Chapter 2
The 9 "C's" of Pressure-Flow Urodynamics

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There exists no generally agreed upon orderly or methodical approach to interpreting pressure-flow urodynamic (PFUD) studies. The amount of information produced during a routine PFUD study can be imposing to fully 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 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 [1]. In doing so, this system minimizes the potential for "missing" an important and relevant finding on the tracing. This framework is easy

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Table 2.1 The 9 "C's" of pressure-flow urodynamics

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

to understand, remember, and applicable to all PFUD studies for virtually all lower urinary conditions.

The 9 "C's" are listed in Table 2.1. In the functional classification as popularized by Wein [2] 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." In the filling phase, the "C's" consist of contractions (involuntary), compliance, continence, capacity, and coarse sensation. In the emptying phase contractility, complete emptying, coordination, and clinical obstruction are evaluated.

The "C's" are not specific for all types of urinary dysfunction or all urodynamic abnormalities. Nevertheless, by organizing and interpreting a study within this framework, it provides an 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 patients 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.

The 5 C's of Filling and Storage

There are five key parts of the filling and storage portion of the PFUD study that should be recorded in the final interpretation of the study. This segment of the PFUD study is sometimes referred to as "filling cystometry." This portion commences with bladder filling and ends with the command "permission to void" [3].

The aims of this part of the study are to assess involuntary detrusor activity, bladder compliance, sensation, capacity and, in the appropriate setting, urethral function.

Contractions refer to the presence or absence of phasic (or terminal) involuntary bladder contractions with respect to detrusor function (specifically during bladder filling only) [3]. Though the actual definition of an involuntary bladder contraction is sometimes debated, the finding of the characteristic wave form, along with whether it is spontaneous or provoked, or phasic or terminal should be recorded. The pressure and volume and amplitude of such a finding may be recorded as well, although the clinical significance of such information is variable and debatable depending on the clinical circumstances of the patient under study. Nevertheless, just as importantly, the absence of such a finding should be recorded as normal.

Compliance is the relationship between the change in bladder pressure and bladder volume during bladder filling. Physiologically, compliance is determined by the innate viscoelastic properties of the bladder. Generally the rise in bladder pressure with filling, in the absence of involuntary bladder contractions, is very small, and frequently imperceptible. Compliance is calculated by dividing the change in bladder volume by the change in bladder pressure at the point in the PFUD study just prior to the command to void, and in the absence of an involuntary bladder contraction [4]. Normative values are not universally agreed upon and compliance is generally recorded as either normal or abnormal. Abnormal bladder compliance is a significant risk factor for upper urinary tract deterioration. Classically, abnormal compliance can be seen in radiation cystitis, neurogenic bladder (especially spina bifida), and denervated bladders following radical pelvic surgery.

Coarse sensation of bladder filling is quite subjective and variable due to the very artificial and non-physiological circumstances under which the PFUD study is performed. Using the term "coarse sensation," though fairly non-descript, is pragmatic and useful. In general, the description of the sensation of bladder filling is very general and abnormalities of sensation may be described as absent, reduced, or increased [3]. Due to the need for urethral catheterization, causing some degree of urethral discomfort and/or pain, as well as the tip of the catheter within the bladder and the non-physiological filling rate, fluid and fluid temperature, the perception of bladder filling can be considerably altered. Furthermore, the patient's ability to perceive sensation and verbally express to the examiner such sensations as the bladder fills are somewhat compromised. The volumes at which the first sensation of bladder filling, first desire to void, normal desire to void, strong desire to void, urgency, and pain are documented. It is essential to note when such sensations correlate with particular urodynamic findings such as bladder overactivity. Normative parameters and assessment methods for bladder sensation have been proposed but none are universally accepted [5].

Continence refers to the presence or absence of urinary leakage during the PFUD study. Urinary incontinence may be due to abnormalities of bladder function (involuntary detrusor contractions, or abnormal compliance), or urethral function, or a combination of both. Incontinence occurring coincident with an involuntary bladder contraction is termed detrusor overactivity incontinence [4]. Stress incontinence, due to diminished sphincter function, may be provoked with cough or Valsalva or other maneuvers. Urethral function during bladder filling may be assessed by abdominal leak point pressure or urethral pressure profilometry. Incontinence recorded during the study may reproduce the patient's symptoms or not. For the patient without a clinical complaint of urinary incontinence, the finding of stress or detrusor overactivity incontinence is often artifactual and of little clinical significance. Alternatively, in the patient with a clinical complaint of urinary incontinence, it is important to make every effort to reproduce the incontinence during the study. For purposes of interpreting the study, it is important to record whether incontinence was noted during the study, the type of incontinence, and whether it reproduced the patient's symptoms. Other parameters specific to the episode(s) of incontinence such as volume infused, bladder pressure, urethral pressure, and sensation at the moment of incontinence should be recorded as well.

Cystometric capacity is the volume contained within the bladder at the point during the filling phase of the PFUD study when the patient cannot tolerate further filling. This is also termed maximum cystometric capacity. This is usually recorded as cc or ml. This volume is often quite different from the functional bladder capacity that is obtained from a voiding diary or frequency/volume chart in combination with a post-void residual. Voiding diaries should be obtained prior to an urodynamic evaluation as they can be useful in determining the clinical relevance of the cystometric bladder capacity. Cystometric capacity is generally smaller than the functional bladder capacity. Normative values for cystometric capacity are widely variable and have been reported between 370 and 540 cc ±100 cc [6].

The 4 C's of Bladder Emptying

The bladder emptying or voiding phase of the PFUD study is sometimes referred to as voiding cystometry. This phase commences with the command "permission to void" and ends when the subject under study considers themselves to have completed micturition [3].

Contractility is the strength of detrusor contraction or force generation during voiding. In order to empty properly, the detrusor must generate a contraction of adequate magnitude and duration to overcome outlet resistance and empty the contents of the bladder satisfactorily. Contractility is related to force generation by the detrusor and overall bladder outlet (urethral) resistance during voiding. However, the assessment of contractility may also be affected by anatomic abnormalities such as bladder diverticula or massive vesicoureteral reflux that result in dissipation of pressure during the contraction. In addition, in some cases contractility may be difficult to assess where urethral resistance is very low or negligible such as in cases of severe stress urinary incontinence. There are various formulae that have been developed in order to assess contractility such as the bladder contractility index (BCI), especially in men; however, these should be interpreted in the context of the clinical situation [7, 8].

Abnormalities of contractility include conditions that result in an inability to obtain, maintain, or sustain an adequate contraction. This may be due to poor detrusor force generation overall (neurogenic or myogenic) or due to inadequate duration of the contraction. Contractility is most often recorded as either normal or abnormal (underactive); however, using the BCI a numerical value may be obtained classifying the contraction as strong, normal, or weak.

Complete emptying indicates the lack of a significant post-void residual (PVR). The precise definition of what constitutes an elevated PVR is not universally agreed upon. PVRs are often assessed twice during the PFUD study. The initial PVR value is obtained by catheterizing the bladder after instructing the patient to void to completion just prior to the start of the PFUD study. The second PVR is obtained at the end of the PFUD study and is calculated by subtracting the voided volume from the infused volume. Incomplete emptying (elevated PVR) is due to either detrusor underactivity or bladder outlet obstruction or a combination of both. Complete emptying may be recorded as normal or abnormal, or as the PVR values obtained.

Coordination refers to the synchronization of the detrusor contraction and the voluntary and involuntary activity of the bladder outlet, including the bladder neck, and smooth and striated sphincters (vesicourethral coordination). Normal voiding commences with the relaxation and opening of the bladder outlet just prior to the detrusor contraction. The coordinated outlet remains open for the duration of the bladder contraction. If all or part of the bladder outlet does not open prior to the onset of a detrusor contraction, or fails to remain open for the duration of the contraction, this is abnormal. Many conditions can lead to a lack of coordination between the bladder and bladder outlet including detrusor striated dyssynergia and dysfunctional voiding ("non-neurogenic neurogenic bladder"). Lack of coordination between the bladder and bladder outlet may result in high pressure voiding, and/or incomplete bladder emptying. For purposes of documentation, vesicourethral coordination is present or absent.

Clinical obstruction, or bladder outlet obstruction is defined by the relationship between bladder pressure and urinary flow. Subjectively, high voiding pressure associated with low urine flow is the definition of bladder outlet obstruction. Objectively, various nomograms and calculations have been devised to more precisely define this dynamic relationship in both men and women but none are universally utilized though the findings between the various methods correlate quite well [9]. Such nomograms categorize individuals as obstructed, equivocal, or unobstructed. Obstruction may occur with or without lower urinary tract symptoms (LUTS). Clinically, LUTS in the presence of obstruction or other negative prognostic signs mandates therapy. In males, obstruction may be secondary to BPH, prostate cancer, urethral stricture, bladder neck contracture, neurological disease, and a variety of other causes. Bladder outlet obstruction in females is less common but may be iatrogenic due to stress incontinence surgery, or due to vaginal prolapse, urethral diverticula, neurological disease, and a variety of other causes. Various nomograms for objectively quantitating female bladder outlet obstruction have likewise been developed but none are universally utilized [10].

The study depicted in Figure 2.1 provides a schema for interpreting a urodynamics study with the context of the "9 C's". This study demonstrates absence of involuntary bladder contractions. The change in Pdet with filling is negligible consistent with normal compliance. There was no incontinence seen during this study. The first sensation of bladder filling occurred at a volume of approximately 100 cc

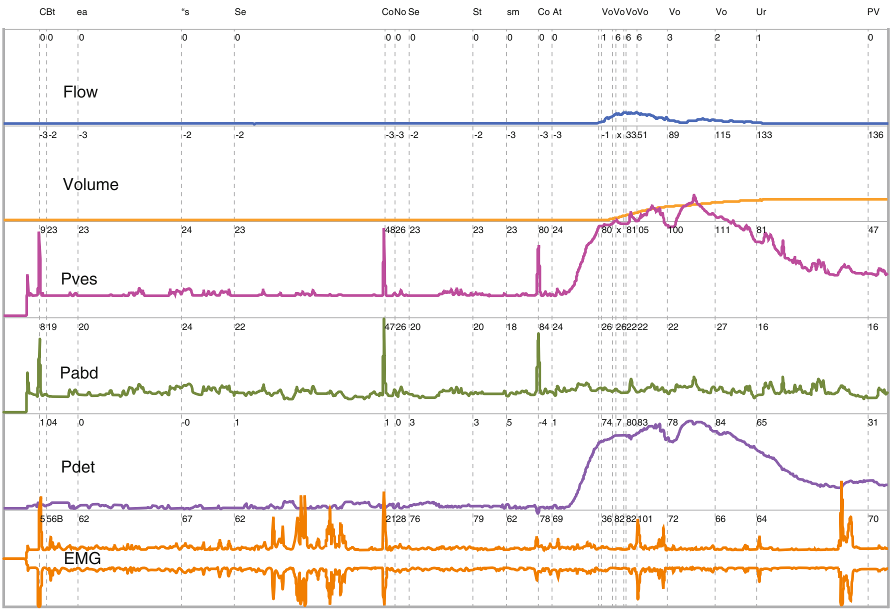

Fig. 2.1 Urodynamic tracing using the "9 C's" organizational schema. This is a 65-year-old male with LUTS. Infused volume (*not shown*) was 230 cc

(Volume infused not shown but is indicated on the tracing by the annotation "Se" just after the 1:00 min mark of the study.) Bladder capacity was 230 cc (infusion volume not shown on this tracing).

Bladder emptying commenced with a volitional detrusor contraction. The command to void was given just prior to the 3:00 min mark and is indicated by the annotation "At." There was no inappropriate activity of the external sphincter as suggested by the EMG during voiding. The bladder did not empty completely as the voided volume was only 136 cc. Detrusor pressure, despite being elevated, was insufficiently sustained to empty the bladder. The voiding pressure in excess of 70 cm H_2O, and the low flow rate ($Q_{max}=6$) is very suggestive of bladder outlet obstruction.

The 9 C's for this study are as follows:

Filling/Storage:

Contractions (involuntary): none
Compliance: normal
Continence: no incontinence demonstrated
Coarse sensation: normal
Capacity: 230 cc

Emptying:

Contractility: abnormal, underactive
Coordination: yes
Complete emptying: no, PVR = 94 cc
Clinical obstruction: yes

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