Chapter 10
The Normal Study

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Introduction

In practice, particularly in a specialized practice, it may be rare that one encounters a normal urodynamic study. Generally, patients may be referred for refractory or complex issues. Patients with less complicated issues may show treatable etiologies based on symptoms, physical exam, or other non-invasive studies such as voiding diaries and post-void residual determination. Other patients may improve with symptom directed therapies, precluding the need for urodynamics. In order to define and assess a normal study, one must be aware of the normal values in each measurable parameter, as well as the appearance, pattern, and configuration of the graphic display, and the variability that is noted in these parameters, even in normal, asymptomatic patients [1, 2]. Additionally, it is important to take into account possible issues with symptom reproducibility that would require a need to optimize the study to better capture urodynamic findings associated with symptoms (as discussed in Chaps. 5 and 7) or whether catheter dampening or other artifact may be masking actual existing findings (discussed in Chap. 6).

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Normal Filling Cystometry

Normal urine storage is facilitated by sympathetic reflexes as well as somatic input. Sympathetic inflow inhibits bladder activity during bladder filling while promoting closure of the bladder outlet. Somatic reflexes mediated through the pudendal nerve augment bladder outlet closure forces and may also suppress activity of the detrusor. Viscoelastic properties of the bladder wall allow filling without an appreciable rise in bladder pressure. On fluoroscopy during filling cystometry with a radiopaque contrast agent, the bladder will be visualized as a smooth walled, distensible viscus, without visualization of the ureters (absence of vesicoureteral reflux), or urethra (absence of incontinence), with the bladder outlet closed at rest. The location of the vesicourethral junction or bladder neck can be identified by the location of the filling urethral (vesical) catheter as it is filled with the radiopaque contrast agent.

Coarse Sensation and Capacity

It has been noted that there is significant variability in sensation parameters in cystometry in normal patients. This is even in nominally similar patients accounting for variations associated with differences in filling rate, infusate temperature, or patient temperature [1]. The ICS defines normal bladder sensation by three defined points during filling cystometry, as listed in Table 10.1 [3]. Maximum cystometric capacity is the bladder volume at which the patient cannot delay micturition and is the sum of the volume voided and residual volume. In eight different studies, mean first sensation of filling (FSF) varied from 100 to 350 cc, mean first desire to void (FDV) ranged from 170 to 325 cc, and mean strong desire to void (SDV) 260–450 cc [1]. The 4th International Consultation on Incontinence [1] attributes this to a possible lack of standardization of definition between studies.

The ICI cites a general guideline for normal sensation parameters during filling cystometry in healthy adult subjects as follows: FSF at 170–200 ml, FDV at 250 ml, and SDV at about 400 ml, with maximum cystometric capacity at around 480 ml [1]. However this is only a guideline and actual values in the "normal" population may

Table 10.1 ICI guideline for normal sensation parameters

Bladder sensation during filling cystometry	Definition	Suggested normal range (ml)
First sensation of bladder filling	Sensation when the patient first becomes aware of the bladder filling	170–200
First desire to void	Feeling that would lead the patient to pass urine at the next convenient moment, but voiding can be delayed if necessary	~250
Strong desire to void	A persistent desire to void without the fear of leakage	~400

vary considerably. In a group of 50 normal volunteers, Wyndaele and De Wachter [4] found that cystometric sensation points were significantly lower in females than males, but also found that there was a significant difference in weight in the two groups which could influence bladder capacity. In children, the expected bladder volume (EBV) may be calculated from the Koff formula ([age in years + 2] × 30 = EBV ml) in older children, and by the formula (38 + [2.5 × age in months] = EBV in ml) in infants [5]. Ultimately, bladder sensation is dependent on a subjective report from a patient who is in extraordinarily unnatural circumstances. Such factors as indwelling urethral and rectal catheters, pain from urethral catheterization, abnormal positioning on a chair (not a toilet), while being publicly observed by the study technician during a very private act can significantly alter a patients perspective and thus likely accounts for some variability and even artifact. Techniques to improve patient comfort and understanding of filling sensation points are outlined in Chap. 7. However, ultimately there are studies that show correlation of patient report with objective data. In healthy volunteers it has been found that the cystometric bladder filling sensations correspond to the filling sensations reported on frequency volume charts [6].

Compliance

Bladder compliance is the relationship between change in bladder volume and change in detrusor pressure and is measured in ml/cm H_2O. Per ICS recommendation, compliance is usually calculated over the change in volume from an empty bladder to that at MCC or immediately before the start of any detrusor contraction that causes significant leakage. Both detrusor pressure measurements (at the start of filling and at MCC respectively) in the calculation of compliance are measured excluding any detrusor contraction [1, 3].

The rise in bladder pressure in a normal individual is barely perceptible in the absence of an involuntary bladder contraction. This unique property of bladder smooth muscle is likely due to a combination of active and passive phenomena. Studies of filling cystometry with physiologic filling rates in healthy subjects reveal mean compliance values from 46 to 124 ml/cm H_2O. The overall range in these studies of normal, asymptomatic subjects is broad, 11–150 ml/cm H_2O in one study of 17 subjects and 31–800 ml/cm H_2O in another [1]. Additionally, the actual performance of filling cystometry may provoke higher pressure increases than what is seen with physiological filling of the bladder, as has been seen in studies comparing filling cystometry to ambulatory urodynamics [7]. In a study of adult patients, Weld et al. [8] proposed a critical compliance value of 12.5 ml/cm H_2O, based on studies of adults with neurogenic bladder.

In defining normative values and placing such numbers in a clinical context, it is important to understand that compliance is a mathematical calculation: intravesical pressure divided by the bladder volume at bladder capacity. From prior studies of intravesical pressure, 40 cm H_2O bladder storage pressure is the value at which the antegrade transport of urine from the upper tract function is compromised and such a pressure puts the kidneys at jeopardy [9]. In patients with diminished compliance and sustained high intravesical storage pressure during filling, it is clinically advantageous to maintain low bladder volumes such that intravesical pressure is consistently kept below this critical level. This is most often done by continuous bladder drainage (catheterization) or frequent voiding or catheterization intervals such that intravesical volume and thus pressure is maintained in a safe range. It should be noted that this often quoted study regarding the risk of elevated intravesical pressure is related to children with myelodysplasia and may not be relevant for non-pediatric age groups and furthermore, the risk of upper tract deterioration may occur at pressures less than 40 mm H_2O.

It has been suggested that bladder compliance is a more complicated entity in pediatric practice because it is related to bladder volume which increases with age. Small pediatric bladders may be more affected by filling rates during urodynamics, and as such, slow filling rates are preferable. The Committee of the International Childrens' Continence Society cites a rule of thumb that 10 cm H_2O or less as an absolute value at expected bladder capacity is acceptable. Additionally, they recommend that as there are no reliable reference ranges for compliance in infancy and childhood, attention be directed more toward the shape of the curve than numbers, looking to see if it is linear or nonlinear, and if nonlinear, in what way it deviates from linearity [5].

Contractions

The occurrence of involuntary detrusor contractions or detrusor overactivity (DO) may be observed in normal, asymptomatic patients during urodynamics. A variety of studies have shown DO in up to 17 % of normal patients, with a mean occurrence of roughly 8 % [1]. The significance of this is unknown. It may be situational, due to sensitivity or trauma of the urethral catheter or to infusate temperature or rate. Although it can occur in normal patients, in the majority of studies, DO comprises a significant urodynamic finding that may explain a number of storage symptoms especially in those cases where it reproduces the patient's presenting complaints.

Continence

For continent individuals there should not be a demonstrable Valsalva or abdominal leak point pressure. Patients with adequate sphincter function and without symptoms of stress incontinence will not leak under any increased physiologic abdominal pressure [10]. There is no "normal" abdominal leak point pressure. Thus, when doing an urodynamic study, the demonstration of urinary leakage during stress maneuvers such as cough or Valsalva in an individual without complaints of urinary incontinence is potentially artifactual due to the circumstances of the study. Of course, the patient who demonstrates a Valsalva leak point pressure on urodynamics but does not have the complaint of SUI should be carefully requestioned to be sure that this does not reproduce any of their symptoms. It is important to note that a lack of leakage in a symptomatic patient with complaints of urinary incontinence should be further investigated. In such individuals, particular provocative maneuvers such as shifting position, or running water during the UDS exam will potentially unmask and demonstrate incontinence. Furthermore, 15 % of women with SUI and 35 % of men with postprostatectomy SUI who are stress continent during the UDS exam will demonstrate an ALPP with the urethral catheter removed [10]. If prolapse is present, stress incontinence should be tested for with the prolapse reduced in order to exclude occult stress incontinence.

Normal Emptying

The normal voiding sequence is a coordinated neuromuscular event initiated with the activation of the micturition reflex. The first recordable event in both voluntary and involuntary voiding is the relaxation of the urethral sphincteric complex, which can be visualized on EMG as a decreased signal. This relaxation results in a decrease in urethral pressure followed closely by a rise in detrusor pressure with opening of the bladder neck and urethra and initiation of urine flow [11]. Flouroscopy during voiding in a normal patient will demonstrate bladder neck funneling and an open urethra with no narrowing or abnormal dilation.

Contractility, Clinical Obstruction, and Complete Emptying

The ICS defines normal voiding as a voluntary continuous contraction that leads to complete emptying in a normal time span in the absence of obstruction [3]. In the normal bladder, as volume increases and the detrusor muscle fibers become more progressively stretched, there is an increase in the potential bladder power and work associated with a contraction. This is most pronounced in the range from empty up to 150–250 ml bladder filling volume. At volumes higher than 400–500 ml, the detrusor may become overstretched and contractility may decrease again [12]—however, this number may be higher in patients who have exceptionally large bladder volumes [11]. Normal detrusor function is incompletely defined solely by absolute values of detrusor pressure because emptying is also related to outlet resistance. For this reason, emptying is best defined through comparison of contractile pressures to their resulting flow rates. Multiple nomograms have been developed to classify this relationship, which will be discussed in Chap. 19. The majority of these nomograms were developed in male patients. The bladder outlet obstructive index (BOOI) (Fig. 10.1), which was derived from the Abrams Griffiths and Schafer nomograms

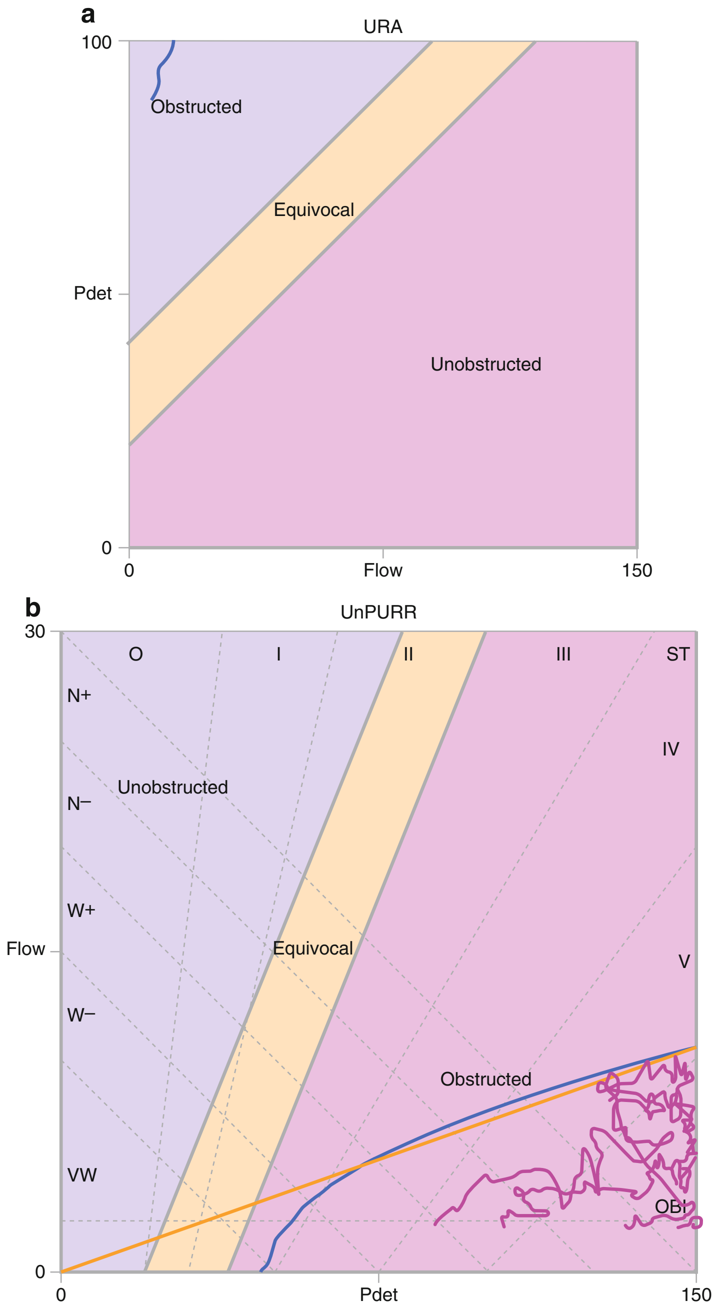

Fig. 10.1 (**a**) Nomograms and formulas defining obstruction and contractility. BOOI = $P_{det}Q_{max} - (2 \times Q_{max})$, BCI = $P_{det}Q_{max} + 5(Q_{max})$, ICS nomogram. (**b**) Composite nomogram

and is the basis for the ICS provisional nomogram, plots Q_{max} against $P_{det}@Q_{max}$ to categorize (male) patients as obstructed, unobstructed, or equivocal. Men are considered obstructed if BOOI is greater than 40, unobstructed if BOOI is less than 20, and equivocal if 20–40. The bladder contractility index (BCI) is derived from Schafer's nomogram (formula in Fig. 10.1). Strong contractility is a BCI greater than 150, normal contractility a BCI of 100–150, and weak contractility a BCI of less than 100 [10]. A composite nomogram incorporates the BOOI and BCI to categorize patients into one of nine groups characterizing the spectrum of obstruction and contractility (Fig. 10.1) [10].

Female patients generally show lower $P_{det}@Q_{max}$ values than men. Empirically, in women, although somewhat controversial, urethral obstruction has been defined by some authors as $P_{det}@Q_{max} > 20$ cm H_2O and $Q_{max} < 12$ ml/s and impaired detrusor contractility as $P_{det}@Q_{max} < 20$ cm H_2O and $Q_{max} < 12$ ml/s (as compared to an empiric cutoff of 40 cm H_2O for $P_{det}@Q_{max}$ in male patients) [11].

Impaired detrusor contractility is characterized by a weak detrusor contraction and a low uroflow. It should be noted that in some patients with low urethral resistance, complete voiding may be accomplished by pelvic relaxation without a significant rise in detrusor pressure. This is considered a normal variant by some authors, explained by the fact that when the detrusor reflex is activated there is no counteractive urethral resistance and the energy is converted to flow. In these patients there may be a very low or no visible rise in detrusor pressure [11].

In all considerations of the pressure flow study it should be kept in mind that the maximum flow rate recorded during pressure flow studies is lower than during free flow. The explanation is not as basic as simple obstruction from the catheter, as this phenomenon has been observed in suprapubic pressure flow studies as well. Possible complex causes might include psychogenic or physiologic causes related to artificial bladder filling [12]. It is recommended that a free uroflow and post-void residual be compared to the pressure flow voiding findings [1]. A normal uroflow curve should be roughly bell shaped, continuous, and not fluctuating. Uroflow is dependent on the voided volume, and nomograms such as the Siroky et al. [13] (developed for male patients) and Liverpool [14] (developed for male and female patients) nomograms which standardize maximum and average flow rates for voided volumes. Normal maximum flow rate ranges are about 20–25 ml/s in men and 25–30 ml/s in women.

Post-void residual (PVR) volumes vary, and one given measurement of PVR may not be accurately representative of typical voiding patterns [1]. PVR, as a measurement in general, increases in reliability when measured on multiple occasions. The ICI has concluded that in review of the literature, there is not an evidence based specific maximum PVR that is considered normal [1]. The Agency for Health Care Policy and Research cite a general rule of PVR less than 50 ml to be adequate emptying and over 200 ml to be inadequate bladder emptying [15]. Lastly, and importantly, in the setting of urodynamics, it should always be taken into account whether the patient felt that the study represented a typical voiding pattern.

Coordination of Sphincters

Normal urine storage is facilitated by a number of physiologic mechanisms that may be seen on the EMG tracing [11]. As the bladder fills, there should be a gradual increase in sphincter EMG activity. Oftentimes, such a subtle increase is not seen on the urodynamic tracing due to the artifact resulting from the use of patch as opposed to needle EMG electrodes. During cough or strain, a reflex increase in sphincter activity should register on the EMG in a normal patient. Suppression of involuntary detrusor contractions by pelvic floor contraction may also be seen (example in Fig. 10.2). Assessment of EMG tracings is complicated by the fact that it may be technically difficult to obtain good quality EMG signals of the desired muscle groups with patch electrodes which are the type most commonly utilized in clinical practice. Needle electrodes, while more accurate in recording pelvic floor activity, are technically difficult to place, painful for the sensate patient, invasive, and expensive. Remarkably, there have been no publications in the last 20 years investigating the benefits of combining EMG with cystometry [1].

Fig. 10.2 Filling cystometry: patient suppresses detrusor contraction with directed pelvic floor contraction

Example 1
Clinical History: 65-year-old female presenting with urge predominant mixed urinary incontinence, using 2–3 light pads per day ("silver-dollar-sized leakage"). Stress incontinence is rare and is precipitated by cough or sneeze. She has had unsatisfactory response to anticholinergics and significant dry mouth. She has no prolapse or demonstrable stress incontinence on exam (Fig. 10.3).

Commentary on Example 1
This tracing demonstrates no increase in P_{det} over the course of filling. There is normal compliance and no detrusor overactivity. There was no stress incontinence

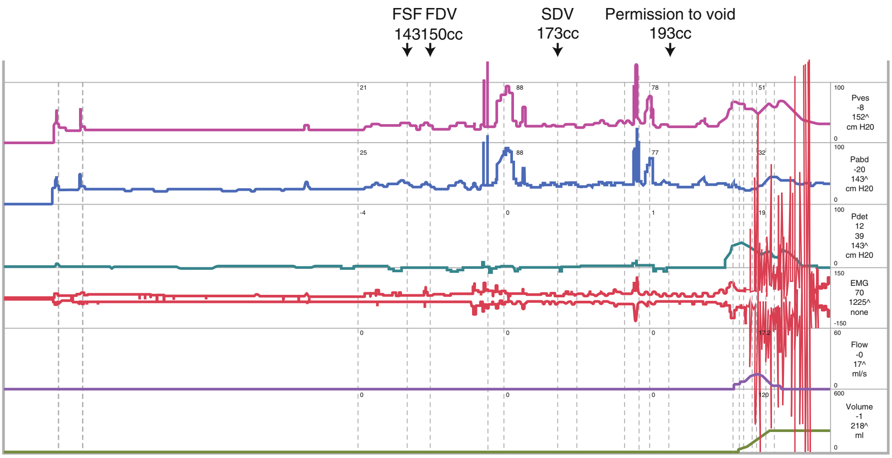

Fig. 10.3 Example 1

with cough or graduated Valsalva at 150 cc and 193 cc. Initial sensation was appropriate, with first sensation of filling at 143 cc, but first desire to void (150 cc) and strong desire to void (173 cc) followed shortly thereafter and bladder capacity was low, at 218 cc. She voids with an appropriate and adequate detrusor contraction, with complete emptying. The flow curve is continuous, but slightly blunted. Q_{max} is 17.2 ml/s. The EMG tracing was quiet throughout filling, with appropriate flaring with cough and Valsalva. There is artifact present in the voiding tracing in the EMG portion, when the transducer became wet.

The quality of the tracing is good. The catheters transmit appropriately, and the only artifact present is in the EMG.

This is a normal study, with the exception of perhaps an increased bladder sensation and reduced capacity. It should be noted, though, that provocative maneuvers on a subsequent fill provoked findings to further support the patient's symptoms.

Example 2

Clinical History: 70-year-old female presenting with urinary frequency and urge incontinence, initially improved with anticholinergics with declining effect. Past medical history is significant for craniotomy for an anterior fossa tumor 6 years prior and hysterectomy 30 years prior for metromenorrhagia. This study is presented in two pages due to the length of the study (Fig. 10.4a–c).

Clinical Commentary for Example 2

This tracing demonstrates essentially normal filling. Initial sensation of bladder filling was appropriate with FSF at 175 cc, although capacity is low, at 284 cc. There was no detrusor overactivity, despite provocative maneuvers of change in fill rate and positional change. There was no stress incontinence with cough and

Valsalva at 150 cc or 225 cc, or with vesical catheter removed. The P_{det} line shows rhythmic decreases secondary to rectal contractions causing isolated increases in the P_{abd} line. Bladder compliance was normal. She was unable to void with the vesical catheter in. Once the vesical catheter was removed, visualized in the second frame with the precipitous drop in P_{ves} and P_{det}, she was able to void. Since the P_{ves} catheter was removed, detrusor contractility cannot be assessed. However, we can see that she did not mount any increase in abdominal pressure during her void suggesting that she did not void by Valsalva. The EMG is appropriately quiet, the uroflow curve is continuous and bell shaped, and on fluoroscopy she has normal bladder neck funneling and an open and nondilated urethra. Her Q_{max} is 25 ml/s. She empties completely. This would indicate a normal void.

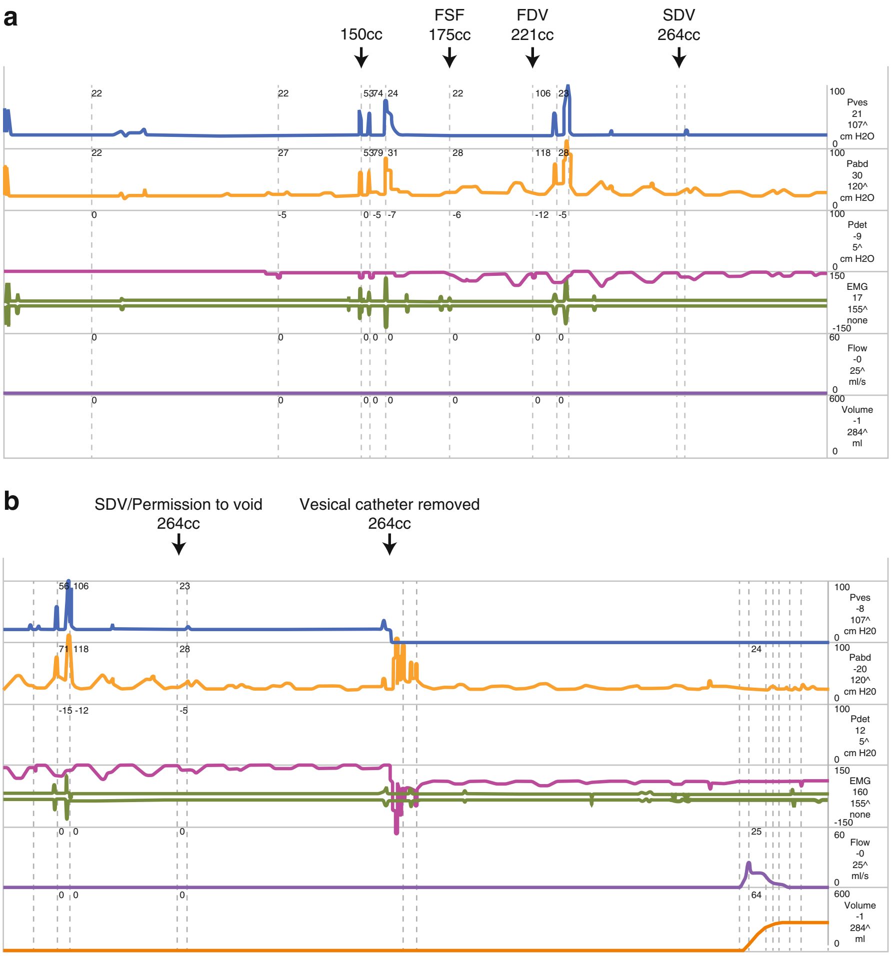

Fig. 10.4 (**a**–**c**) Example 2

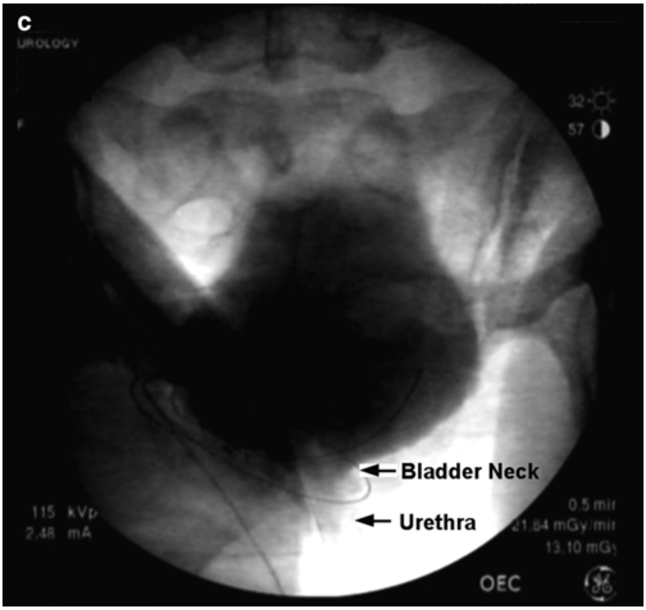

Fig. 10.4 (continued)

The quality of the tracing is good. There is appropriate catheter calibration and transmission and no artifact. The fact that she could only void with the catheter out is a shortcoming, but not uncommon, and there is adequate supplemental information that can be derived from the study to support her voiding pattern. However, her urgency and urge incontinence were not able to be replicated.

Example 3

A 57-year-old male who sustained a fall at work that led to an L3–L4 laminectomy. Two years later he informed his workers compensation insurance company that he was having urinary urgency, frequency, and urge incontinence and erectile dysfunction, reportedly since the time of the initial injury, and he was sent for urodynamic study. Pad test yielded 36 g (Figs. 10.5 a and b).

Clinical Commentary for Example 3

This tracing demonstrates a slight decrease in P_{abd} without a concomitant rise in P_{ves} (annotated by arrow on P_{det} line) which causes a transient increase in P_{det}. However, compliance is normal. There was no detrusor overactivity. Sensation of filling was normal (first desire to void at 225 cc and strong desire at 469 cc), as was capacity at 525 cc. The EMG tracing was quiet throughout with appropriate flaring with coughing and laughing, and also with a slight flare midway through his void, consistent

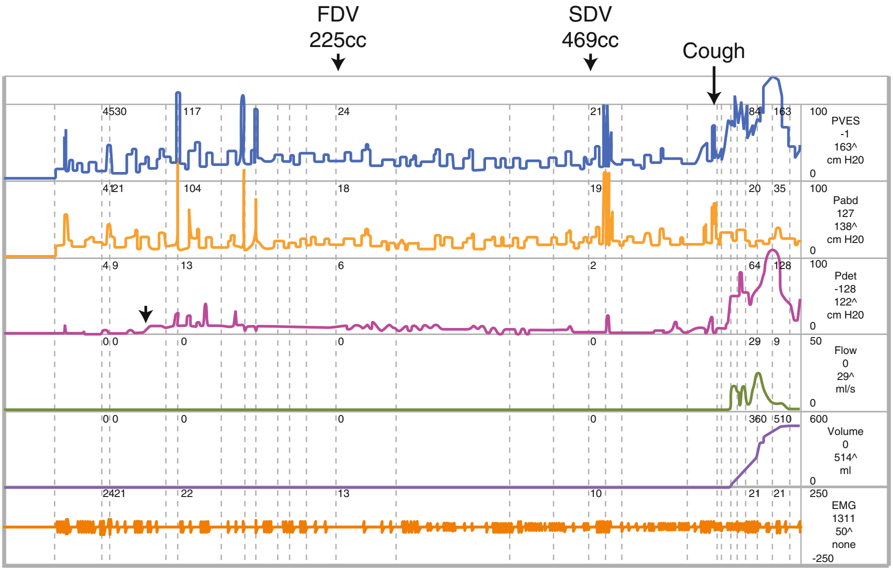

Fig. 10.5 a Example 3

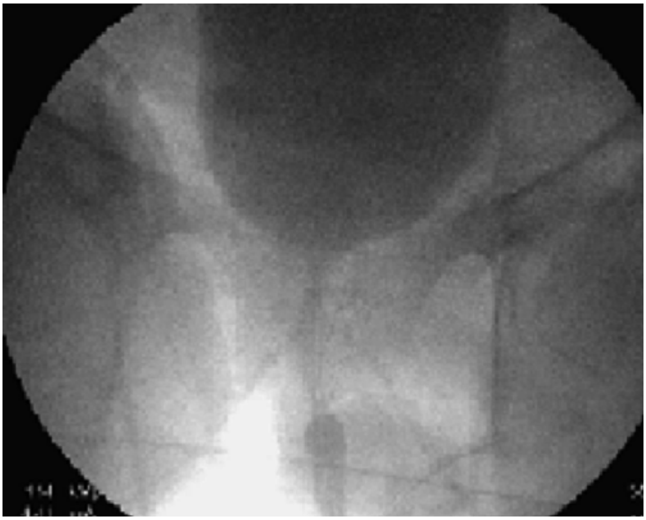

Fig. 10.5 b Voiding image

with guarding. There is a decrease in P_{det} concomitant with the EMG flare. He felt that this void was not indicative of his home voiding pattern. Bladder emptying was accomplished by an adequate detrusor contraction and was complete. The flow curve is somewhat irregular in the first third, but then becomes parabolic in shape.

He does show a suggestion of an aftercontraction, which would be consistent with his clinical history of urgency, as this is sometimes related to overactivity, although no DO was demonstrated on the study. P_{det} at Q_{max} was 64 with Q_{max} of 29, yielding a BOOI of 6. There was no evidence of obstruction. An uninstrumented uroflow showed a normal flow curve. Flouroscopy imaging demonstrates closed bladder neck and a smooth walled bladder at rest (not shown), and normal bladder neck funneling and delineation of the urethra with voiding. There is an artifactual appearance of widening in the distal urethra secondary to a turn in the urethra.

The clinical significance of the finding on this tracing is inconclusive, in terms of looking for neurogenic characteristics related to his back injury. It is a normal study, with the exception of the aftercontraction and the initially abnormal appearance of the uroflow. It is important to recognize that DO may not be reproduced on an urodynamic tracing, again emphasizing the importance of reproducing the patients symptoms during the study. Repeating the study with provocative maneuvers may result in DO.

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