filled to cystometric capacity and in the absence of detrusor overactivity the patient is given permission to void. Ideally, all questions regarding the patients filling phase should be addressed prior to initiating the emptying phase of the study.

Contractility

Once the instruction to void or "permission to void" is given to the patient, they should, to the extent possible, initiate a volitional void. In the setting of normal voiding, urine flow should occur once the pressure generated by the detrusor overcomes the total bladder outlet resistance as the urethra closure forces diminish. There are no defined normative values for P_{det} during volitional voiding. In normal, unobstructed women, a detrusor contraction of 10–30 cm/H_2O is general considered normal. In normal, unobstructed men, a detrusor contraction of 30–50 cm/H_2O is common [6, 15]. When considering "normal" it is important to assess both the magnitude and duration of the detrusor contraction in the context of the ability empty the bladder (Fig. 3.4). It is important to note that some women will normally void via pelvic floor relaxation without generating a measurable detrusor contraction [23]. The lack of a detrusor contraction is not inherently abnormal as long as there is neither a neurologic etiology identified nor abnormal bladder emptying. While nomograms and calculations have been established to more objectively describe contractility in both men and women, these nomograms must be utilized in conjunction with clinical observations [2, 14].

Not infrequently, patients have a "shy bladder" or psychogenic inhibition and are unable to void during the emptying phase of the procedure. Allowing a faucet to run or giving the patient privacy in the UDS suite can often create a suitable environment for initiation of micturition. If the patient is still unable to void, performing the voiding phase on a non-invasive uroflow can still provide some valuable information. When documenting the interpretation of the UDS tracing contractility is usually reported as normal, absent or underactive. There is no defined threshold for underactivity, but rather contractility is assessed in the context of the bladder's ability to empty appropriately, and in

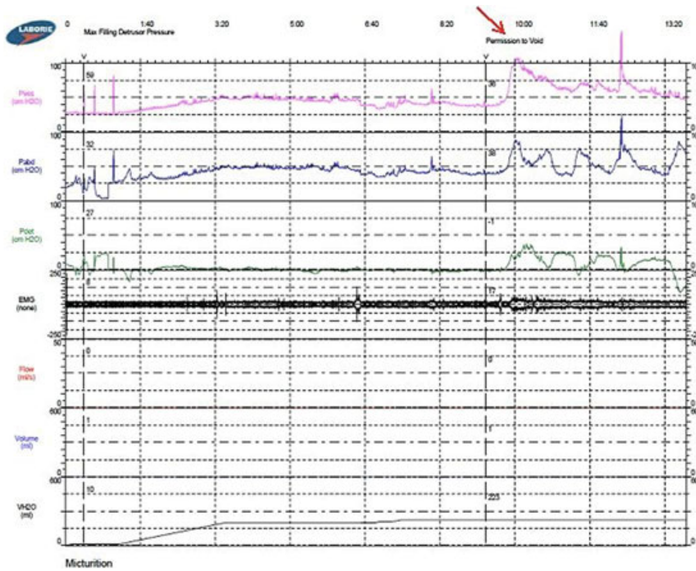

FIGURE 3.7 Detrusor underactivity. Note there is some artifact from P_{abd}, but the waveform of P_{ves} after permission to void command is given demonstrates a poorly sustained, detrusor contraction (*arrows*) that reaches approximately 25 cm H_2O and is inadequate to generate a urine flow

most cases is related to the residual outlet resistance during the void (Fig. 3.7).

Coordination

The first recordable event in micturition is electrical silence of the pelvic floor EMG. Thus, coordination of voiding requires that the smooth and striated sphincters relax and open just prior to the onset of the detrusor contraction. During a normal void the bladder neck and sphincter should remain open for the duration of the entire void. When increased EMG activity is seen or a lack of opening of the bladder outlet is noted on video urodynamics, a pathologic condition may exist.

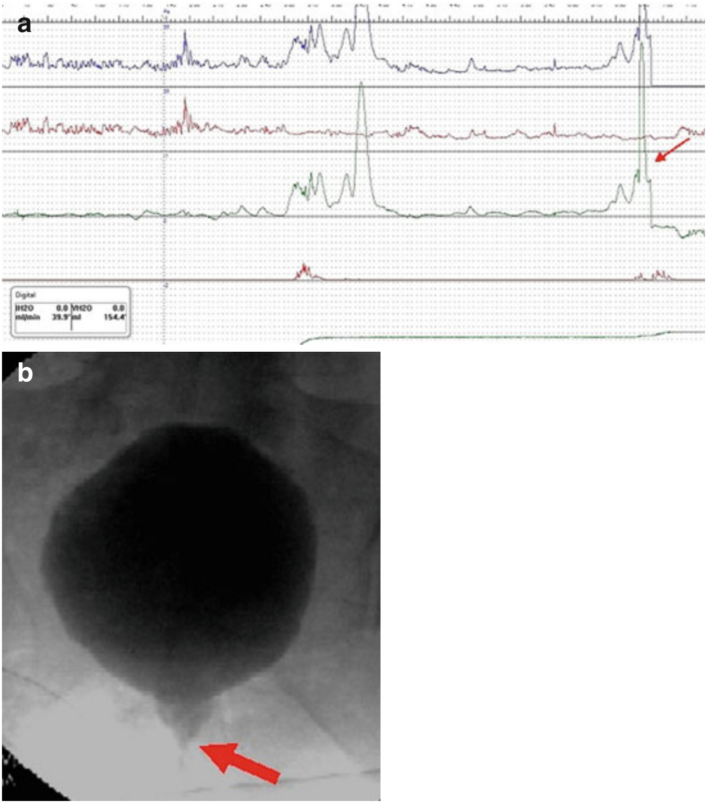

FIGURE 3.8 Dysfunctional voiding. This tracing is from a neurologically normal female. She voided P_{ves} out (*thin arrow*), but note the increased detrusor pressure and low urine flow rate consistent with BOO. Voiding images reveal a dilated proximal urethra and bladder neck with a narrowed midurethra (*thick arrow*). (**a**) Urodynamic Tracing. (**b**) Fluoroscopic Voiding Image

If there is a lack of coordination in a patient without a known neurologic condition consideration of a spinal condition may warrant referral to a neurologist. Lack of coordination in voiding may be seen in conditions such as detrusor external sphincter dyssynergia (DESD) and dysfunctional voiding (Fig. 3.8). However, apparent but artifactual uncoordinated voiding may be seen in patients with pain related to the urethral catheterization for the UDS study. In such suspected cases, it is important to review the non-invasive (unintubated) uroflowmetry flow pattern to rule out catheter related pain artifact resulting in an aberrant uroflow [10]. When documenting the interpretation of the UDS tracing, coordination is usually reported as coordinated, or uncoordinated.

Complete Emptying

As noted previously, just prior to beginning the UDS study the patient is catheterized for a PVR. At the conclusion of the study a second PVR is calculated by subtracting the voided volume in the uroflow transducer from the infused volume. Emptying can be one of the more difficult parameters to accurately reproduce during urodynamics. Micturition is typically a private event, which can be hard to replicate in a urodynamics lab. Urodynamics requires multiple transducers to be placed, two of which are invasive (urethrovesical and rectal) and may result in pain and thus suppression of the micturition reflex. Additionally, the other individuals in the UDS laboratory (there is often a technician performing the study as well as a fluoroscopy technician in the room) may induce psychogenic inhibition due to voiding in front of others.

Complete emptying is defined by the lack of a significant post void residual (PVR). However, there is no universally accepted cut off for a normal/abnormal PVR in either men or women. Typically, in men a PVR less than 50–100 mL is considered adequate bladder emptying, while a PVR greater than 200 mL is considered abnormal [4]. When documenting the interpretation of the UDS tracing complete emptying is usually reported as normal or abnormal. Typically, the PVR is also reported in ml.

Clinical Obstruction

Clinical obstruction, also referred to as bladder outlet obstruction (BOO), is defined by the relationship between

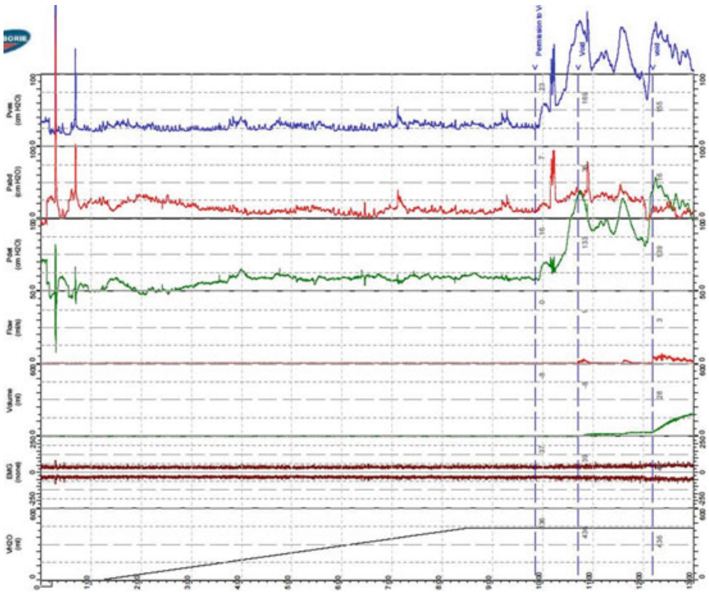

FIGURE 3.9 Benign prostatic obstruction. During voiding there is an elevated detrusor pressure with a weak urinary flow rate consistent with bladder outlet obstruction. BOO Index = P_{det} @ Qmax − 2 × Qmax. BOOI = 125 − 2(5) = 115 is consistent with bladder outlet obstruction

bladder pressure during voiding and urine flow. BOO is generally defined as high voiding pressure and low urine flow but may also occur in the setting of detrusor underactivity in which the voiding pressure may be attenuated. BOO can result from a variety of causes. In men prostatic obstruction (Fig. 3.9), urethral stricture and bladder neck contractures are common etiologies. In women, the most common cause is probably iatrogenic due to prior SUI surgery or vaginal prolapse (Fig. 3.10). Other less common causes include primary bladder neck obstruction (Fig. 3.11), and dysfunctional voiding. While there are multiple nomograms to assess bladder outlet obstruction, there is no accepted definition of obstruction, nor dominate nomogram to establish the diagnosis [7, 8]. While nomograms

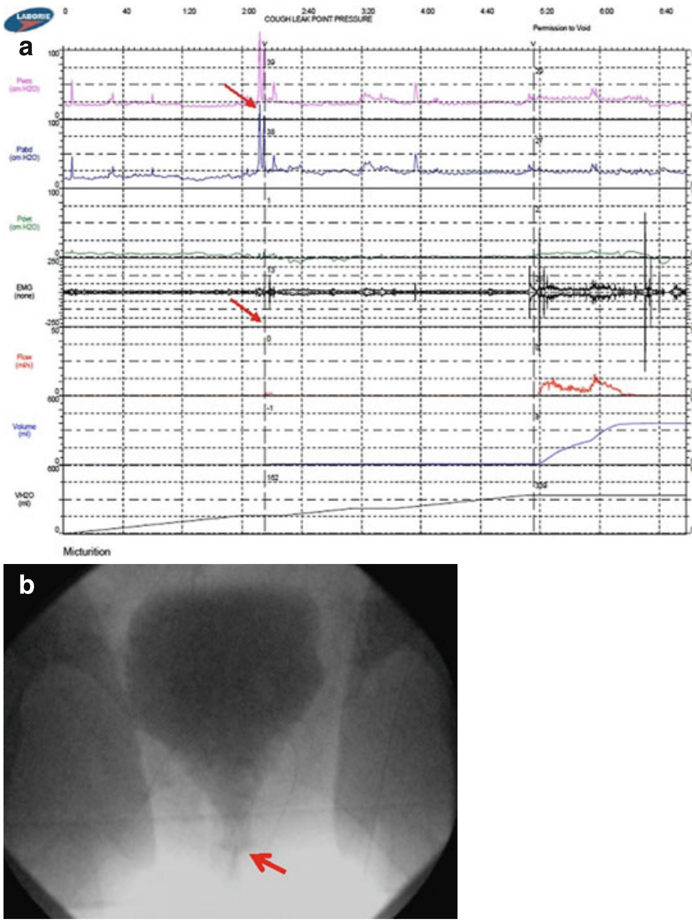

Figure 3.10 (**a**) Obstructing midurethral sling. Valsalva demonstrates SUI (*thin arrows*) and during volitional voiding there was a low urinary flow rate and detrusor underactivity. Voiding images below reveals an abrupt cutoff of contrast at an obstructing midurethral sling (*thick arrow*) with dilation of the proximal urethra. (**b**) Obstructing Midurethral Sling. Abrupt cutoff of contrast at an obstructing midurethral sling (*thick arrow*) with dilation of the proximal urethra

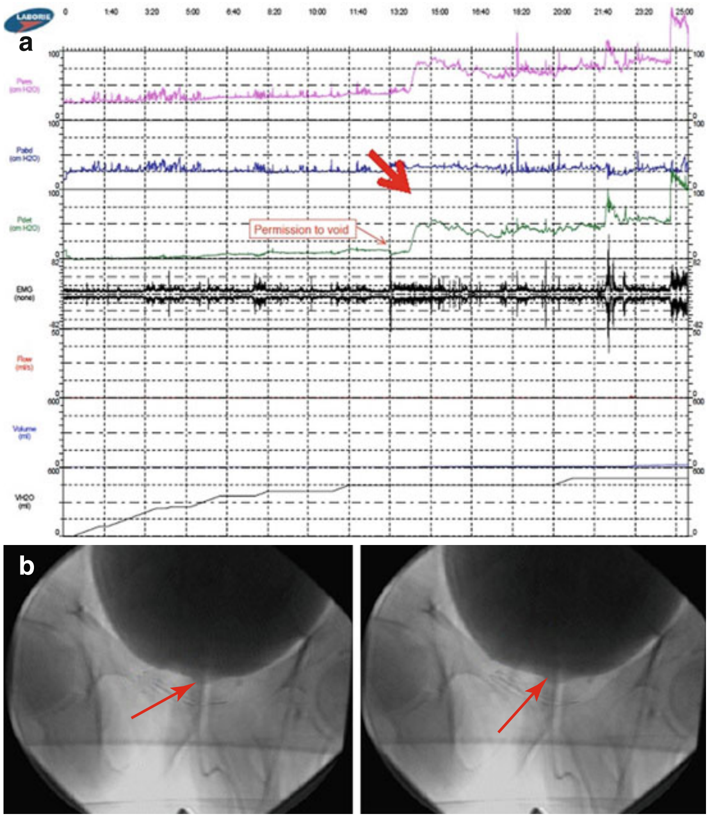

FIGURE 3.11 Primary bladder neck obstruction. The *thick arrow* denotes a strong detrusor contraction without flow. The *thin arrows* on video images demonstrate a closed bladder neck during attempt to void. (**a**) Urodynamic Tracing. (**b**) Fluoroscopic Voiding Image

have been established to more objectively describe obstruction, these nomograms must be utilized in conjunction with clinical observations [2, 14]. When documenting the interpretation of the UDS tracing clinical obstruction is usually reported as unobstructed, equivocal, or obstructed.

Conclusions

UDS plays an important role in evaluating lower urinary tract function. Over the course of the last few decades as urodynamicists gained an evolving understanding of the lower urinary tract great efforts were undertaken to develop standardized testing formats and terminology to allow for reproducible results that can be communicated to other health care providers. As part of this, we feel that the use of the “9 C’s” provides a simple and concise means to evaluate and report upon the large amount data generated by urodynamics testing.

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