Chapter 4
Urodynamic Testing of Female Incontinence

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Principles of Urodynamics

Pressure flow urodynamics (UDS) is one of the many tools that the continence care provider can employ to make a more precise diagnosis of a woman's urinary symptoms. They are not a substitute for a good history and physical exam, and their results in isolation without clinical context are difficult to interpret. In general, urodynamics should be used when the clinical diagnosis is unclear with a more basic assessment, and the results will change patient management.

A simple decision aid in determining if the urodynamics need to be performed is assessing the uncertainty in the diagnosis and multiplying this by the risk of the decision being made, either the risk of a missed important diagnosis or the risk of the procedure.

Uncertainty of diagnosis × Risk of procedure or missed diagnosis = Need for urodynamics

For example, if a patient has mixed incontinence on history (uncertainty of stress urinary incontinence (SU)I vs. urgency urinary incontinence (UUI) is high) and chooses pelvic floor physical therapy (risk is zero since this will help either condition), then the need for UDS is zero (high × 0 = 0) because it is not important to know if she indeed has SUI or UUI to proceed with her care since PFPT can treat both conditions. Another example would be a woman with urinary retention immediately after a sling procedure that has persisted for months who had no voiding

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symptoms and a low residual prior to the sling. In this case, the uncertainty of the diagnosis is zero even though the risk of the needed surgical procedure is high ($0 \times \text{high} = 0$) and UDS are not needed.

Instances where the need for UDS has been well investigated are in the care of index cases of stress incontinence in women. The Value trial [1] randomized women with uncomplicated SUI undergoing sling placement to UDS or standard clinic assessment prior to surgery. The results of the UDS did not change management plans or the surgical outcome; hence, in this population, it is not needed. Studies on UDS testing trends have shown that the rate of preoperative testing has decreased since this study has been published [2]. A review of a 5% sample of Medicare beneficiaries with mixed incontinence found that regardless of the surgical approach in these women, preoperative UDS did not change the risk of re-intervention following surgery, further emphasizing that good clinical decision-making can be done without UDS, but with a good history and physical exam and potentially noninvasive testing [3].

The utility of urodynamics was assessed in a more complex population of patients, none of which were index cases of SUI, and among the 285 studies performed, the treatment plan changed in 43% of cases as a result of the UDS results, with 35% having a change in the surgical plan [4]. Fluoroscopy was used in most studies with helpful findings in 29.5% of cases.

Several studies have sought to assess the prognostic ability of UDS in predicting surgical outcomes for other incontinence procedures. Nobrega et al. assessed several urodynamic parameters in 99 patients with detrusor overactivity (DO) undergoing sacral neuromodulation and unfortunately did not find any urodynamics parameters that predicted the success of the staged procedure [5]. Similarly, the urodynamic diagnosis of DO prior to botulinum toxin injection did not alter patient-reported outcomes compared to those patients without DO [6]. In a series of male patients, however, higher BOOI (and elevated PVR) did predict a higher risk of urinary retention requiring self-catheterization [7].

Urodynamics, however, are often a cornerstone of urological diagnosis with many clinical scenarios where they are essential. Examples include assessments for safety compliance in neurogenic lower urinary tract dysfunction (NGLUTD) or differentiating between outlet obstruction or detrusor underactivity (DU) in a woman with retention. The AUA Guidelines discuss the use of UDS, and both the female stress incontinence and OAB guidelines state that UDS should not be used in the initial workup of the uncomplicated patient but recommend their use for diagnostic purposes and complex patients [8, 9]. In this chapter, the International Continence Society's (ICS) good urodynamic practices and terms will be referenced as the standard terminology [10].

Urodynamics Testing Alternatives

There are several noninvasive and cost-effective testing modalities that can be employed before or instead of formal pressure flow urodynamic studies.

A *post-void residual (PVR)* with either a bladder scanner (ultrasound) or a catheterized measurement of residual intravesical urine volume is an excellent screening tool to assess for incomplete bladder emptying or retention. This measurement is particularly helpful when it is very high or when there is a baseline value for that woman for comparison, such as a woman who had a residual of 0 ml before an incontinence procedure but now has a residual of 200 ml. There is no established "normal" value for residual urine [11]; a good rule of thumb in the context of expected deterioration of bladder contractility with age is that residual urine is totally normal if less than one's age. The method of collection should be specified since there are both false positives and negatives associated with each. Examples of a false-positive result with the ultrasound method include ascites, peritoneal dialysis, pregnancy, or an ovarian cyst where fluid outside the bladder is mistakenly measured. A false negative can result if the scanner is not directed towards the bladder or if the catheter used for collection is not placed completely within the lumen of the bladder or is withdrawn too soon.

A *uroflowmetry* (simple uroflow) measures the flow rate of the urine stream as a volume in milliliters per second and when combined with a post-void residual provides information on voiding dysfunction. This has the added benefit of physiological voiding in a private setting and should be performed in the patient's usual voiding position. A uroflowmetry is considered part of the ICS standard urodynamic test [10] where it is performed immediately before the study to obtain unintubated uroflow and residual urine results. Patients should arrive for the test with a comfortably full bladder and wait for their usual urge to void to be felt. A pitfall in uroflowmetry is having a woman void before her bladder is full often resulting in low voided volume (<150 cc) which is difficult to interpret since low volume voids are slower inflow and the male nomograms exclude these measurements. Conversely, uroflowmetry may be abnormal if voiding was postponed for too long before the test, with an overdistended bladder [10].

Measured values include the maximum flow rate (Qmax), average flow rate (Qave), and voided volume. The values for uroflowmetry in normal women vary considerably by voided volume, unlike in men where flow rates also decrease with age [12]. There is actually little data on normal uroflowmetry in women, unlike men where this measure has been widely utilized in the diagnosis of bladder outflow obstruction (BOO) from prostatic obstruction with clear normative values [13]. Women often void with very high flow (>30 ml/s = hyperflow), and the curve is bell-shaped, but voiding time is shorter than in men. Qave ranges from 17 to 24 ml/s in normal women and Qmax from 23 to 33 ml/s, with voided volume ranges between 250 and 550 ml and residual urine typically less than 15 ml [12]. The curve can be described as bell-shaped (normal), flat (very slow), flat peaked (evidence of obstruction), hyperflow (normal in women), and a straining pattern (use of abdominal muscle for voiding with sawtooth pattern) (Fig. 4.1).

Voiding diaries can give excellent physiologic information about bladder behavior outside of the testing environment where results can be altered by anxiety, discomfort, and a non-physiologic filling rate. Most measure fluid intake volume and fluid type as well as voided volume, sensation of urgency, and leakage

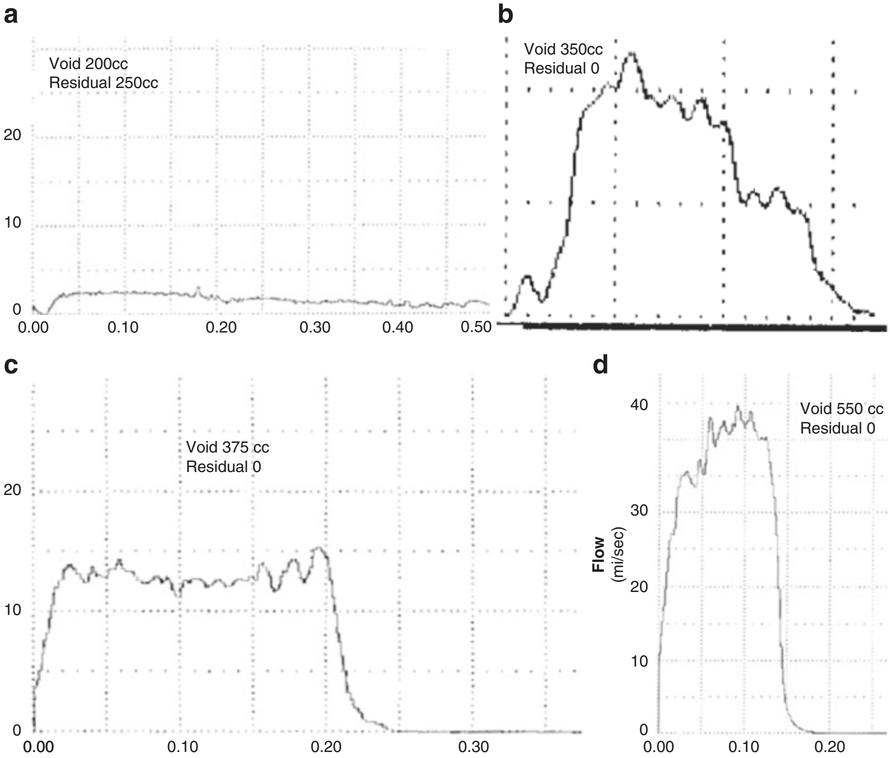

Fig. 4.1 (**a**–**c**) Uroflow tracings from the same female patient with (**a**) obstructing stricture with peak flow 3 ml/s, (**b**) after stricture dilation with the normal flow of 22 ml/s, (**c**) 1 year later after stricture recurrence max flow 15 ml/s with flat top flow pattern, and (**d**) hyperflow of a woman with SUI 45 ml/s

episodes during a set period of time. These provide an objective measure of daytime and nighttime frequency as well as more accurate bladder capacity that tends to be higher than in the testing environment. These results can serve to tailor conservative recommendations surrounding fluid intake [14] and can be used to measure the nocturnal polyuria index which is critical in diagnosing causes of nocturia.

Pad tests are a simple way of quantifying urine loss over a period of time. They are calculated by measuring the wet pad(s) minus the weight of the same number of dry products. In non-menstruating women, the pad net gain is mostly urine, but perspiration and vaginal discharge can contribute to the volume as well.

Short-term pad tests can be accomplished by drinking 500 ml of fluids in 15 min then wearing a pad in the office for 1 h accomplishing several prescribed physical activities such as walking and climbing stairs. Any value over 1 g is considered positive for urinary incontinence. A long-term pad test involves collecting all pads worn for 24–48 h. A net gain of 8 g in 24 h or 2 g on any individual pad is considered incontinence [12].

A *simple cystometric test*, also called “eyeball urodynamics,” involves placement of a catheter and drainage of the urine content for a measured post-void residual followed by filling of the bladder with sterile saline using a cone tipped syringe and observing the fluid column. Any rise in the column accompanied by urgency is considered an episode of DO. Sensations are recorded similarly to a standard urodynamics study with first sensation, any urgency, and maximum capacity recorded. The catheter is then removed and a supine cough and Valsalva stress test performed with direct visualization of any leakage. If negative, the patient can be placed in a standing position and perform maneuvers (jumping/squats) and coughs with an absorbent paper towel on the perineum. Advantages of this approach are a much faster study than pressure flow UDS, and patients can perform more maneuvers than are possible when connected to UDS catheters. This test is well suited to the woman in whom you suspect SUI but require significant activity to provoke it. In a woman with prolapse in whom you want to assess for occult SUI, this is an ideal test to perform with both the prolapse reduced and not reduced since the presence of SUI with the prolapse reduced is helpful in counselling regarding the need for a prophylactic sling during the POP repair. If this test does not demonstrate SUI in a woman undergoing prolapse surgery, formal UDS are an excellent method if suspicion is high [15]. Simple cystometric testing does not provide any information on voiding pressures or robust information on DO, but is well suited to diagnose SUI.

Urodynamics Testing and Interpretation

If one is going to perform a test, you need a question that needs to be answered. The urodynamics testing can be best optimized if the technician performing the testing is aware of the question at hand. In general, most urodynamics are performed to answer one or more of the following questions [16]:

1. Is this incontinence stress, urgency, or both?
2. In a woman with persistent incontinence post sling or other procedure, does she have SUI, UUI, or obstruction?
3. In a woman with NGLUTD, is her urinary tract safe? (reflux, poor compliance, adequate capacity, DO)
4. In a woman with elevated residual urine, is it atonic bladder, voiding dysfunction, or obstruction?

If one frames the testing environment around answering one or more of these questions, it makes interpreting the test much easier and allows the technician to tailor testing accordingly. For example, in a woman with a question of incontinence who does not leak during the study, the technician can perform more Valsalva and cough maneuvers or change the woman’s position to standing to try to elicit SUI, or in a woman with retention, you may allow to fill to higher volumes to give her the best possible chance of eliciting voiding. This simplified diagnostic organization also makes interpretation easy since your goal in interpretation surrounds answering the clinical question at hand and allows you to potentially ignore findings that are perhaps simply artifacts of the study such as incomplete bladder emptying during the pressure flow study on a woman with incontinence who has a normal pre-study PVR.

Antibiotics and Patient Preparation for UDS

Preparation for a urodynamic study should be straightforward. Patients should be encouraged to hydrate, take all prescribed medications, and eat regular meals on the day of testing. All patients should be asked about signs and symptoms of a UTI and at a minimum have a urinalysis performed on the day of the procedure to screen for urinary tract infection. The definition of a UTI varies across many studies but can be best defined as a positive urinalysis/dipstick plus symptoms suggestive of a UTI and a positive urine culture [17]. Dipstick urinalysis is the most readily available and is therefore most widely used [18]. A dipstick negative for blood, leucocyte esterase, nitrites and protein has a 98% predictive value [19]. However, it is not rare for women with LUTS to present with a positive LE or nitrites on a dipstick. A urine culture requires laboratory assessment, and results will not be available the same day; hence, urine microscopy could be performed in this situation (if available) to assess for bacteriuria. Symptom assessment is critical in these situations since bacteriuria alone is not a contraindication to urodynamics. A positive urine culture without symptoms is simply bacteriuria, not a UTI, and does not require treatment, nor should it alter the UDS results. If bacteriuria is suspected based on dipstick or microscopy, then the study can proceed, but with antibiotic prophylaxis [18]. In the event that a woman does present with symptoms of a UTI and a positive dipstick, she very likely has a UTI; hence, a culture should be sent, and the urodynamics should be delayed until she is treated [18].

A best practice policy statement on urodynamic antibiotic prophylaxis was published in 2017, and based on the available evidence, women with normal genitourinary anatomy and without risk factors do not require antibiotics at the time of UDS to prevent UTI. This comprises a large percentage of urodynamics patients, and avoidance of antibiotics in this population is a way that we can contribute to antibiotic stewardship and avoid the cost and side effects of these drugs. Risk factors where antibiotics are recommended either because of increased risk of UTI post-procedure or that their medical condition would result in a more serious complication should they get a UTI include patients with neurogenic lower urinary tract dysfunction, bladder outlet obstruction, or elevated post-void residual, age over 70, presence of current bacteriuria (known or suspected based on dipstick), immunosuppression/corticosteroid use and immune deficiency, chronic catheter use, and those patients who have recent total joint implants.

The antibiotic of choice should depend on your local antibiogram generated from regional resistance patterns, but in general, a single dose of double strength

Table 4.1 Antibiotics and risk factors for UTI after urodynamics

Need for peri-procedure antibiotics for urodynamics		
Yes	No	Antibiotic of choice in order of safety and efficacy
Neurogenic lower urinary tract dysfunction	Patients without genitourinary anomalies	1. Trimethoprim sulfamethoxazole DS PO
Elevated post-void residual	Diabetes	2. Cefalexin 500 mg PO or amoxicillin/clavulanate 875 mg PO
Asymptomatic bacteriuria	Prior genitourinary surgery	3. Levofloxacin 500 mg PO or ciprofloxacin 500 mg PO or gentamicin 80 mg IM
Immunosuppression	Recently hospitalized patients	
External urine collection device (condom catheter)	History of recurrent UTI (not current)	
Any form of indwelling catheter	Post-menopausal women	
Intermittent catheterization	Nutritional deficiencies/obesity	
Age over 70	Cardiac valvular disease	
Total joint wrisk factor or <2 years	Pins, plates or screws	

trimethoprim-sulfamethoxazole is the first choice. Other factors to consider include patient allergies and tolerance to antibiotics and prior urine cultures, particularly in those women who have recurrent UTIs or known bacteriuria where prior cultures can guide antibiotic selection. See the table for a list of antibiotics and risk factors requiring antibiotics which can be posted in your urodynamics suite as an easy reference guide (see Table 4.1) [18].

Other risks of urodynamics studies include urethral trauma from catheter insertion, which can be minimized with good technique and experience; dysuria, which can be managed with Pyridium or acetaminophen/ibuprofen as needed; transient urinary retention in those patients at risk for retention; and patient physical or emotional discomfort, which can be significantly mitigated with supportive staff.

The anxiety surrounding a UDS test for a patient and the impact of this emotional distress and physical discomfort on the test results are real. In a high anxiety state, it is more difficult to void, and patient satisfaction with your care will suffer. In an academic setting with a dedicated urodynamics nurse that surveyed 314 patients about their experience, 50.7% did not find the study either emotionally or physically uncomfortable, 55% of patients thought the study experience was better than expected, and 37% felt the study was as expected. However, 29% felt the physical component was the most uncomfortable with the urethral catheter being the worst part. Emotional discomfort was the worst part for 12% of patients with anxiety being the most commonly reported component (27%), followed by embarrassment (18%). Patient factors that predicted less physical discomfort were not surprisingly older age and the presence of a neurological condition [20]. Interventions to decrease pain and anxiety such as music and informational videos in a randomized trial did not decrease these symptoms compared to usual care [21]; however, satisfaction with the study has been associated with confidence in the technical ability of the provider and the maintenance of privacy [22].

Systematic Interpretation of a UDS Study

There are many references on standards in urodynamics that discuss the detailed nuance of study performance [10, 23–25] that are beyond the scope of this chapter but are nonetheless essential reading in good urodynamic performance. Like any other complex diagnostic study, having a systematic method of reading the test is important for quality control and to ensure findings are not missed.

The cystometrogram involves continuous fluid filling of the bladder with abdominal and intravesical pressure measurements. Cystometry ends with the permission to void or with incontinence of total bladder volume [10]. The filling solution and rate should be specified. There are two rates of filling possible. One is the maximum physiologic filling rate estimated by body weight in kilograms divided by four which is typically 20–30 ml/min. However, filling is often faster than this physiologic rate for convenience purposes. Also, the patient continues to produce urine during the test (up to 25% of the volume); hence, the cystometric capacity is the filling volume plus any urine produced. In women, the abdominal pressure can be measured with a rectal catheter or a vaginally placed catheter with no difference in discomfort or patient acceptability; however, vaginally placed catheters are more often lost or expelled [10] and are less reliable.

An easy-to-remember mnemonic for the cystometrogram portion is the 4Cs (capacity, compliance, contractions, coughs) and 2Ss (sensation, Sphincter function), followed by the pressure flow portion of the study.

The pressure flow study begins immediately after permission to void and ends when the detrusor pressure returns to baseline or the patient considers voiding complete. It is important to note that the values analyzed are only valid for a voluntary void and not a leak generated by an incontinence episode/DO. Values should be measured for maximum urine flow in ml/s (Qmax) and the detrusor pressure at the maximum flow (PdetQmax) as well as any abdominal straining during voiding detected in Pabd, the shape of the voiding curve, and sphincter relaxation noted as relaxation on electromyography (EMG). Pressure flows are often plotted with the flow on the *x*-axis and pressure on the *y*-axis in a time-based graph. The shape of the flow curve can be a smooth arc, flat, or fluctuating [26]. See Table 4.2 and Fig. 4.2 for examples of systematic reading of a UDS study.

Table 4.2 Systematic urodynamics reading guide

Systematic reading mnemonic	Measurement	Units	Normal value
Cystometrogram			
Capacity	Maximum cystometric capacity (MCC)	ml, only accurate within 10 ml	Approx. 500 ml in women
Compliance	Δvolume/Δpressure	ml/cmH2O	>20 associated with upper tract deterioration, but typically much higher
Contractions	Presence of DO during CMG portion of the study (can also be seen as an aftercontraction in PFS)	Present or absent Duration (seconds), amplitude Pdet (cmH2O), and concomitant leaks reported	Absent
Coughs	Both Valsalva leak point pressure (VLPP) and Cough leak point pressure (CLPP) maneuvers. Collectively, these are called abdominal leak point pressure ALPP	cmH2O	Absent
Sensation	Record: First sensation of filling (FSF) First desire to void (FDV) Strong desire to void (SDV) and any urgency episodes	ml	No specified values but identified as normal, absent, reduced, and increased Expect FSF at 30% of capacity and FDV at 60%
Sphincter function	Does EMG rise with maneuvers?	EMG measured with two surface electrodes on the perineum	EMG should rise with maneuvers
Pressure flow:			
PDetQmax	Detrusor pressure at maximum flow	cmH2O	Tends to be lower in women, and can be 0 in normal women
Qmax	Maximum flow	Ml/s	Can be very high in women, no upper limit of normal
Straining	Abdominal pressure rise and vesical pressure rise	Present or absent	Not always pathological, as some people augment voiding with abdominal contraction
Sphincter relaxation	EMG reading		Should decrease with void

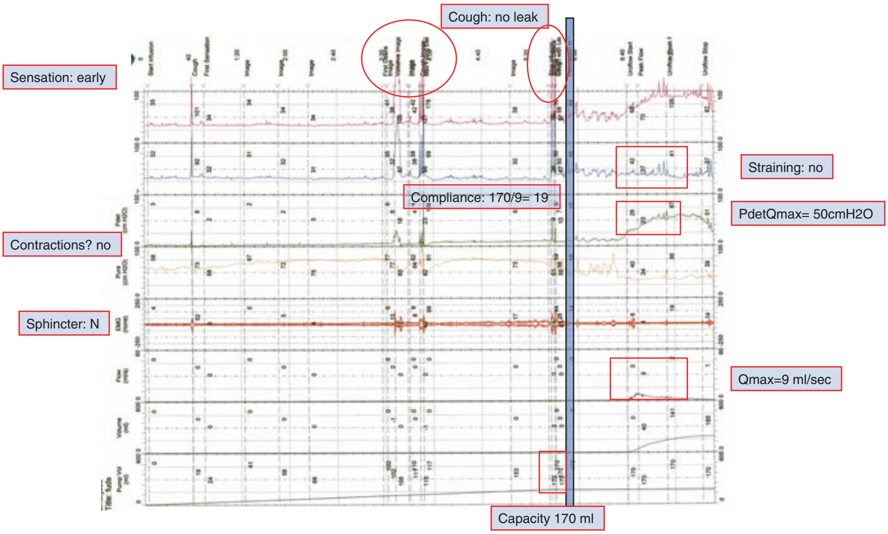

Fig. 4.2 Systematic reading of a urodynamic study. Female with new-onset urgency post sling. Diagnosis: small bladder capacity, borderline normal compliance, no DO, no SUI, early urgency, normal sphincter guarding with cough, and relaxation with void. With a flow of 9 ml/s and PdetQmax of 50 cmH2O, a diagnosis of BOO is made based on all definitions and fluoroscopic images show urine pooling in the urethra (Fig. 4.8b)

Urodynamic Diagnoses

In reality, there are only a handful of diagnoses that can be made with pressure flow urodynamics. These include SUI, DO, detrusor underactivity/atonic bladder, bladder outlet obstruction (functional or anatomic), and poor bladder compliance. The addition of fluoroscopy during the study can increase diagnostic information, but is not typically needed unless anatomic anomalies are suggested. During urodynamic interpretation, if one keeps this list of possible diagnoses in mind, it simplifies reading studies.

Stress Urinary Incontinence

Stress urinary incontinence is defined as "the complaint of involuntary loss of urine on effort or physical exertion or sneezing or coughing" [27]. It is diagnosed on urodynamics either with urine leakage demonstrated during cough maneuvers or Valsalva in the absence of a detrusor contraction. During the cystometrogram, a Valsalva and a series of three progressively stronger coughs are performed at 200 ml filling and again at bladder capacity. If there is leakage in the absence of detrusor overactivity, then SUI is diagnosed. If leakage is observed, a value is recorded as the cough leak point pressure (CLPP) or a Valsalva leak point pressure (VLPP), with the lowest recorded value being the abdominal leak point pressure (ALPP). There is

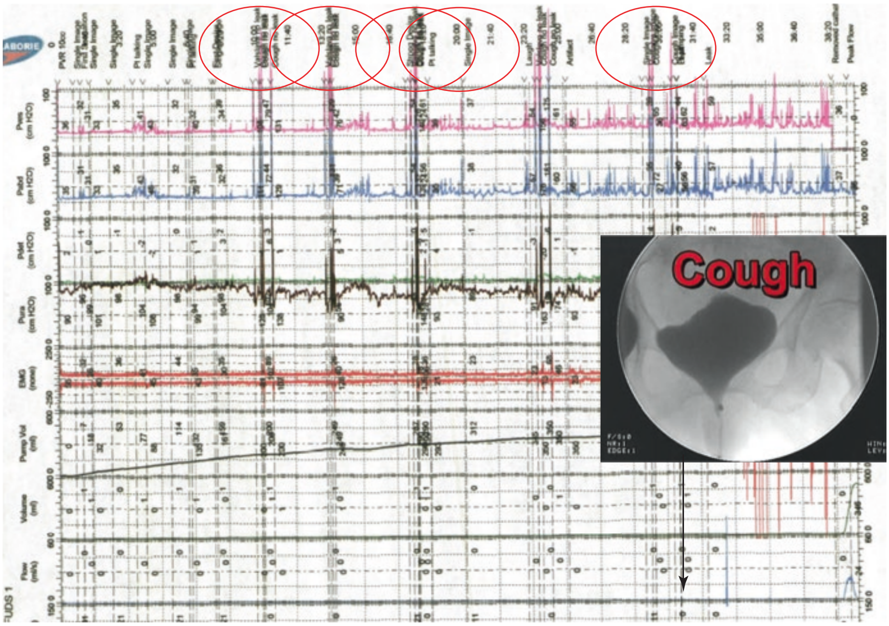

Fig. 4.3 SUI: Woman with symptoms of SUI not demonstrated on full bladder exam hence urodynamics performed. SUI was not demonstrated at 200c; hence, maneuvers were repeated at 250, 300, and 390 ml. Small volume leak not recorded on flow (black arrow), but a leak on fluoroscopy seen at 390 ml with cough

no standard pressure recording that is universally accepted with some recording, the abdominal pressure reading (Pabd), and others utilizing the vesical pressure recording (Pves). Cough LPP tend to have higher pressures than Valsalva [28], and the CLPP or VLPP pressure is recorded at the exact moment where the leakage is observed. A cough is so brief that this can be difficult to pinpoint. It has been observed that both of these values decrease with increased bladder volumes during the study and that those women with worse urinary incontinence tend to have lower recorded abdominal leak point pressures [28]. If clinical suspicion is very high for SUI and no leakage is observed, it is appropriate to repeat maneuvers at maximum cystometric capacity (see Fig. 4.3) and to have the woman do extra maneuvers such as going from sitting to standing or jumping if that is what causes her to leak at home.

A potential error in the diagnosis of SUI on urodynamics can occur if the maneuvers are performed with the urodynamics catheter in place. Even though it is of a small caliber (7F) and most women with SUI (>90%) will leak with the catheter in place, there are women with SUI on physical exam who fail to leak during UDS, and removing the catheter will "unmask" SUI. Up to 50% of women with SUI symptoms, but no leakage during UDS, will demonstrate SUI once the catheter is removed [29]. These women do not necessarily have high leak point pressures with the mean VLPP in this study being only 67 cmH2O. Hence, if a woman has SUI on history or this is seen on bedside examination, but not reproduced during UDS, the catheter should be removed and maneuvers repeated. To avoid the need for a new urodynamics catheter during the pressure flow portion of the procedure, the voiding portion of the test can be completed and then the bladder refilled and the catheter removed for stress maneuvers [9]. Attention should be paid to patient positioning; a woman who only leaks standing is not going to leak supine and will be unlikely to leak sitting. Hence, maneuvers should be repeated in the position she leaks.

Intrinsic sphincter deficiency is clinically important to diagnose prior to incontinence surgery since procedure success is diminished, particularly for transobturator synthetic slings [30]. This can be diagnosed with maximum urethral closure pressure, which is difficult to interpret due to varying measurement techniques and different reference values depending on the catheter type used [30]. As such, ALPP is more commonly utilized to diagnose ISD. ISD was most often cited with a cutoff value of <60 cm H20 [30], but the most recent definition of ISD has now evolved to an imprecise subjective diagnosis. The International Continence Society now defines ISD as a "very weakened urethral closure mechanism." [31]

Detrusor Overactivity

Detrusor overactivity is defined as a non-volitional rise in detrusor pressure during filling either spontaneous or provoked. Provocative maneuvers include a supraphysiologic filling rate, a change of position, cough, laugh, or handwashing/water running. It can be accompanied by a sensation of urgency, or the patient may be unaware (see Fig. 4.4).

The pressure rise can result in urine loss during the contraction. There is no minimum threshold of detrusor pressure considered diagnostic of DO (low amplitude DO example in Fig. 4.6), but the higher amplitude and longer duration of contractions imply worse disease and can predict renal deterioration in NGLUTD [32]. DO is considered idiopathic in patients without neurological disease and considered neurogenic DO in those with a clinical history of these conditions [31]. There is no visible difference between these two conditions on the tracing, and urodynamics cannot be utilized to diagnose a neurological disease. An "after contraction" is a continued or new detrusor pressure that rises immediately after the flow has ended [10] and is also diagnostic of DO. There is also a known phenomenon of "cough-associated detrusor overactivity," which is an onset of DO that occurs immediately following the cough maneuvers and can be mistaken by patients as SUI, but will be evident as DO on UDS [10]. See Fig. 4.5.

Common artifacts that can be confused with DO are rectal vault contractions or passage of gas during maneuvers that can cause a transient drop in Pabd [23]. Also, similarly to SUI, DO is more likely to occur in the upright position, so a woman should be at least in the seated position for the study [10].

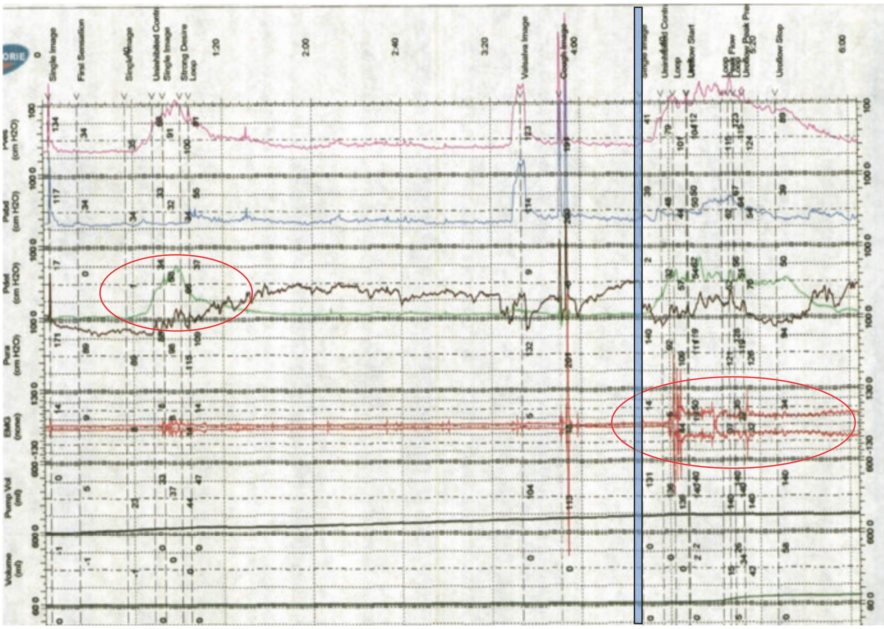

Fig. 4.4 Detrusor overactivity and functional obstruction: A woman with incontinence and pelvic pain. DO of high amplitude 80 cmH2O at 38 ml, no SUI, small bladder capacity 131 ml with a painful void with evidence of obstruction with PdetQmax of 56 and evidence of significant EMG firing. (Fig. 4.8e of spinning top appearance of the bladder)

Detrusor Underactivity or Atonic Bladder

Incomplete bladder emptying, straining to void, slow flow, or total urinary retention in women can be a result of bladder outlet obstruction or poor bladder contractility. These diagnoses are difficult to differentiate with anything but a pressure flow study during UDS. Further complicating this diagnostic dilemma is that some women will not be able to generate a bladder contraction or void during the UDS study due to anxiety or discomfort, and in these cases, a definitive diagnosis cannot be made. This is defined as "situational inability to void as usual" and should be discussed with the patient if they express that this voiding episode has not been representative [10].

Detrusor underactivity is a urodynamic diagnosis defined as a contraction of reduced strength and/or duration, resulting in prolonged bladder emptying and/or a failure to achieve complete bladder emptying within a normal time span. It is important to remember that many women void volitionally without any difficulty, with a very low detrusor contraction, or with augmented abdominal straining, and this is not pathological. There are varying criteria used to diagnose DU in women. Groutz defined it as a Qmax<12 ml/s with a void of at least 100 ml or a PVR of 150 ml on two or more free uroflow readings [33]. Abarbanel and Marcus use the criteria of

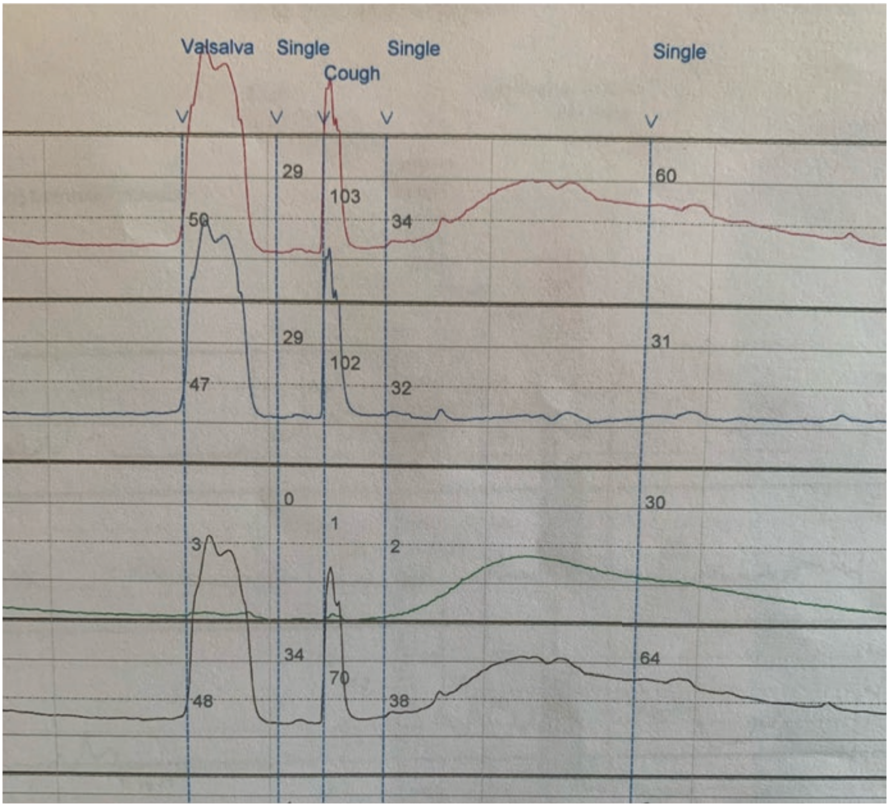

Fig. 4.5 Cough associated DO: episode of DO immediately following cough and Valsalva maneuvers "cough associated detrusor overactivity" in a woman with subjective symptoms of SUI based on leakage after coughing

PdetQmax<30 cmH2O and Qmax<10 ml/s during pressure flow study [34], and Gammie et al. [35] used PdetQmax <20 cmH2O and Qmax <15 ml/s voiding less than 90% without any clinical obstruction. In men, bladder contractility index has been used to define DU with a BCI < 100 being diagnostic [13]. See Fig. 4.6.

$$\text{Bladder contractility index}\left(\text{BCI}\right) = \text{pdetQmax} + 5\text{Qmax}$$
$$\text{Strong} = \text{BCI of} > 150$$
$$\text{normal contractility} = \text{BCI of } 100 - 150$$
$$\text{weak contractility} = \text{BCI of} < 100$$

$$\text{Bladder voiding efficiency, called voided percent}\left(\text{Void\%}\right) = \text{amount voided / total bladder volume} = \text{void}/\left(\text{void} + \text{PVR}\right) * 100$$

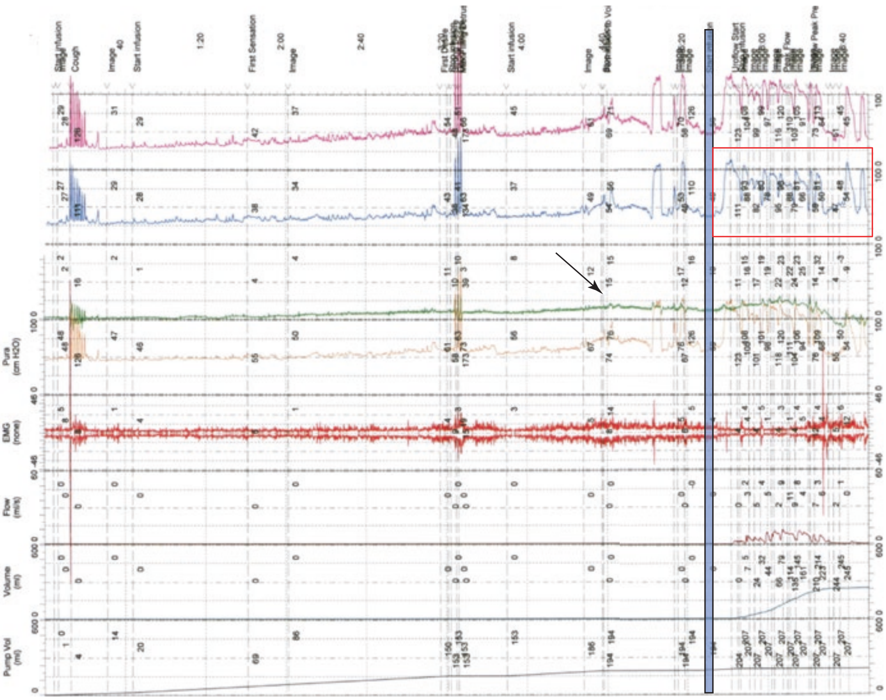

Fig. 4.6 Detrusor underactivity and DO: An 84-year-old with incontinence and straining to void after radiation treatment for cervical cancer 30 years ago. She has borderline compliance 194 ml/12 cmH2O = 16. There is a small DO episode black arrow with no leak. During pressure flow, PdetQmax = 22 cmH2O, Qmax = 9 ml/s., straining: yes- see red box BCI=PdetQmax+5Qmax = 22 + 9 * 5 = 67

In a large series of 1015 women with non-neurogenic LUTS evaluated urodynamically, 15% had DU utilizing the Groutz definition, 10% by the Ababarnel criteria, and 6% with the Gammie criteria. The latter two criteria are both deemed clinically significant at differentiating between those with and without DU [36]. Straining is seen as an increase in both the Pves and Pabd pressure. This can be observed during position changes or during attempts to void [10]. See Fig. 4.6.

Bladder Outflow Obstruction

Bladder outflow obstruction (BOO) is often called bladder outlet obstruction; however, the new correct terminology is bladder outflow obstruction [10]. The diagnosis of BOO in women is more difficult than in men due to a lack of consensus on a urodynamic diagnosis [37]. Several nomograms exist but all characterize BOO as an increased detrusor pressure and reduced urine flow rate.

Groutz et al. defined urethral obstruction as a persistently low free flow rate of less than 12 ml/s combined with a detrusor pressure at maximum flow greater than 20 cm H2O during the pressure-flow study [33]. Lemack & Zimmern suggested that women with voiding detrusor pressure of 25 cm H2O or more, together with a flow rate of 12 ml/s or lower, were obstructed [38]. Kuo defined bladder outflow obstruction as a voiding detrusor pressure of 50 cm H2O or greater together with a narrow urethra on voiding cystourethrography [39]. Blaivas and Groutz developed an often used obstruction nomogram based on statistical analysis of the maximum detrusor pressure during the pressure-flow study of voiding, together with the maximum flow rate Qmax in repeated free uroflow studies. Patients with pdetQmax greater than 57 cm H2O were classified as either moderately or severely obstructed. Those with pdet below 57 cm H2O were classified as either mildly obstructed or unobstructed, depending on the value of free Qmax. Among a group of 600 consecutive women, 6% were mildly obstructed, 2% were moderately obstructed, and fewer than 1% were severely obstructed [40]. Nitti et al. defined obstruction qualitatively as radiographic evidence of narrowing in the presence of a sustained detrusor contraction. For obstructed women, the mean values of pdetQmax and Qmax were 43 cm H2O and 9 ml/s, respectively [41].

Akikwala [42] compared the different approaches to diagnosis in a cohort of 91 women with 25 having likely obstruction and found that the definition proposed by Nitti had the greatest concordance [42]. Most recently, Solomon and Greenwell [43] created a new nomogram proposing a female BOOI calculated as PdetQmax-2.2Qmax. If fBOOI is <0, then there is a less than 10% chance of obstruction and if fBOOI>5 then 50% chance of obstruction. This nomogram was validated in a patient population of women undergoing surgery for relief of obstruction where the nomogram was accurate at predicting symptom relief following surgery [44]. See Fig. 4.2 for an example of BOO due to a sling (anatomic) and Fig. 4.4 for BOO due to voiding dysfunction (functional).

There are only a handful of possible etiologies that could cause BOO in women which include fixed anatomical obstructions such as an overtightened urethral sling, urethral stricture, pelvic organ prolapse, or malignancy. There is a suggestion that UDS are not needed in the case of a suspected obstruction following sling surgery since a clinical history of new significant voiding symptoms is essentially diagnostic of obstruction and UDS are only needed in those cases where there are exclusively storage symptoms [45]. The other large category of BOO is functional obstructions, which is a failure of the outlet to relax. These functional obstructions include dysfunctional voiding, which is "an intermittent and/or fluctuating flow rate due to involuntary intermittent contractions of the periurethral striated muscle during voiding in neurologically normal individuals," [27] or detrusor sphincter dyssynergia, which is "a detrusor contraction concurrent with an involuntary contraction of the urethral and/or periurethral striated muscle." Occasionally, the flow may be prevented altogether. The easiest way to differentiate between these conditions is clinical history as a person can only have DSD due to a neurological condition without exception.

The presence of the urodynamics catheter is proposed to possibly impact flow rate. Groutz looked at flow rates with a 7F catheter in place compared to a free flow study and found a decrease in flow with the catheter in place [46]; however, other studies have not found this same impact [47]. It does however seem prudent that if the urodynamicist has doubt of the validity of a uroflow during the UDS with a catheter in place, a free flow can be performed to ensure the catheter is not causing obstruction or discomfort preventing voiding.

NGB Safety or Poor Compliance

The detrusor leak point pressure (DLPP) is the lowest detrusor pressure at which urine leakage occurs in the absence of either a detrusor contraction or increased abdominal pressure [48]. Detrusor leak point pressure measurement was introduced in myelodysplastic children as an indicator of the risk of upper urinary tract deterioration [48]. In these patients and others with neurogenic lower urinary tract dysfunction, the detrusor leak point pressure is important because a high value is correlated with a higher risk of upper urinary tract pathology. The absolute value associated with worse risk has historically been 40 cmH2O [48] but may be higher in adult populations [32]. Non-neurogenic patients do not have a DLPP, and this term is often confused with ALPP or leaking occurring with an episode of DO.

The primary reason for performing UDS studies in patients with NGLUTD is that their upper urinary tract can be at risk from their disease and some of these urodynamic findings do not have obvious symptoms. In a large systematic review [32], those patients with spina bifida and spinal cord injury as their neurological diagnosis were at higher risk of upper tract deterioration, specifically hydronephrosis, than those with multiple sclerosis. Poor bladder compliance and high DLPP both put patients at risk.

Bladder compliance is defined as the change in volume over the rise in detrusor pressure during filling cystometry (see Fig. 4.7).

$$\text{Compliance} = \Delta\text{volume} / \Delta\text{pressure}$$

This calculation ignores any episodes of detrusor overactivity, and these can make the calculation more difficult. Also, a sustained bladder contraction can mimic loss of bladder compliance but will abate if filling cytometry is stopped. This is a good way to determine if the pressure rise is DO or loss of compliance. Cutoffs for normal compliance vary from <10 to <30 ml/cmH2O, but in most neurologically intact individual's compliance, it is well over 100 ml/cmH2O.

Detrusor overactivity is a common finding in patients with NGLUTD occurring in approximately 60% [32] and is a clear explanation for urinary incontinence. The Pdetmax of contractions ranges from 35 to 115 cmH2O and pressures above

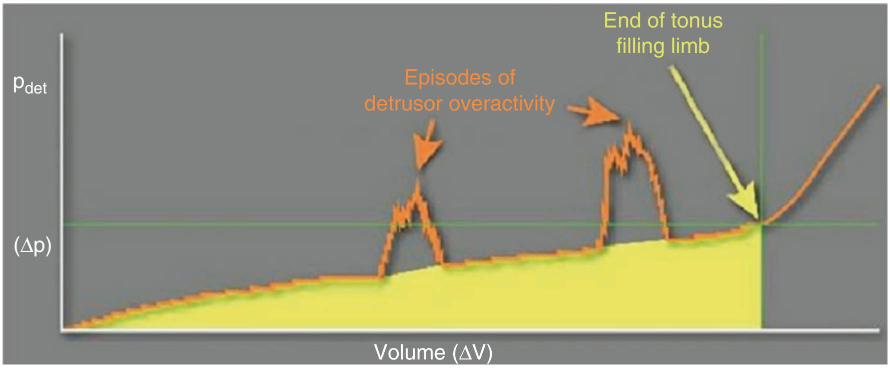

Fig. 4.7 Compliance calculation: solid yellow area represents best-fit pressure-volume relationship for calculation of compliance. Note only the initial compliance curve is used in the calculation and not terminal compliance or episodes of detrusor overactivity

75 cmH2O are an independent risk factor for UUTD [32]. The duration of the contraction ranges from 48 to 236 s with higher duration predicting hydronephrosis (236 vs 114 s). DSD is seen in up to 44% of patients with NGLUTD and is another predictor of UUTD.

Anatomic Diagnoses Seen on Fluoroscopy

Simultaneous fluoroscopy during UDS utilizing contrast-based bladder filling media provides additional anatomical information, with the added burden of fluoroscopic equipment and radiation exposure to the patient and urodynamicist. The additional information can be of great benefit particularly in the NGLUTD population [49] where vesicoureteric reflux and bladder neck abnormalities can be clearly visualized. Other populations where fluoroscopy can be of benefit are women with retention where the source of obstruction can be seen and assists in the diagnosis of sling obstruction location, pelvic organ prolapse as a source of obstruction, and the classic spinning top bladder of voiding dysfunction. Other findings can include urethral diverticulum, bladder diverticulum, or trabeculations (Figs. 4.8 and 4.9).

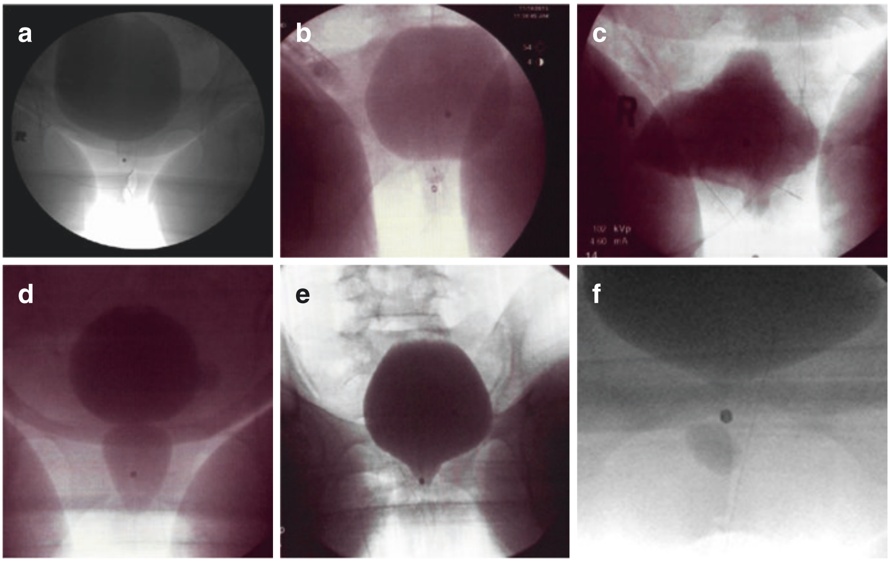

Fig. 4.8 Urethral findings on fluoroscopy: (**a**) primary bladder neck obstruction seen during voiding, (**b**) contrast held up at the level of a sling with pooling of the contrast, (**c**) DSD and trabeculated bladder in a woman with MS, (**d**) severe BOO with sling placed at the distal urethra causing massive obstruction and ballooning of urethra with the void, (**e**) voiding dysfunction with spinning top bladder with the void, (**f**) urethral diverticulum discovered incidentally

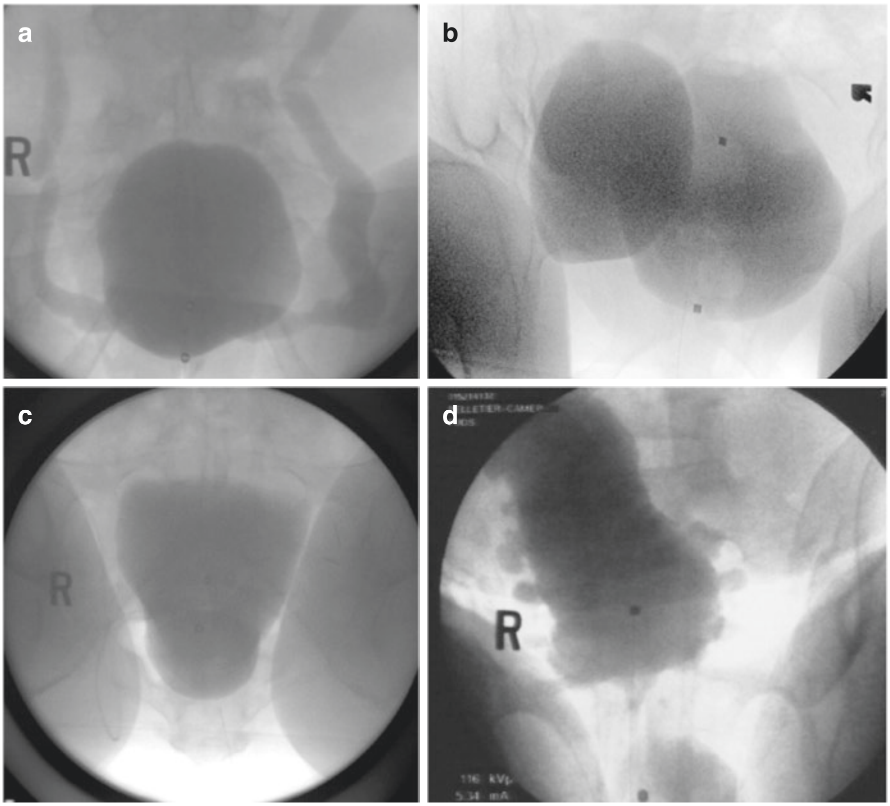

Fig. 4.9 Bladder and ureteral findings seen on fluoroscopy: (**a**) grade 4 bilateral reflux in a neurogenic bladder, (**b**) large bladder diverticulum, (**c**) cystocele causing BOO during the void, (**d**) severe bladder trabeculations causing a Christmas tree-shaped bladder associated with poor bladder compliance

Conclusion

Urodynamics is a powerful tool in the diagnosis of LUTD in women and are best used when less invasive investigations do not yield a diagnosis, and accurate diagnosis is important to the treatment of the patient. Urodynamics interpretation is best done systematically with a cautious eye for artifacts in the tracing and knowledge of the patient's clinical condition to ensure results are congruent. Urodynamics testing is also more useful when a clear and concise diagnostic question is formulated before undertaking the test to ensure the most accurate results are achieved. Urodynamics can reliably diagnose SUI, DO, DU, BOO, and poor bladder compliance, and the addition of fluoroscopy can further identify anatomical anomalies in those select patients where it is needed.

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