Chapter 11
Bladder Filling and Storage: "Capacity"

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Introduction

Bladder capacity is a measure used to estimate the volume of urine a patient can comfortably hold. It can be determined in many ways and often changes from void to void making it a rather imprecise measure of the true amount of urine the bladder is able to hold. The ability of bladder capacity measures to accurately predict the cause of bladder symptoms such as frequency or urgency of urination is limited but provides the clinician with a general idea of bladder dynamics, toileting patterns, and impact on patient quality of life. Patients often report decreased bladder capacity, or the subjective symptom that their bladder does not hold as much as it used to, based on a more frequent desire to go to the toilet. Complaints such as "I have a small bladder" or "my bladder shrunk" are common reports as are "I must rush" and "sometimes I don't make it." A frequency–volume chart or voiding diary may provide slightly more objective measures of bladder capacity but does not insure the bladder was actually *full* at the time of voiding since the decision to void is often made out of convenience, opportunity, or fear of needing a toilet when one may not be available. Frequency–volume chart measures reflect a large range of volumes at which the patient chose to go to the toilet (Table 11.1) and rarely are these annotated with the reason why the patient chose to void.

From the frequency–volume chart maximum and average-voided volumes can be determined as can the median functional bladder capacity which is defined as the median maximum voided volume during every day activities [1]. A 3-day chart is preferred and will likely demonstrate a greater range of voided volumes and a larger maximum voided volume than a 1-day diary [2].

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Table 11.1 Bladder diary

Time Interval	Urinated in Toilet	Incontinent Episode Amount L/S	Reason for Urine Leakage	Type/Amount of Liquid Intake
6 am				
7 am	450			
8 am				Coffee
9 am	200			
10 am				Coffee
11 am				
Noon	200			Iced Tea
1 pm				
2 pm	300			
3 pm				
4 pm				
5 pm	200			
6 pm				wine/water
7 pm				
8 pm	300			
9 pm				
10 pm-Midnight	200			
Midnight-2 am				
2-4 am				
4-6 am				

Type of Pad_____None________________ # Pads Used_____0_____

Normal bladder capacity should be considered as a wide range of acceptable values and likely varies with age and 24-h urine volume [2]. In children, normative values for bladder capacity were initially estimated using linear functions versus age; [3] however, this method was found to substantially underestimate bladder capacity and not account for the upper and lower limits of normal [4]. Despite its shortcomings linear equation estimates are often referenced as a measure of normative values [5]. Further studies have suggested that bladder capacity correlates logarithmically with age in children to account for a growing bladder and should be interpreted as normal within two standard deviations of the mean (between the 5th and 95th percentiles) [6].

Cystometry is a component of urodynamic testing that measures the pressure–volume relationship of the bladder. It is also used to assess bladder capacity, compliance, sensation, and uninhibited bladder contractions. The cystometrogram is a graphic representation of the pressure volume relationship annotated with patient reported sensations and other important findings. Sensations are purely subjective and therefore depend on a cooperative and informed patient for reliability. The artificial environment in which cystometry is performed including the non-physiologic retrograde filling of the bladder can produce artifacts in the results. A nervous or fearful patient, or one who is experiencing discomfort from the urodynamic catheter,

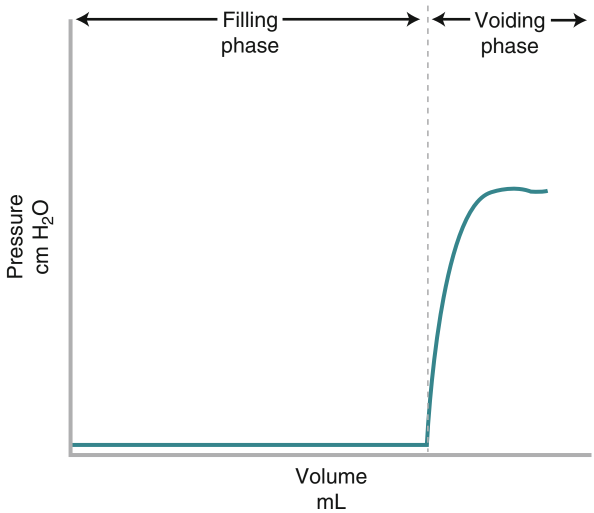

Fig. 11.1 Idealized pressure–volume relationship demonstrating low pressure storage during the filling phase and a rise in pressure during the voiding phase. Adapted from Campbell-Walsh urology, 10th ed., Elsevier; 2012

may report sensations and symptoms that are not reflective of their presenting bladder complaint. Conversely, a sedated or stoic patient may not report sensations reflective of their complaint.

Cystometric capacity is the bladder volume at the end of filling cystometry when the patient reports a normal desire to void. It is generally the point where permission to void is given; however, in some situations further volume may be infused. Maximum cystometric capacity is the volume at which a patient reports that they cannot hold any more in their bladder and can no longer delay voiding [1]. The end point for bladder filling should be well annotated on an urodynamics tracing such that the clinician interpreting the information can properly categorize the final infused volume as either cystometric capacity or maximum cystometric capacity. Capacity measures reflect not only voided volume, but also post-void residual urine. An idealized pressure–volume relationship demonstrates a detrusor pressure near zero during the filling phase until cystometric capacity is reached, and generation of detrusor pressure corresponding to the initiation of voluntary voiding (Fig. 11.1).

Measuring Cystometric Capacity

Good Urodynamics Practices are outlined in Part 1 of this book but are briefly reviewed here in relation to cystometric capacity measurement. Initial bladder volume and detrusor pressure should be zero at the start of an urodynamic study. This is achieved by emptying the bladder to completion with a catheter prior to placing the sensor tipped urodynamic catheter. In addition, vesical pressure and abdominal pressure should be equalized to establish a subtracted detrusor pressure of zero.

Bladder filling begins at a rate determined by the urodynamicist, usually between 10 and 100 ml s/min. This rate may be held constant throughout the study or may be altered in response to patient parameters. The patient will also make urine at a rate determined by their hydration status and underlying renal function contributing to the volume in the bladder during the study. Given the short duration of time over which an urodynamic study is typically performed this latter contribution is often ignored. There is data to suggest however that natural filling during cystometry should be accounted for since it may occur at a rate of 6.1 ml/min, increasing bladder capacity 14 % [7]. Other studies have suggested a rate of 1.4 ml/min increasing capacity 12.1 % [8]. Instructions given to patients regarding hydration and the "need to come with a full bladder" may influence the rate of urine production during the urodynamics test. Specifically, when patients are informed that they must give a urine sample or perform a non-invasive uroflow on arrival they may drink excessively before testing [7]. In addition, prolonged set up and testing time can further increase the contribution of natural filling to infused volume, impacting the accuracy of capacity measures [8].

Sensation during filling cystometry is reported by the patient and documented on the urodynamics tracing. Once a normal desire to void is reported by the patient, cystometric capacity is documented. Next, the patient may be instructed to report when he or she can no longer delay micturition and this volume is recorded as maximum cystometric capacity. The capacity measures obtained should be compared to the voided volumes noted on the frequency–volume chart to ensure consistency and reliability of the urodynamic test measures. Artifact secondary to the non-physiologic fill rate and abnormal situation of being observed during a normal private process can impact measurements obtained. Repeat fill cycles of the bladder may be needed and are encouraged to accurately interpret bladder capacity. Abrams has correlated patient reported sensation during urodynamic testing with maximum cystometric capacity. He found that first sensation of bladder filling correlated with roughly 50 % of maximum capacity while normal desire to void and strong desire to void correlated with 75 and 90 %, respectively [9].

In situations where abnormal bladder function exists, cystometric capacity may be reached before the patient can report a desire to void. For example, in patients with impaired sensation, cystometric capacity is the volume at which bladder filling was stopped. There can be several reasons for stopping and this should be well annotated on the urodynamics tracing. With impaired compliance, high detrusor pressures may prompt the urodynamicist to stop filling; in other situations, pain, involuntary voiding, or a maximum predetermine filling volume may prompt discontinuation. Detrusor overactivity or impaired compliance may lead to leakage of urine before the patient reports sensation of fullness; in these situations, cystometric capacity is measured as the volume at which leakage began. In the setting of sphincteric incompetence, capacity measures may be artificially low due to passive leakage across the sphincter. Occluding the urethral outlet with a catheter balloon can increase capacity measures. Maximum cystometric capacity is only defined for patients with normal bladder sensation and therefore generally only cystometric capacity is reported in this population.

Definitions of Normal and Abnormal

Normal cystometric capacity should be interpreted as a wide range of acceptable values. Reference ranges for normal cystometric capacity in adults have not been universally agreed upon primarily because the question still remains on how well this reflects pragmatic functional bladder capacity. Normal cystometric capacity is generally defined as 300–550 ml with larger values obtained in men compared to women [10]. These reference values represent mean values obtained on a sample of only 28 men and 10 women with no history of urologic disease. Mean age was only 24 years, which is hardly comparable to the population of patients generally undergoing urodynamic testing. In another study of 32 highly selected, middle aged volunteers without urologic disease, mean cystometric capacity was 586 ± 193 ml; this is much higher than several previous reports [11].

Abnormal cystometric capacity can be either too small or too large. Small capacity may result from involuntary bladder contractions, bladder pain, impaired compliance, or bladder oversensitivity. Yoon and Swift [12] defined abnormally small maximum cystometric capacity as less than 300 ml but advised using caution in interpreting low cystometric capacity as abnormal in the setting of a normal functional bladder capacity on frequency–volume charts. Large capacity may result from poor or absent bladder sensation during filling or neurologic bladder dysfunction. Large bladder capacity, outside of the range of normal, is generally not interpreted to be pathologic in the absence of neurologic disease. Artifact, as noted above, from catheter placement, filling rate, media temperature, media type, patient positioning, provocative measures such as coughing, patient discomfort or patient anxiety may impact reliability of this measure [13, 14]. For example, during cystometry a patient is generally positioned in either the seated or the standing position for the duration of the test. When completing a 24-h frequency–volume chart a patient generally changes body positions throughout the day and night with the largest voided volumes generally recorded after sleeping in the recumbent position. The impact of patient position on the variability in daytime voided volumes has not been reported. Faster filling rates during cystometry have been shown to produce lower maximum cystometric capacity measures [13]. Room temperature filling media which is much cooler than body temperature urine has been shown to result in lower maximum cystometric capacity measures as well [14]. The non-physiologic fill rate used during urodynamic testing may impact bladder sensations as well as bladder compliance. Prior studies have shown that supraphysiologic fill rates used during urodynamic testing produce an increase in bladder wall pressure and a decrease in bladder compliance [15]. It is unclear if bladder wall pressure influences bladder sensation and ultimately diminishes maximum cystometric capacity.

Relation to Functional Capacity

Frequency–volume charts and bladder diaries are felt to be more accurate representations of true bladder capacity since these measures document the patients voiding patterns in a more natural environment than cystometry during urodynamic testing. However, the act of keeping the journal may influence voiding patterns making the patient more in tune with their bladder sensations. Diokno et al. [16] reported that moderate correlation exists between functional bladder capacity and cystometric capacity thus establishing validity of the cystometric bladder capacity measure ($r = 0.493$, $p < 0.01$). Further studies on women with incontinence confirmed correlation between the two measures but showed a statistically significant difference in volumes obtained, with a smaller volume recorded at the time of cystometry. Thus they interpreted the data as displaying a weak clinical relationship between the two measures [12]. Yoon and Swift report poor positive predictive value (51.4 %) of cystometry in detecting abnormalities in bladder capacity but good negative predictive value (84.0 %). Thus, *normal* bladder capacity during cystometry correlates strongly with *normal* functional bladder capacity.

Videourodynamic Assessment

Radiologic imaging of the bladder and urethra during urodynamic testing can be performed with synchronous fluoroscopy termed videocystourethrography. This is generally reserved for patients with more complex clinical presentations or those with neurologic dysfunction. Concomitant imaging of the bladder and urethra allows direct observation of the effects of bladder events. During bladder filling and at capacity, an assessment of bladder shape, position with respect to the pubic symphysis, conformation of the bladder neck, diverticuli and vesicoureteral reflux (VUR) is undertaken (Fig. 11.2a, b). Leakage of urine can be detected at earlier time points and at smaller volumes using fluoroscopy than the standard uroflow sensor.

Urodynamic Examples of Conditions of Altered Capacity

Bladder oversensitivity is defined as an increase in bladder sensation or urgency that may occur during filling cystometry in the absence of a rise in detrusor pressure [1]. This term is reserved for situations where sensations are reported at volumes felt to be lower than normal. Generally an early first sensation, an early first desire to void, an early strong desire to void, and low maximum cystometric capacity are noted (Fig. 11.3).

Several conditions such as overactive bladder, bladder pain syndrome (BPS), and urinary tract infection (UTI) are associated with bladder oversensitivity. Urodynamic tracings similar to Fig. 11.3 are commonly seen with each of these conditions. The

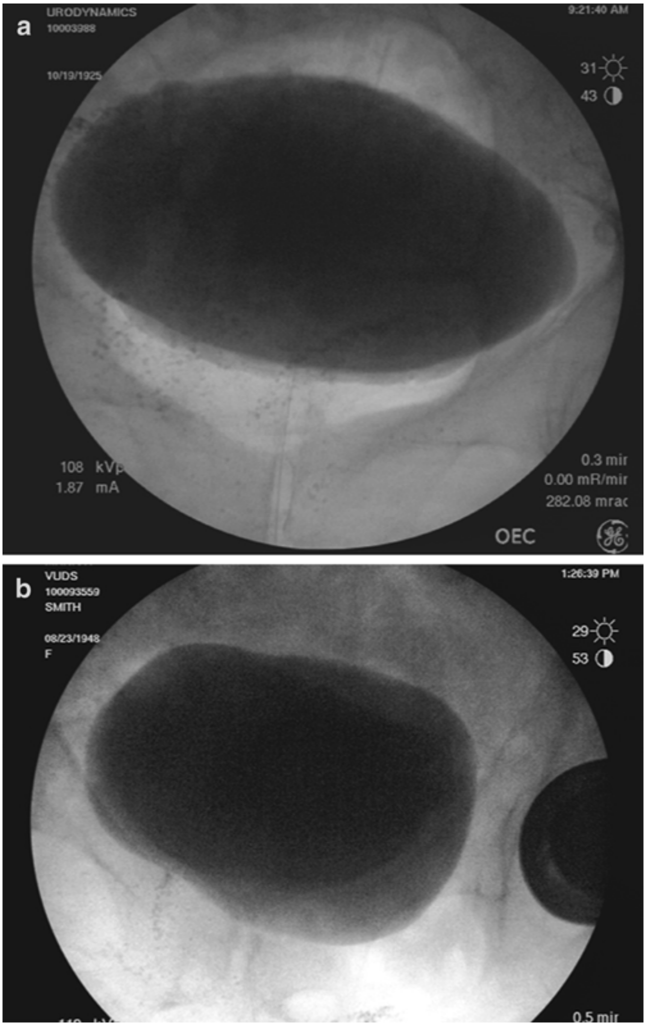

Fig. 11.2 (**a** and **b**) Videofluoroscopic images corresponding to maximum cystometric capacity showing a smooth contoured bladder without evidence of diverticuli, vesicoureteral reflux, bladder neck funneling, or bladder prolapse

hallmark signs on urodynamics are early reported sensations and low cystometric capacity and maximum cystometric capacity.

Overactive bladder syndrome (OAB) is a clinical condition consisting of bothersome urinary symptoms. The International Continence Society has defined OAB as urgency of urination, with or without urgency urinary incontinence (UUI), usually accompanied by frequency and nocturia [17]. OAB may produce urgency during urodynamic testing, which can be purely sensory in nature or have a

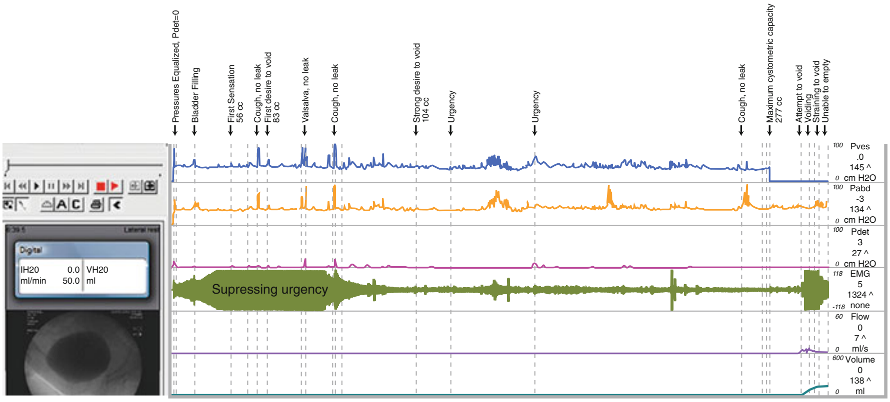

Fig. 11.3 Cystometrogram showing small cystometric capacity. Vesical pressure and abdominal pressure were equalized at the start of the study with a corresponding detrusor pressure of zero. Valsalva followed by cough were performed during the filling phase of the study without associated leakage of urine. With increasing fill volume the patient reports early first sensation (56 cc), early first desire to void (83 cc), and early strong desire to void (104 cc). Increased EMG activity is noted as the patient is suppressing urgency. The patient could no longer delay micturition and reached maximum cystometric capacity at 277 cc. This cystometrogram represents bladder oversensitivity

corresponding rise in detrusor pressure (see detrusor overactivity below). OAB impacts cystometric and maximum cystometric capacity and effective treatment can improve urodynamic parameters as well as patient complaints [18].

BPS is the preferred term for the clinical condition previously referred to as interstitial cystitis. It is defined as the complaint of suprapubic pain related to bladder filling, accompanied by other symptoms such as increased daytime and nighttime frequency, in the absence of proven urinary infection or other obvious pathology [17]. BPS often produces bladder discomfort at low cystometric capacity in the absence of a rise in detrusor pressure during urodynamic testing. Effective treatment can improve cystometric and maximum cystometric capacity as well as patient symptoms [19].

UTI can be defined clinically as the presence of dysuria or bladder pain associated with voiding, and pathologically as the presence of bacteria in a properly obtained urine culture associated with a pyuria, or by several other heterogeneous parameters [20]. Generally, UTI causes increased bladder sensitivity and bladder discomfort at low cystometric capacity. Urodynamic testing should be avoided in the setting of acute UTI. If performed, urgency and/or discomfort in the presence or absence of a rise in detrusor pressure will likely be noted.

Detrusor overactivity (DO) is an involuntary bladder muscle contraction that occurs during filling cystometry often producing a sensation of urgency corresponding to a rise in detrusor pressure (Fig. 11.4a, b). DO can be phasic, which can occur once or several times throughout an urodynamic study and may or may not lead to

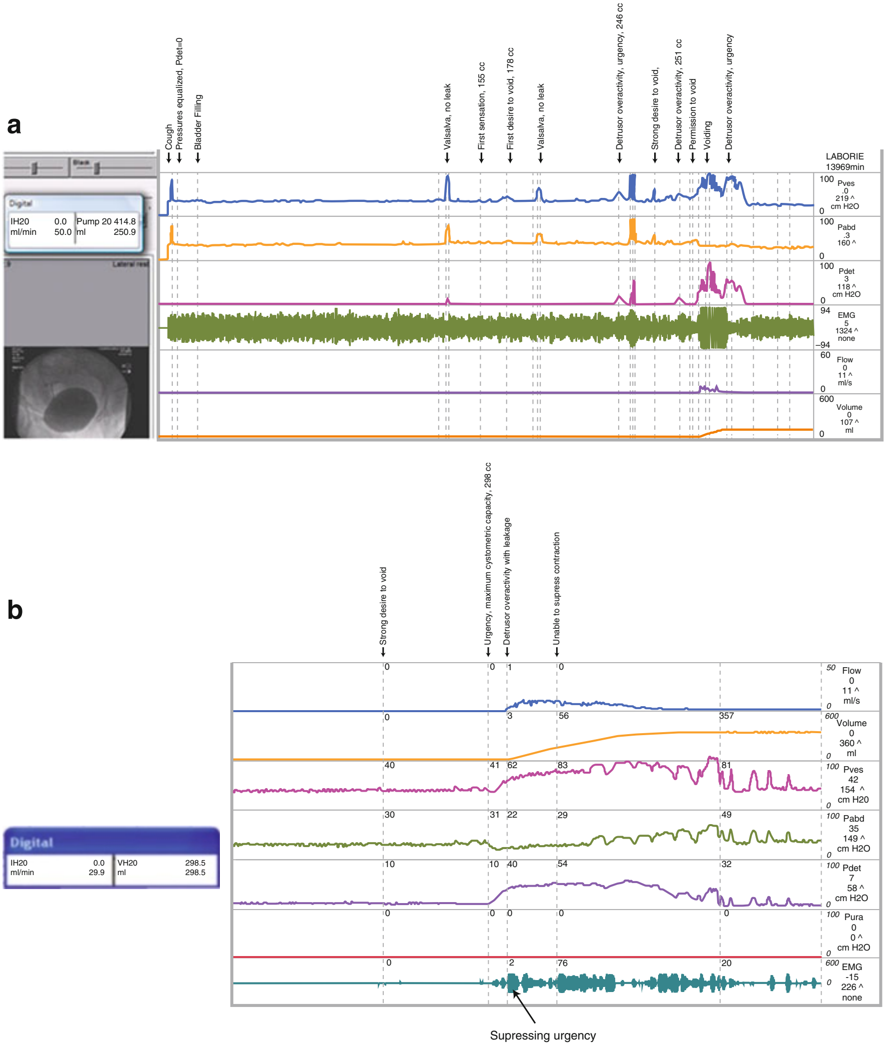

Fig. 11.4 (**a**) Cystometrogram showing detrusor overactivity associated with patient reported urgency. Videofluoroscopic image at cystometric capacity demonstrates a smooth bladder without evidence of trabeculation, diverticuli, vesicoureteral reflux, or bladder neck funneling. Vesical pressure and abdominal pressure were equalized at the start of the study with a corresponding detrusor pressure of zero. With increasing fill volume the patient reports first sensation at 155 cc, desire to void at 178 cc, and strong desire to void at 251 cc. Phasic detrusor overactivity is seen at 246 and 251 cc. After the involuntary contraction subsided, permission to void was granted and the patient volitionally voided. Following voiding another detrusor contraction with associated urgency was noted. (**b**) Cystometrogram demonstrating terminal detrusor overactivity associated with patient reported urgency and leakage of urine. Vesical pressure and abdominal pressure were equalized at the start of the study with a corresponding detrusor pressure of zero. At a maximum cystometric capacity of 298 cc the patient reported urgency and a strong desire to void. Detrusor overactivity and associated leakage followed. Increased EMG activity was noted as the patient attempted to suppress the involuntary bladder contraction

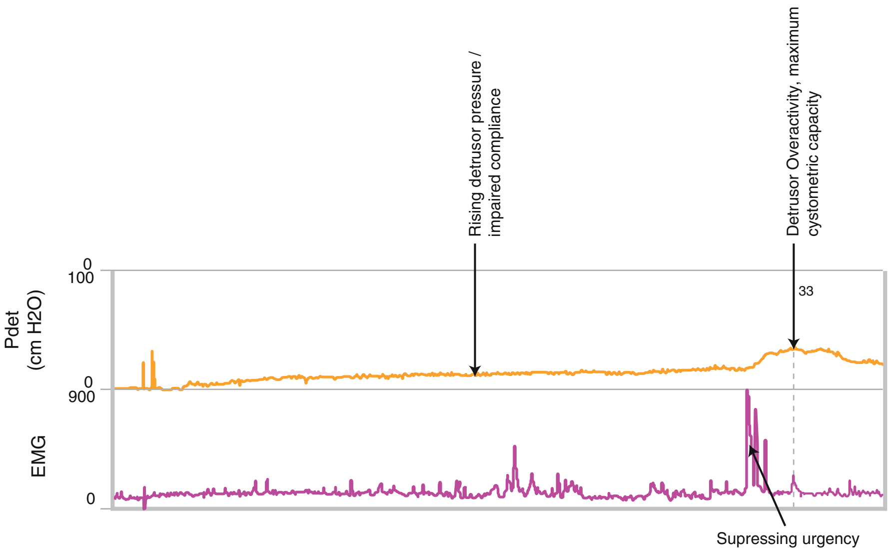

Fig. 11.5 Cystometrogram with impaired bladder compliance. Vesical pressure and abdominal pressure were equalized at the start of the study with a corresponding detrusor pressure of zero. With increasing fill volume the detrusor pressure steadily rises to a peak of 33 cm H_2O. Increased EMG activity is noted as the patient is suppressing urgency associated with increasing detrusor pressure. Maximum cystometric capacity corresponds to the volume at which the patient could no longer delay micturition

urinary incontinence; or terminal, which is a single involuntary contraction that leads to complete bladder emptying [21]. DO can elicit urinary leakage ranging from drops of urine to complete bladder loss; regardless of amount, this is termed detrusor overactivity leakage. DO may be the result of neurogenic bladder dysfunction, or idiopathic OAB. DO generally decreases cystometric capacity.

Impaired bladder compliance produces an abnormal rise in detrusor pressure during filling cystometry (Fig. 11.5). This rise in pressure is generally felt to be due to impaired visco-elastic properties of the detrusor muscle. The patient may or may not report urgency as the pressure rises and leakage of urine may occur if the detrusor leak point pressure is reached. VUR or impaired drainage from the upper urinary tract may occur secondary to high pressure in the bladder. Impaired compliance generally decreases cystometric bladder capacity.

Neurogenic bladder dysfunction can produce a variety of clinical and urodynamic effects depending on the exact location of the neurologic lesion. When lesions are located above the level of the brainstem detrusor overactivity may be seen leading to decreased bladder capacity and symptoms of OAB (Fig. 11.6).

When lesions are located between the brainstem and the sacral spinal cord, detrusor sphincter dyssynergia (DSD) as well as detrusor overactivity may be seen, generally leading to a decrease in bladder capacity with or without impaired compliance and symptoms of both OAB and difficulty emptying/urinary retention. DSD

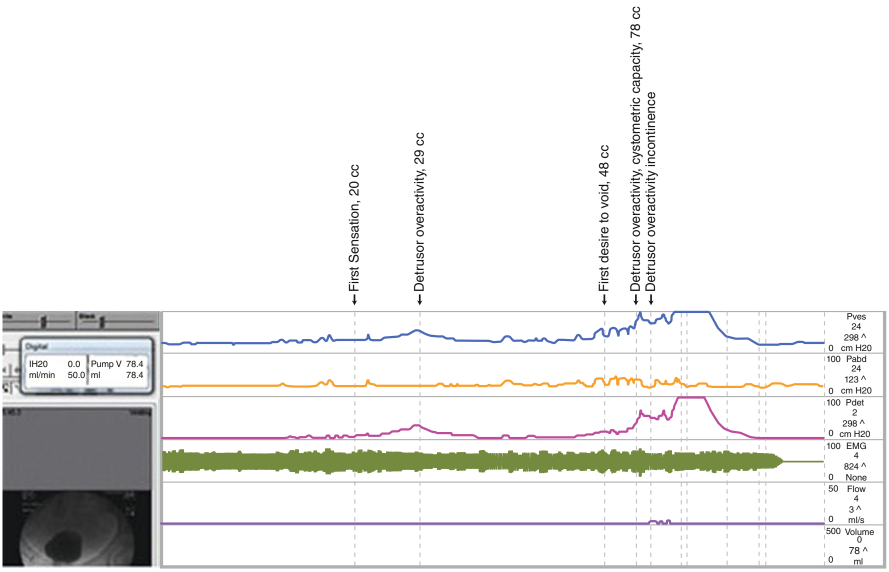

Fig. 11.6 Cystometrogram in a patient with neurogenic bladder dysfunction and severely diminished cystometric capacity. Vesical pressure and abdominal pressure were equalized at the start of the study with a corresponding detrusor pressure of zero. First sensation was reported at 20 cc, detrusor overactivity was seen at 29 cc, and first desire to void reported at 48 cc. A second involuntary contraction was seen at 78 cc with corresponding leakage of urine

can produce drastic changes in bladder function and anatomy as a result of obstruction at the level of the urethral sphincter (Fig. 11.7a, b).

When lesions are located at or below the sacral spinal cord an atonic bladder or a poorly contractile bladder with or without impaired compliance may be seen associated with symptoms of difficulty emptying, complete urinary retention, and incontinence without sensation. Diabetic cystopathy is a peripheral neuropathy producing a hypotonic or atonic bladder. Large capacity is generally noted and can be associated with detrusor overactivity (Fig. 11.8).

Anatomic Considerations of Bladder Capacity

Bladder diverticula can be the result of obstructed voiding, surgical intervention or can be congenital (Fig. 11.9). Bladder capacity is the sum of the volume held in the bladder and the diverticulum. This measured bladder capacity during urodynamic testing is likely an overestimate of functional bladder capacity. Most diverticuli have fairly small ostia and as a result empty poorly during voiding. The diverticulum remains distended with stagnant urine and can be a nidus of infection and stone formation. When the bladder is emptied to completion using a catheter

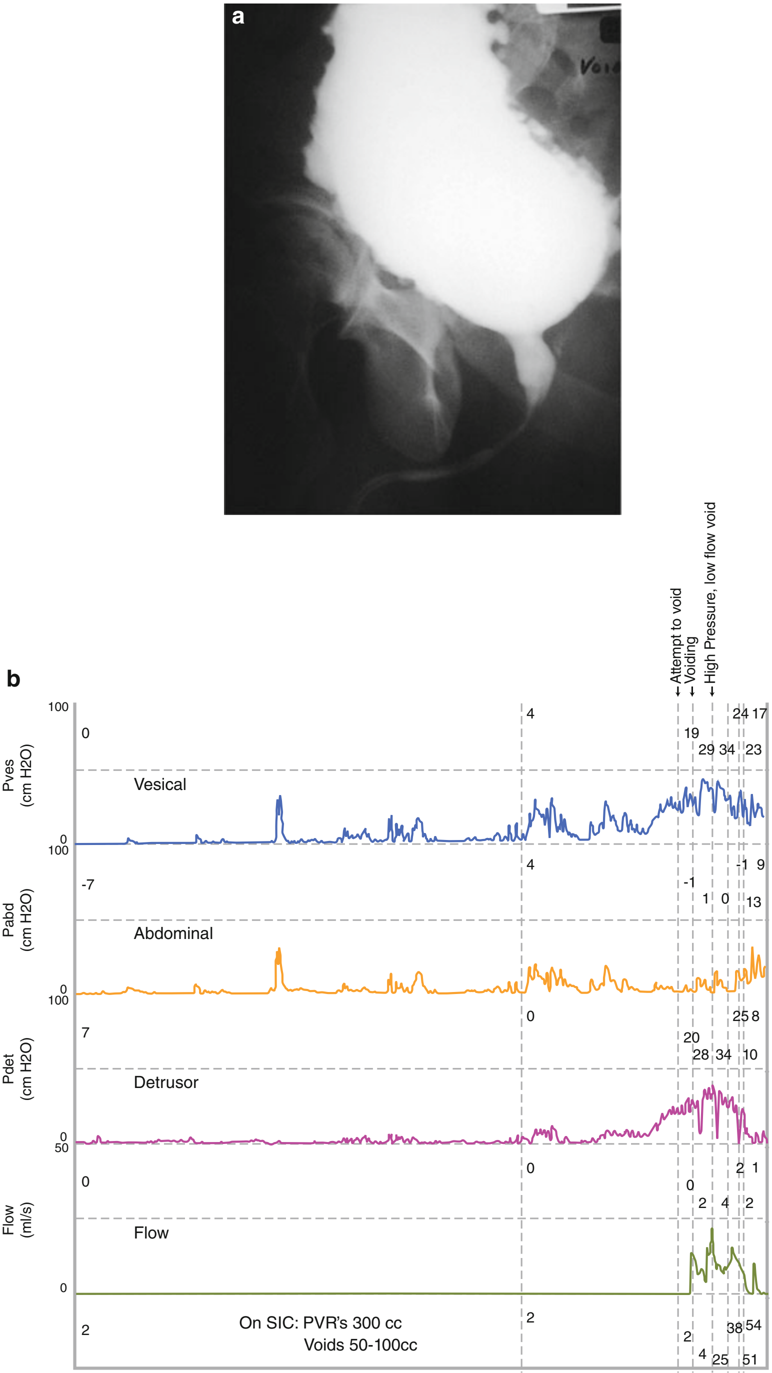

Fig. 11.7 (**a** and **b**) Videofluoroscopic image and accompanying cystometrogram in a patient with DSD producing and obstructed voiding pattern and anatomic distortion of the bladder and urethra. Failure of the urinary sphincter to relax during voiding produces a high-pressure detrusor contraction, low flow across the urethra, and incomplete bladder emptying. With time bladder trabeculation, diverticuli and proximal urethral dilation result

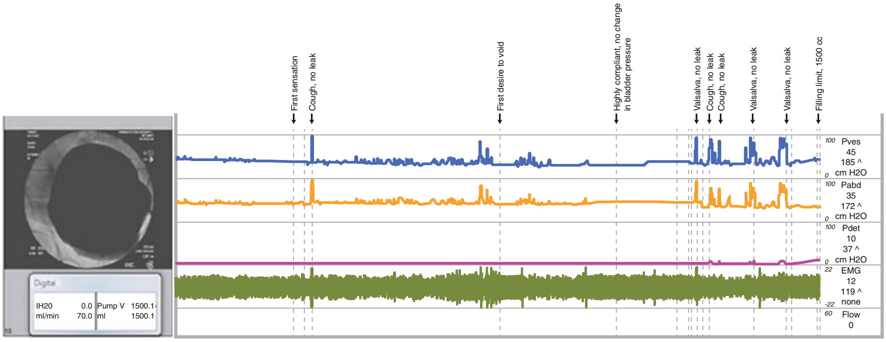

Fig. 11.8 Cystometrogram of a patient with diabetic cystopathy showing a hypocontractile large capacity bladder, maximum cystometric capacity was never reached. Vesical pressure and abdominal pressure were equalized at the start of the study with a corresponding detrusor pressure of zero. Filling was discontinued at a volume of 1,500 cc. This bladder is highly compliant without evidence of detrusor overactivity

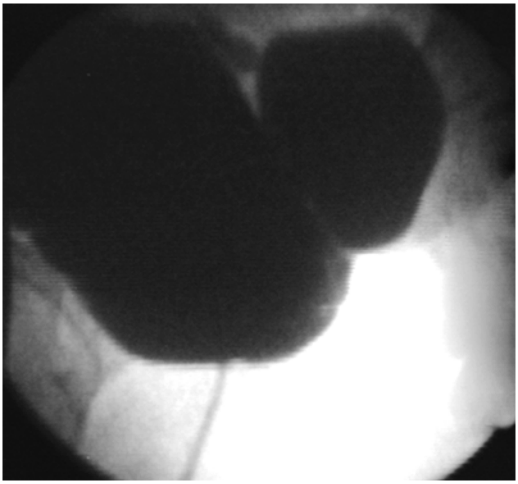

Fig. 11.9 Videofluoroscopic image of a large bladder diverticulum. Cystometric capacity reflects the sum of the bladder and diverticular volume

at the start of urodynamic testing the diverticulum may empty thereby allowing it to fill during the filling phase of the study. The capacity measures obtained will therefore reflect the cumulative volume of the bladder and the diverticulum. This overestimation of functional capacity may be significant when the diverticulum is large in size.

Pelvic organ prolapse can produce urinary tract obstruction. Cystoceles can be visualized during fluoroscopy as the bladder fills to capacity (Fig. 11.10). Capacity includes the volume of urine held in the normally positioned bladder as well as the prolapsing portion. Much like a diverticulum, the prolapsing portion of the bladder may fail to empty during voiding thereby diminishing the functional bladder capacity. When a catheter is placed to drain the bladder at the start of urodynamic testing,

Fig. 11.10 Videofluoroscopic image of significant cystocele. Cystometric capacity reflects the sum of the orthotopic and prolapsing bladder volume

Fig. 11.11 Videofluoroscopic image of severe right-sided vesicoureteral reflux. Cystometric capacity reflects the sum of the bladder volume and the collecting system volume

the prolapsing portion may have the opportunity to drain to completion thereby elevating the capacity measured obtained during the test. The overestimation of functional bladder capacity may be significant especially when the prolapsing portion of the bladder is large and kinked during voiding.

VUR may be seen on fluoroscopy as the bladder fills to capacity or during the voiding phase (Fig. 11.11). Bladder capacity is the sum of the volume held in the bladder as well as the collecting system (kidney and ureter) of the refluxing unit. The collecting system may fail to empty during voiding thereby diminishing the functional bladder capacity. When a catheter is placed to drain the bladder at the start of urodynamic testing, the refluxing unit may have the opportunity to drain to completion thereby elevating the capacity measure obtained during the test. The overestimation of functional bladder capacity may be significant especially when the reflux is high grade into a dilated upper urinary tract.

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