2 Voiding Dysfunction

Diagnostic Evaluation

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INTRODUCTION

Voiding dysfunction usually presents in one of two ways. The first is in the form of symptoms. Symptoms related to voiding dysfunction are broadly referred to as lower urinary tract symptoms (LUTS). LUTS have classically been divided into obstructive symptoms such as difficulty initiating a stream, decreased force of urinary stream, need to push and strain to void (stranguria), hesitancy or intermittent urine flow, and irritative symptoms such as urinary frequency, urgency, and nocturia. In addition, symptoms of incontinence and lower abdominal

From: *Current Clinical Urology: Voiding Dysfunction: Diagnosis and Treatment*
Edited by: R. A. Appell © Humana Press Inc., Totowa, NJ

or pelvic pain may exist. The second way in which voiding dysfunction presents is in the form of urinary tract decompensation such as incomplete bladder emptying or urinary retention, renal insufficiency, and recurrent urinary tract infections. It is possible for patients who present with urinary tract decompensation to have little or no symptoms. In the case of symptoms, evaluation and treatment are often driven by the degree of bother to the patient. In many cases, patients with mild LUTS of a minimal bother will not even bring these to the attention of their physician. However, when urinary tract decompensation is diagnosed, a more aggressive diagnostic and treatment plan must be implemented. There are also patients who have diseases known to effect the lower urinary tract and cause voiding dysfunction, yet do not have significant symptoms or obvious signs of decompensation. These include patients with a variety of neurological conditions such as spinal cord injuries or multiple sclerosis, or non-neurological conditions such as prior pelvic irradiation or extensive pelvic surgery. In many cases careful evaluation of the urinary tract will uncover underlying voiding dysfunction. Thus the diagnostic evaluation of voiding dysfunction will be influenced by the type and degree of bother of symptoms, the presence of urinary tract decompensation, and coexisting medical conditions that might affect the lower urinary tract or its treatment.

In this chapter we will discuss the diagnostic evaluation of voiding dysfunction. It is important to realize that this evaluation is not the same for all patients and will be influenced by many factors, including those previously mentioned. Before discussing the evaluation in detail, we will first present a classification system for voiding dysfunction, which should help the clinician plan a proper diagnostic evaluation and treatment plan.

CLASSIFICATION OF VOIDING DYSFUNCTION

In order to formulate a plan for the diagnostic evaluation of voiding dysfunction, an understanding of the possible causes of symptoms or urinary tract decompensation and the possible manifestations of a coexisting condition is necessary. In order to accomplish this, a practical classification of voiding dysfunction is invaluable. The functional classification system proposed and popularized by Wein *(1)* is simple and practical and allows treatment options to be formulated according to classification. In simple terms, voiding dysfunction can be divided into three categories:

1. Failure to store urine.
2. Failure to empty urine.
3. Failure to store and empty.

For example, the symptom of urinary frequency or incontinence is usually associated with dysfunction of the storage phase of micturition, whereas decreased force of stream or elevated postvoid residual are associated with dysfunction of the emptying phase. In addition, we can view voiding dysfunction in simple anatomical terms:

1. Bladder dysfunction (overactive, underactive).
2. Bladder outlet dysfunction (overactive, underactive).
3. Combined bladder and outlet dysfunction.

These two concepts can be combined so that one can imagine that a patient could present with urinary incontinence (failure to store) secondary to bladder overactivity or bladder outlet underactivity. Similarly a patient with urinary retention (failure to empty) might have an underactive—or hypocontractile—bladder or an overactive—or obstructing—outlet. Failure to empty and failure to store as well as bladder and outlet dysfunction are not mutually exclusive conditions and can exist in multiple combinations. These very simple concepts can be applied to all types of voiding dysfunction. Therefore when evaluating voiding dysfunction, from history and physical examination to simple and comprehensive testing, keeping these concepts in mind can greatly facilitate the process.

HISTORY

The patient's history is the first step in directing the clinician toward the appropriate evaluation and treatment. It should provide the clinician with a detailed account of the precise nature of the patient's symptoms. It is important to remember that the history is only as accurate as the patient's ability to describe their symptoms, therefore, some skill is required by the physician to obtain this information. This is especially true for patients who have difficulty communicating or those who are anxious or embarrassed about their condition. A classic illustration of this is in the study by Diokno et al. *(2)* in noninstitutional elderly patients. They found that only 37% of incontinent men and 41% of incontinent women told a physician about their condition *(2)*.

The history begins with an assessment of a patient's symptoms and their onset. Each symptom should be characterized as to its onset, frequency, duration, severity, and bother; and exacerbating or relieving factors. It is important to note whether the onset of the symptom occurred after a specific event such as surgery, childbirth, menopause, or with the use of a new medication. Any prior treatments by other physicians for their symptoms and the resultant outcome should also be noted. Specific questions about childhood and adolescent voiding troubles or problems with toilet training should be asked.

Patients will often present with one or more voiding symptoms that have been traditionally separated into irritative or obstructive in nature. Irritative voiding symptoms are common presenting complaints that may herald a number of different types of voiding dysfunction. Urgency is defined as an intense desire to void secondary to an abrupt sensation of bladder discomfort or as a conditional response from the fear of urine leakage. Frequency is defined as more than seven diurnal voids and may reflect excessive fluid intake, diuretic use, or excessive caffeine consumption. Nocturia is nighttime frequency and may be secondary to detrusor overactivity, reduced bladder capacity, or excessive fluid/caffeine intake prior to bedtime. Daytime frequency without nocturia may be suggestive of timing of diuretic medications or a psychogenic component to the voiding dysfunction. Dysuria refers to the burning sensation that occurs during micturition and implies bladder, urethral, or prostatic inflammation. Obstructive voiding symptoms include decreased force of urinary stream, straining to void, hesitancy (the prolonged interval necessary to voluntarily initiate the urinary stream), and interruption of urinary stream. They may be present in men with bladder outlet obstruction secondary to benign prostatic enlargement or urethral stricture, or in women with pelvic organ prolapse. Abrams *(3)* has suggested replacing the terms obstructive and irritative symptoms with symptoms of storage (e.g., frequency, urgency, incontinence) and symptoms of voiding (hesitancy, decreased force of stream, incomplete emptying) *(3)*. This is consistent with the functional classification presented above and may be more useful when evaluating patients initially by history.

One of the most distressing of all urinary symptoms is incontinence. When evaluating the symptom of incontinence, it is essential to query extensively about the nature and severity of the incontinence. From a conceptual standpoint, urinary incontinence can occur as a result of bladder overactivity or inadequate urethral sphincter function (or a combination of both) and these in turn can result from a variety of conditions *(4)*. Urinary incontinence is simply defined as the involuntary loss of urine, however, this can be further characterized according to the information relayed by the patient:

1. Urge incontinence: The symptom is incontinence is associated with a sudden uncontrollable desire to void. This condition is usually due to involuntary detrusor contractions.
2. Stress incontinence: The symptom is incontinence that occurs during coughing, sneezing, physical exertion, changes in body position, or other action that causes an increase in abdominal pressure. This condition may be caused by sphincter abnormalities or bladder overactivity provoked by physical activity.
3. Unconscious incontinence: The symptom of incontinence is unconscious and occurs without patient awareness of urges or stress or increases in abdominal pressure. This condition may be caused by bladder overactivity, sphincter abnormalities, overflow, or extraurethral causes such as a fistula or ectopic ureter.
4. Continuous leakage: The symptom is a complaint of continuous loss of urine. This may be caused by sphincter abnormalities or extraurethral causes.

It is not always possible to determine the etiology of incontinence based on history alone. However, careful history taking as to the nature of the incontinence and when it occurs is critical in directing the diagnostic evaluation and treatment options.

As previously mentioned, it is essential to determine the duration of symptoms. When symptoms are acute, or subacute, history may reveal an obvious cause of transient voiding dysfunction as a medication or acute nonurologic illness. This is demonstrated by the mnemonic DIAPPERS developed by Resnick *(5)* to describe causes of transient incontinence: delerium, infection, atrophic vaginitis/urethritis, pharmaceuticals, psychological, endocrine, restricted mobility, and stool impaction.

Questionnaires and symptoms scores can be helpful in assessing the type of symptoms a patient has, the degree of bother of symptoms, and/or effect on quality of life that symptoms produce. Two such example are the American Urologic Association Symptom Index (International Prostate Symptom Score), originally designed to assess men with LUTS secondary to benign prostatic hyperplasia *(6)*, and the I-QOL, designed to assess the impact of incontinence on quality of life *(7)*. In cases where voiding dysfunction does not present danger to a patient, it is often the degree of bother or effect on an individual patient's quality of life that drives evaluation and treatment decisions. Symptom scores and quality of life assessments are very useful in monitoring response to treatment for an individual or in clinical trials.

After a thorough assessment of a patient's presenting symptoms, the history should then focus on related areas. There are several aspects of a patient's history that may be intimately related to voiding function. Sexual and bowel dysfunction are often associated with voiding dysfunction. Therefore the review of symptoms should focus on these areas including defecation (constipation, diarrhea, fecal incontinence, changes in bowel movements), sexual function, dysparunia, and pelvic pain. As neurological problems are frequently associated with voiding dysfunction, a thorough neurological history is critical, including known neurologic disease as well as symptoms that could be related to occult neurological disease (back pain, radiculopathy, extremity numbness, tingling, or weakness, headaches, changes in eyesight, and so on). In addition to a focused history regarding LUTS and voiding dysfunction, a thorough urological history is important. This includes a history of hematuria, urinary tract infections, sexually transmitted diseases, urolilthiasis, and urological malignancy and their treatment.

The past medical history should provide information about concurrent medical diseases, obstetric and gynecologic history, past surgical history, and medication use. Many medications have profound effects on the lower urinary tract or can effect fluid mobilization and urine production and thus contribute to LUTS. Examples of medications that may be associated with voiding dysfunction include alpha-adrenergic agonists, such as pseudoephedrine, diuretics, antidepressants, and anticholinergics.

A detailed history of known neurological diseases (e.g., stroke, Parkinson's disease, spinal cord injury, multiple sclerosis, myelodysplasia, and so on) is important because these diseases have the potential to affect bladder and sphincteric function. A history of medical diseases such as diabetes or congestive heart failure can cause LUTS by their effects on the lower urinary tract or fluid mobilization.

For women with voiding dysfunction, obstetrical and gynecological history is extremely important. Pregnancy and childbirth, particularly vaginal delivery, are associated with voiding dysfunction, especially incontinence and pelvic prolapse. Thus, number of pregnancies, deliveries (including method, i.e., vaginal vs cesarean), and the onset of the symptoms in relation to these events is important. Symptoms can sometimes be related to a woman's menstrual cycle and careful questioning in this regard should be done. A women's hormone status (pre-, peri-, or postmenopausal) and the onset of symptoms with changes in status should be noted. Estrogen deficiency may cause or contribute to LUTS, including irritative symptoms of frequency and urgency, as well as incontinence. If the patient is postmenopausal, it is important to note whether the patient is being treated with hormone replacement therapy. Careful questioning regarding a history of endometriosis and gynecological malignancy should be performed.

Prior surgery may have effects on lower urinary tract function. This includes surgery on the lower urinary tract (e.g., prostate surgery in men or incontinence surgery in women). Other pelvic surgery such as gynecological surgery or lower intestinal surgery also may affect the bladder directly or indirectly through damage to the nerve supply to the bladder or sphincter. For example, new onset total incontinence after hysterectomy raise the suspicion of a vesicovaginal fistula while urinary retention after an abdominal perineal resection of the rectum may be indicative of injury to the neural innervation of the bladder. History of pelvic radiation for treatment of pelvic malignancy (urological, gynecological, or rectal) is important as this can have a marked effect on lower urinary tract function and LUTS.

PHYSICAL EXAMINATION

A complete physical exam is important; however, certain aspects of the exam need to be emphasized. A focused physical examination should be performed to:

1. Assess the bladder for masses and fullness;
2. Assess the external genitalia;
3. Assess the pelvic floor, including anal sphincter tone, and thoroughly examine for support defects, prolapse, and other pelvic conditions in women;
4. Assess the prostate in men;
5. Demonstrate incontinence in patients with that symptom;
6. Detect neurologic abnormalities that may contribute to voiding dysfunction.

The abdominal exam, which includes examination of the flanks, begins with inspection for scars, masses, or hernias. Examination of the back should be performed to check for scars and scoliosis which may be an indication of potential spine abnormalities that may contribute to voiding dysfunction. Suprapubic palpation is performed to determine if the patient has a distended bladder or pelvic mass.

In women, a systematic examination of the vagina and pelvis is important. This is first done in lithotomy position and may be repeated with the patient standing. The external genitalia are first inspected followed by evaluation of the vaginal mucosa for signs of atrophic vaginitis, indicating estrogen deficiency, previous surgery, and vaginal discharge. The urethral meatus should be observed and the urethra palpated for any abnormalities. The anterior vaginal compartment is examined next. This can be aided by applying slight pressure wall with the posterior blade of a small vaginal speculum. The position of the urethra, bladder neck, and bladder can be observed at rest and with straining to evaluate support of these structures and determine the presence of urethral hypermobility and cystocele. Also with coughing and straining, the urethra should be observed for urine loss and whether that loss occurs with hypermobility. In cases of stress incontinence, a Q-tip test may be performed to determine the degree of urethral hypermobility. This is done by placing a Q-tip inside the urethra with its tip at the urethrovesical junction and observing the degree of rotation with straining. Hypermobility is defined as a resting or straining angle greater than 30° from the horizontal. The central vaginal compartment is examined next. The uterus and cervix should be evaluated at rest and with straining to determine prolapse. Bimanual examination is done to evaluate the presence of uterine, adnexal, or other pelvic masses. If the patient has had a hysterectomy, the vaginal cuff should be assessed for enterocele. This is often best accomplished by first retracting the anterior vaginal wall and then the posterior wall. Finally the posterior vaginal compartment is examined by retracting the anterior vaginal wall with the speculum blade. A large rectocele is easily identifiable. Examination for rectocele can be aided by a simultaneous rectal exam, which will also assess perineal integrity, anal sphincter tone, bulbocavernosus reflex, and rectal prolapse. If it is difficult to distinguish between a high rectocele and enterocele, simultaneous rectal and vaginal exam with the index finger and thumb may palpate the enterocele sliding above the anterior rectal wall. The pelvic examination may be repeated with the patient standing with one foot on the floor and the other on a step. This may give a more realistic assessment of the degree of prolapse.

Genital examination in men should include inspection of the urethral meatus and palpation of the penile and bulbar urethra. During rectal exam, anal sphincter tone and bulbocavernosus reflex are assessed, as is the size and consistency of the prostate.

A focused neurologic exam may yield important information regarding voiding dysfunction. Symptoms related to voiding dysfunction may be among the earliest manifestation of nervous system disease *(8)*. A neurologic exam should begin with an observation of the patient's general appearance and gait. Lack of coordination, tremor, or facial asymmetry may be signs of neurologic disease. The upper and lower extremities are evaluated for gross motor coordination, strength, and sensation along dermatome distributions. The deep tendon reflexes at the knee and ankle should be assessed, as well as bulbocavernosus and perianal reflexes, including an evaluation of the muscle tone of the anal sphincter. A patient with a neurologic lesion at the sacral level may demonstrate diminished anal sphincter tone, perianal sensation, or absent bulbocavernosus reflex. Patients with a suprasacral spinal cord lesion will demonstrate spastic paralysis and hyperactive reflexes below the level of the lesion.

LABORATORY TESTING

Urine analysis is part of the standard evaluation of the patient with LUTS and voiding dysfunction. Urinalysis can screen for pyuria, bacturia hematuria, and the presence of glucosuria or proteinuria. Voiding dysfunction and LUTS can be associated with infection, malignancy, or medical illness such as diabetes, which can be discovered as a result of an abnormal urine analysis. When abnormalities are found on urine analysis, further testing may be warranted such as urine culture in cases of suspected infection or urine cytology, endoscopic, and radiographic studies when microscopic hematuria is present.

Blood tests are useful in select cases of voiding dysfunction. The most common tests are those that evaluate renal function, e.g., serum blood urea nitrogen and creatinine, in cases where renal insufficiency is known or suspected.

In select cases, more specific blood and urine testing may be performed, but these are usually dependent on patient history and physical as well as the results of simple tests.

SIMPLE TESTS FOR EVALUATING VOIDING DYSFUNCTION

When history and physical exam alone are insufficient to make a diagnosis or institute treatment, or when more objective information is desired, the clinician may start with simple tests to evaluate lower urinary tract function. These are noninvasive or minimally invasive (placement of a urethral catheter) tests that can provide information that may influence treatment or further diagnostic evaluation. The most basic of these include a voiding and intake diary, measurement of postvoid residual volume, uroflowmetry, and pad testing. Bedside or eyeball urodynamics is also a simple test and is described at the end of the section on urodynamics.

Voiding and Intake Diary

A diary is an extremely useful way to describe the nature and quantify the severity of symptoms such as frequency, nocturia, and incontinence. It also provides a baseline to assess future treatment. A voiding and intake diary should include the time, type and amount of fluid intake, the time and amount of each void, and any associated symptoms such as incontinence, extreme urgency or pain. The diary should be done for a period of 24 h, and several days are preferred. The patient should also note how representative a particular 24-h period was of his or her normal symptoms.

Postvoid Residual

The postvoid residual volume (PVR) is defined as the volume of urine remaining in the bladder immediately following voiding. It provides information on the ability of the bladder to empty as well as its functional capacity (voided volume plus PVR). Normal lower urinary tract function is usually associated with a negligible PVR; however, there is no agreement as to what an "abnormal" or clinically significant value is. Thus, elevated PVR is somewhat arbitrary. This being the case, most would agree that a PVR of greater than 100 mL is elevated, although perhaps not significant. Elevated PVR may be an indication of detrusor hypocontractility or bladder outlet obstruction and may prompt further evaluation depending on the patient and the symptoms or condition being evaluated. PVR can be measured directly by in and out urethral catherization or determined noninvasively by ultrasonography. Portable bladder scanners based on ultrasound technology are now available to determine bladder volume.

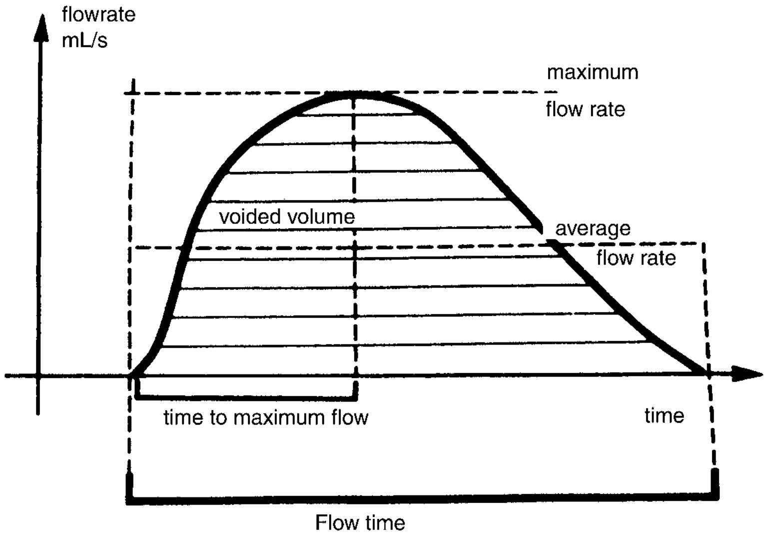


Fig. 1. Normal flow curve and pattern depicting the terminology of the International Continence Society relating to the urodynamic description of urinary flow. Adapted with permission from ref. *8a*.

Uroflowmetry

The determination of urinary flow rate over time, or uroflowmetry, is a simple way to measure bladder emptying. In and of itself, a uroflow is rarely able to determine the cause of voiding dysfunction; however, in conjunction with a careful history and physical, it can provide valuable information. In addition, it is extremely useful in selecting patients for more complex urodynamic testing. Uroflow is measured by a device called a uroflowmeter. Modern uroflowmeters consist of electronic collection equipment with graphic expression of the flow rate as a function of time.

Common parameters determined by uroflowmetry include (*see* Fig. 1):

1. Voided volume: Actual volume of urine voided.
2. Flow time: Time during which measurable flow occurs.
3. Total voiding time: The total time of void taking into account periods of no flow in the patient with an intermittent pattern.
4. Maximum flow rate (Q_{max}): The highest flow rate achieved during the voiding episode (i.e. the highest point on the curve).

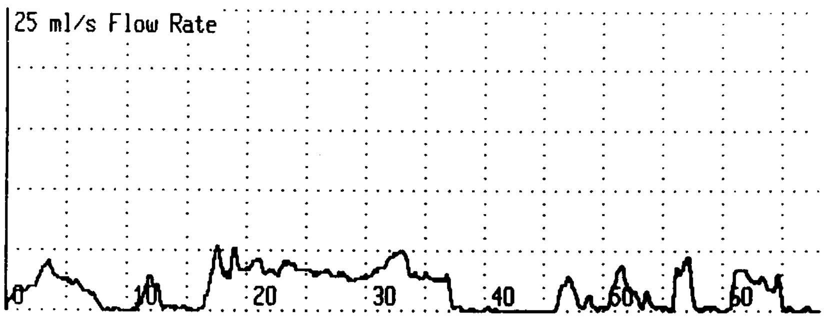
5. Time to maximal flow: The elapsed time from the beginning of voiding to the point of maximal flow. It is generally about one third of the total voided time.
6. Mean flow rate (Q_{ave}): Voided volume divided by flow time. Only interpretable if flow is continuous and uninterrupted.

There is considerable overlap in flow rates between normal and abnormal patients. Q_{max} seems to have a greater specificity than Q_{ave} in determining abnormal voiding *(9)* and has become the most commonly used uroflow parameter. Urinary flow rate and Q_{max} varies as a function of patient age, sex, anxiety, and voided volume. Several nomograms have been established to classify Q_{max} as normal or abnormal based on Q_{max} and voided volume *(10–12)*. Since Drach et al. *(13)* described a linear relationship between Q_{max} and voided volume above a voided volume of 150 mL, and a hyperbolic relationship between the two below this volume, voided volume of 150 mL has been commonly used as a minimum volume to make an accurate assessment of the uroflow. This is a major limitation in patients who do not routinely void with volumes 150 mL or greater.

In addition to the parameters previously mentioned, the overall flow pattern is also important. Visual inspection of the uroflow curve can give valuable insight into the patients voiding dysfunction. A normal flow curve is a continuous, almost bell-shaped, smooth curve (Fig. 1). Interruptions or spikes and valleys in the flow may be indicative of voiding dysfunction. Intermittent flow pattern is characterized by one or more episodes of flow increasing and then decreasing and is commonly owing to abdominal straining (Fig. 2). A single uroflow measurement may not be representative for a given patient *(14)*. Therefore, measuring multiple voiding events is a much more reliable indicator of the patient's voiding pattern. In addition, to have a reliable uroflow measurement, the flow event must represent the patient's usual voiding pattern. This can be simply assessed by asking the patient after completing the uroflow test if the void was representative of their typical pattern with respect to its volume and force.

Abnormal flow rates and patterns are suggestive of voiding dysfunction. They may be caused by a variety of conditions, including bladder outlet obstruction, impaired detrusor contractility, or learned voiding behaviors. Although an abnormal uroflow suggests a problem, it cannot differentiate between causes or make a definitive diagnosis *(15)*. More comprehensive urodynamic testing is needed to make a precise diagnosis.

Uroflow is more commonly utilized in men as opposed to women, probably because of the relatively high incidence of bladder outlet



Results of UROFLOWMETRY

Voiding Time	T100	65	s
Flow Time	TQ	42	s
Time to max Flow	TQmax	17	s
Max Flow Rate	Qmax	5.5	ml/s
Average Flow Rate	Qave	2.8	ml/s
Voided Volume	Vcomp	118	ml

Fig. 2. Abnormal flow pattern, showing interrupted stream and low Qmax (5 mL/s). Adapted with permission from ref. *9*.

obstruction and decreased flow in elderly men *(16,17)*. Again it must be emphasized that uroflow alone cannot make a diagnosis of obstruction. In males, Q_{max} and voided volume normally decrease with age. Girman et al. *(18)* found that in a group of asymptomatic men of ages 40–79 yr, Q_{max} dropped from a median of 20.3 mL/s (40–44 yr) to 11.5 mL/s (75–79 yr), and voided volume decreased from a median of 356 to 223 mL over this same time period. Uroflow is not as frequently used for women with voiding dysfunction. Uroflow tends to be higher in normal women than it is in age-matched normal men *(19)*. This is owing to the fact that the female urethra is short and only the voluntary part of the external urethral sphincter seems to provide any sort of outlet resistance during voiding. In women, normal Q_{max} ranges between 20–36 mL/s with a bell-shaped curve and short flow time *(20)*.

Pad Test

For patients who have the symptom of incontinence, the pad test is a method that can be used to quantify urine loss based on the measurement of weight gain of absorbent pads over a period of time. Several different pad tests have been described, using variable periods of time (20 min to 48 h) and conditions (exercises, daily activity) *(21–24)*. Shorter tests are usually performed with a standard bladder volume. The pad test provides a quantification of urine loss, but cannot distinguish between causes of incontinence. Pad testing is commonly used in research and clinical trials on incontinence treatments. It may also be useful in clinical practice to assess severity of incontinence and response to treatment.

URODYNAMICS

Urodynamics is the study of the transport, storage, and evacuation of urine by the urinary tract. It is comprised of a number of tests that individually or collectively can be used to gain information about lower urinary tract function and can provide a precise diagnosis of the etiology of voiding dysfunction. However, in order to use urodynamics in a practical and effective way, it is important for the clinician to know when and why a urodynamic investigation should be performed. There are situations in which the information gained from history and physical exam, and simple tests like uroflow and postvoid residual determination, is sufficient to make a clinical decision. In other cases, it is necessary to monitor physiological parameters in a more comprehensive and precise way. For example, sometimes a limited evaluation cannot adequately or accurately explain a patient's symptoms, or a patient may have a medical condition known to affect the urinary tract in potentially serious and/or unpredictable ways (e.g., neurological disease).

Once the decision has been made to perform urodynamics on a particular patient, it is important to consider what information is expected from the test *(25)*. The simple fact that a patient has symptoms or a disorder that may affect the lower urinary tract is not sufficient to start the urodynamic evaluation. A list of problems or questions that should be solved or answered by urodynamics should be made before any testing is performed. All patients are not alike and therefore each urodynamic evaluation may be different depending on the information needed to answer the questions relevant to a particular patient. We follow three important rules before starting a urodynamic evaluation *(25)*:

1. Decide on questions to be answered before starting a study.
2. Design the study to answer these questions.
3. Customize the study as necessary.

By following these simple rules, one can maximize the chance of obtaining useful information from a study. It is also critical to have an understanding of the possible causes of a patient's symptoms and the urodynamic manifestations of a pre-existing condition. The functional classification previously described is particularly useful in this regard, because urodynamic testing easily classifies problems into failure to empty or failure to store and further into bladder dysfunction and/or bladder outlet dysfunction.

Multichannel Urodynamics

The various components of the urodynamic evaluation include monitoring of bladder pressure during filling (cystometrogram), monitoring of bladder pressure and simultaneous urinary flow rate during voiding (voiding pressure flow study), and monitoring of pelvic floor and external sphincter activity (electromyography). Usually abdominal pressure is also monitored during filling and voiding so that subtracted detrusor pressure can be determined (*see* Cystometrogram). In select cases, the urethral pressure can also be assessed during storage and voiding (urethral pressure profilometry). It is when these components are combined together as "multichannel urodynamics" that a most sophisticated study of the lower urinary tract is obtained.

CYSTOMETROGRAM

The cystometrogram (CMG) is a measure of the bladder's response to being filled. Normally the bladder should store increasing volumes of urine at low pressure and without involuntary contractions. CMG determines the pressure-volume relationship within the bladder and also provides a subjective measure of bladder sensation with the cooperation of the patient. Ideally, the CMG should mimic normal bladder filling and gives an accurate assessment of true bladder function.

CMG is performed by filling the bladder at a constant rate (usually 10–100 mL/s) with fluid (normal saline or contrast media) or gas (such as carbon dioxide). Filling occurs via a catheter, which is inserted transurethrally or suprapubically. Usually there are two lumens on the catheter, one to measure pressure and one to fill the bladder. Most urodynamisists have abandoned gas cystometry because fluid is more physiologic and allows the determination more parameters. The reader is referred elsewhere for a more detailed description of the technical aspects of cystometry *(26)*.

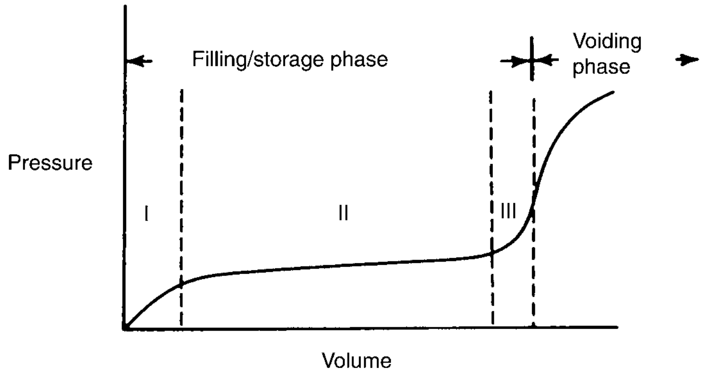


Fig. 3. Idealized normal adult cystometrogram. Phases I, II, and III occur during filling and phase IV during voiding. Phase I reflects the bladder's initial response to filling. Phase II is the tonus limb and reflects bladder pressure during the majority of the filling phase. As the vesicoelastic properties of the bladder reach their limit phase, III is entered where pressures begin to increase just prior to phase IV, the voluntary contraction phase. (Clinically the pressure change from phases I to II is often imperceptible and—depending on how much the bladder is allowed to fill—phase III may not be appreciated as a significant pressure change.) Adapted with permission from ref. *8a*.

Several parameters may be evaluated by CMG:

1. Sensation.
2. Filling pressure.
3. Presence of involuntary or unstable contractions.
4. Compliance (filling pressure in relation to volume).
5. Capacity.
6. Control over micturition.

Sensation is the part of cystometry that is truly subjective and therefore requires an alert and attentive patient and clinician. It is difficult to quantify sensation, which can vary greatly under different conditions. It may be affected by factors such as infusion rate and temperature of the filling solution as well as the level of distraction of the patient. The true value of the CMG with respect to sensation is when a symptom is mimicked and sensation can be correlated with changes in vesical pressure.

Normally as the bladder fills, it maintains a relatively constant and low pressure, usually not exceeding 5–10 cm H_2O above starting or baseline pressure (Fig. 3). It will store increasing volumes of urine without a significant rise in pressure. The only time the bladder should contract is during the voluntary act of voiding. However, under certain circumstances, a bladder may contract involuntarily. Involuntary contractions may be associated with the symptoms of frequency, urgency, urge incontinence, pain, or the perception of a normal desire to void. The International Continence Society (ICS) has classified involuntary detrusor contractions into two broad categories *(27)*:

1. Detrusor instability: involuntary contractions not associated with an underlying neurologic lesion. Detrusor instability may be caused by inflammation, infection, bladder outlet obstruction, aging, and so forth, or in many cases is "idiopathic." Activity may be spontaneous or provoked by certain movements, position, etc. ICS originally required a contraction of at least 15 cm H_2O for the classification of unstable bladder. However, we feel comfortable classifying any involuntary rise in detrusor pressure that is accompanied by an urge as detrusor instability.
2. Detrusor hyperreflexia: involuntary contractions associated with a known neurologic lesion. Typically, these are upper motor neuron lesions such as supra sacral spinal cord lesions, multiple sclerosis, or cerebrovascular accident.

Detrusor instability and detrusor hyperreflexia may look identical on CMG (Fig. 4). However, instability is more likely to be phasic and of lower pressure and can more often be inhibited. Hyperreflexic contractions tend to be more numerous and of higher pressure. These are only generalizations, however, and the terms instability and hyperreflexia are strictly defined by the patient's neurological status and not the CMG appearance of the involuntary contraction.

Compliance refers to the change in volume/change in pressure and is expressed in mL/cm H_2O. Since the bladder is normally able to hold large volumes at low pressures it is said to be highly compliant. The spherical shape of the bladder as well as the viscoelastic properties of its components contribute to its excellent compliance allowing storage of progressive volumes of urine at low pressure. When the bladder is unable to maintain low pressure with increasing volume, compliance is decreased or impaired. This may occur when there is prolonged bladder outlet obstruction as the "overworked bladder" becomes scarred as smooth muscle is replaced by collagen. It can also result from radiation, surgery on the bladder, tuberculosis, and other chronic infectious diseases, as well as other conditions that affect the size, shape, and vesicoelastic properties of the normal bladder. The measurement of compliance is important because high prolonged elevated storage pressures have been shown to have a deleterious effect on the kidneys.

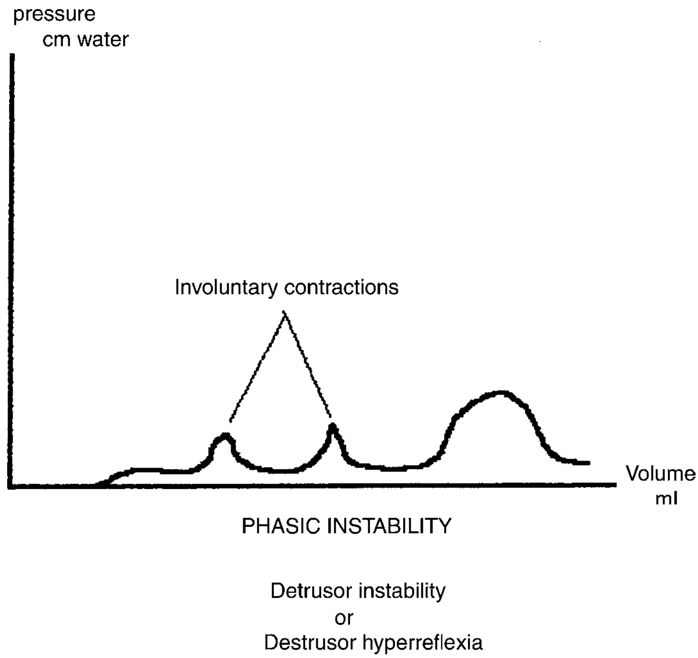


Fig. 4. Involuntary detrusor contractions. Note the multiple involuntary rises in bladder pressure during filling. This could be an example of detrusor instability or hyperreflexia and that distinction would be determined by the absence or presence of a neurological lesion.

McGuire and associates have shown that in neurogenic bladder sustained pressures of 40 cmH_2O or greater during storage can lead to upper tract damage *(28)*. In practical terms, the concept of compliance is actually more useful than its absolute value. The calculated value of compliance (in cmH_2O) is probably less important than the absolute bladder pressure during filling (Fig. 5).

When bladder pressure is monitored through a transurethral or suprapubic catheter, the pressure that is recorded is actually the sum of intra-abdominal pressure and the pressure generated by the detrusor itself, either through a contraction or wall tension with bladder filling, i.e., compliance. Cystometry can be performed as a single channel study where the bladder pressure (Pves) is measured and recorded during filling and storage or as a multi-channel study where abdominal pressure (Pabd) is subtracted from Pves to give the detrusor pressure (Pdet). Abdominal pressure can be recorded via a small balloon catheter that

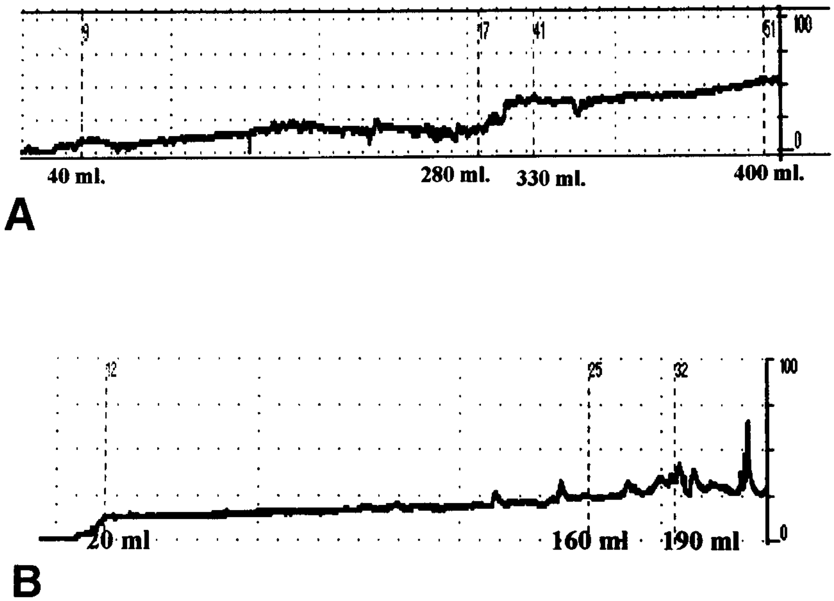


Fig. 5. Impaired compliance. This CMG shows a gradual loss of compliance between 40 and 280 ml with filling pressures of 17 cm H_2O at 280 mL. Between 280 ml and 330 mL there is a rapid rise in pressure to 41 cm H_2O which continues to rise to 51 cmH_2O until filling is stopped at 400 mL. The storage pressures occurring from 300 ml on clearly present potential danger to the kidneys. Adapted with permission from ref. *26*.

is placed in the rectum or vagina. The ability to calculate subtracted detrusor pressure allows one to distinguish between a true rise in detrusor pressure and the effect of increased abdominal pressure (e.g., straining, Valsalva) (Fig. 6).

Voiding Pressure Flow Study

Cystometry assesses the bladder's response to filling, however, by itself tells nothing about the bladder's ability to empty. This can be determined by allowing a patient to void (voluntarily or involuntarily) during bladder pressure monitoring. When the simultaneous measurement of uroflow is added, i.e., voiding pressure-flow study, detrusor contractility as well as the resistance of the bladder outlet can be determined (Fig. 7). In fact, detrusor pressure during voiding is actually determined by the amount of outlet resistance. The more resistance,

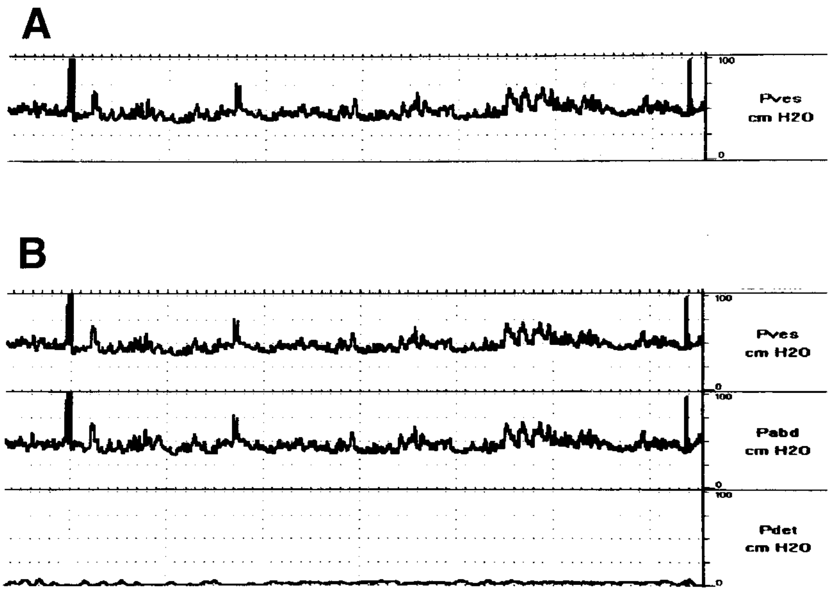


Fig. 6. Adding intra-abdominal pressure monitoring gives a better representation of the true detrusor pressure. (**A**) Single channel study showing multiple spikes and rises in vesical pressure (Pves). Without having simultaneous monitoring of intra-abdominal pressure, it is impossible to tell if these pressure spikes are due to a rise in detrusor or abdominal pressure. (**B**) Same tracing with intra-abdominal pressure monitoring added. It can now be determined that the changes in Pves are due to the changes in abdominal pressure (Pabd). When one looks at the subtracted detrusor pressure curve (Pdet), it is flat without any significant rises. Adapted with permission from ref. *26*.

the more forceful the bladder will contract *(29)*. Since any given bladder has a set bladder outlet relation, the higher the pressure, the lower the flow. Thus obstruction can be defined as relatively high pressure and low flow. In cases where contractility is impaired, the same detrusor pressure will result in a lower flow.

Voiding pressure flow studies are extremely important in evaluating lower urinary tract symptoms and voiding dysfunction. For example, bladder outlet obstruction and/or impaired detrusor contractility may be directly responsible for symptoms (e.g., decreased uroflow, incomplete emptying); abnormal voiding can affect the bladder's ability to store and result in an abnormal cystometrogram (e.g., detrusor instability or decreased compliance caused by bladder outlet obstruction).

In general, one can diagnose bladder outlet obstruction when high pressure and low flow are seen on a voiding pressure flow study.

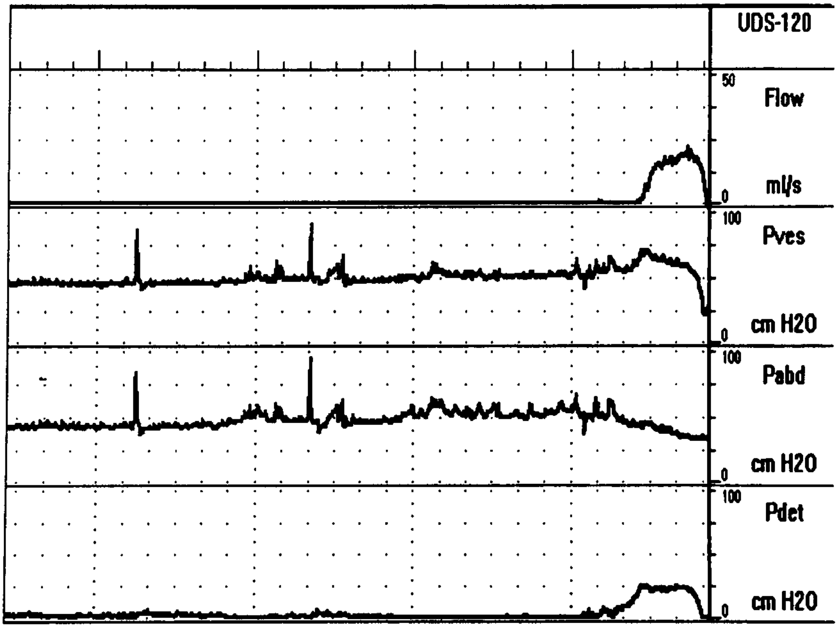


Fig. 7. Normal voiding pressure-flow study in a male. During voluntary voiding on the right portion of the tracing, there is a rise in Pdet associated with flow. There is a slight decrease in Pabd during the second half of voiding, with Pabd returning to just below baseline. The uroflow curve is relatively normal with Qmax = 22 mL/s. Detrusor pressure during voiding was about 30 cm H_2O.

Sometimes this is obvious (Fig. 8), but other times a more sophisticated analysis of the pressure flow relationship is needed. In men, several such analyses or nomograms have been described to diagnose obstruction and impaired contractility (Figs. 9 and 10) *(16,30)*.

Leak-Point Pressure

Leak-point pressures are used to determine the pressure at which involuntary loss of urine occurs. There are two types of leak-point pressures that can be determined and each represents the measurement of a completely different parameter and concept *(31)*:

1. Abdominal leak-point pressure (ALPP). This pressure, also known as the Valsalva leak-point pressure, is the amount of abdominal pressure required to cause leakage of urine, in the absence of a rise in Pdet. It is a measure of the resistance of the sphincter to rises in Pabd and is

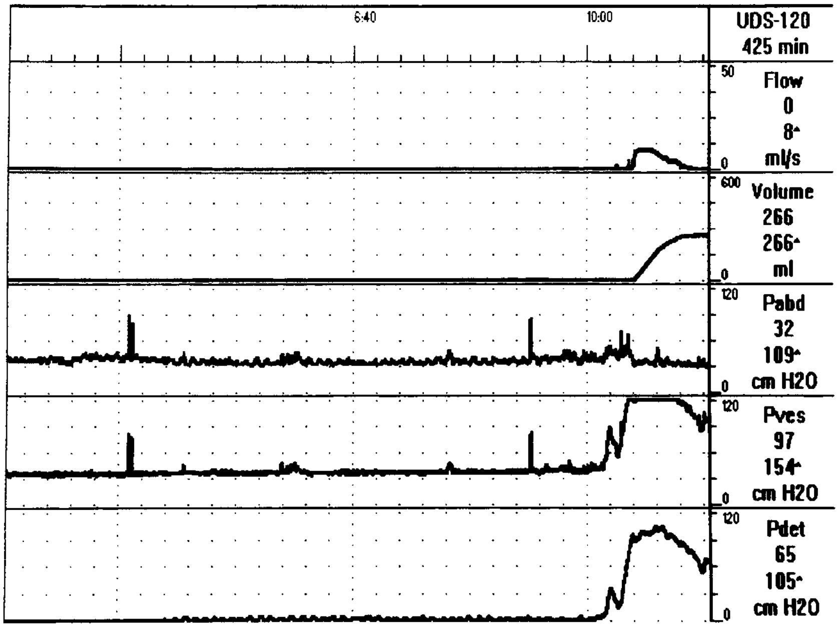


Fig. 8. Classic bladder outlet obstruction seen as high pressure–low flow voiding. Pves, intravesical pressure; Pabd, abdominal pressure; Pdet, detrusor pressure. Adapted with permission from ref. *29a.*

commonly used in evaluating patients with stress incontinence (Fig. 11). There is no "normal" ALPP, because there should not be leakage when any physiologic abdominal pressure is generated. Very low leak-point pressures are suggestive of intrinsic urethral dysfunction.

2. Bladder leak-point pressure (BLPP). This pressure, also known as detrusor leak-point pressure, is the amount of detrusor pressure required to cause leakage in the absence of a rise in Pabd *(32)*. It is a measure of the resistance of the sphincter to rises in Pdet. BLPP is useful in cases of detrusor dysfunction, where storage pressures are elevated, usually in cases of impaired compliance (Fig. 12). The higher the BLPP, the more resistance is provided by the sphincter and the more likely is upper tract damage. BLPP that is 40 cm H_2O or greater during storage can lead to upper tract damage *(28)*.

Electromyography

The storage and emptying phases of the micturition cycle are affected by the perineal musculature including the striated external urethral

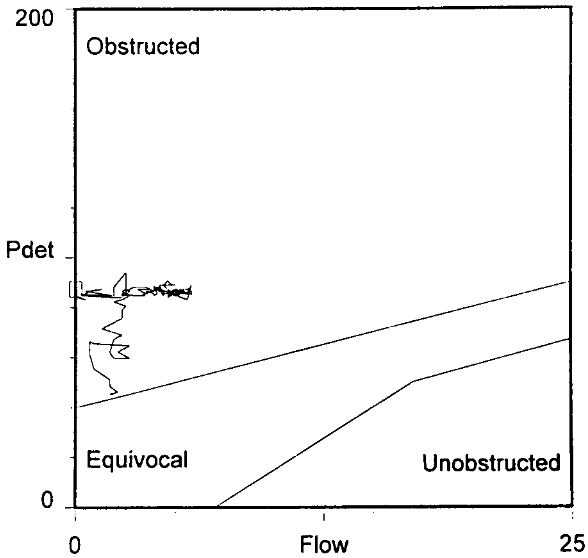


Fig. 9. The Abrams–Griffiths Nomogram. Maximum flow rate and the corresponding detrusor pressure at maximum flow are plotted against each other, with detrusor pressure in cm H_2O on the y-axis and uroflow rate in mL/s on the x-axis. Data from 117 males (>55 years) evaluated for possible prostatic obstruction were used to create zones on their graph representing obstructed, unobstructed and equivocal micturition. The location of the plotted maximum flow point on the graph determines the presence or absence of obstruction or an equivocal state. (In this case the patient would be obstructed.)

sphincter. Sphincter activity can be measured during urodynamic testing either by surface electrodes (similar to those used for electrocardiogram) or by inserting needle electrodes directly into the sphincter muscle *(33)*. When surface electrodes are used, it is actually the activity of the anal sphincter that is measured, but it is extremely rare for anal sphincter activity to be dissociated from urethral sphincter activity.

Normally, external sphincter activity will increase as bladder pressure rises (e.g., with detrusor instability) as a way to protect against incontinence. Conversely, the external sphincter should relax during voiding (Fig. 13). In fact, normally, the external sphincter relaxes before a bladder contraction is initiated. Failure of the external sphincter to relax during voiding can result in lower urinary tract symptoms and dysfunction. This can be a learned behavior (dysfunctional voiding) or can occur involuntarily as a result of neurological disease (detrusor-external sphincter-dyssynergia). Either can result in significant voiding

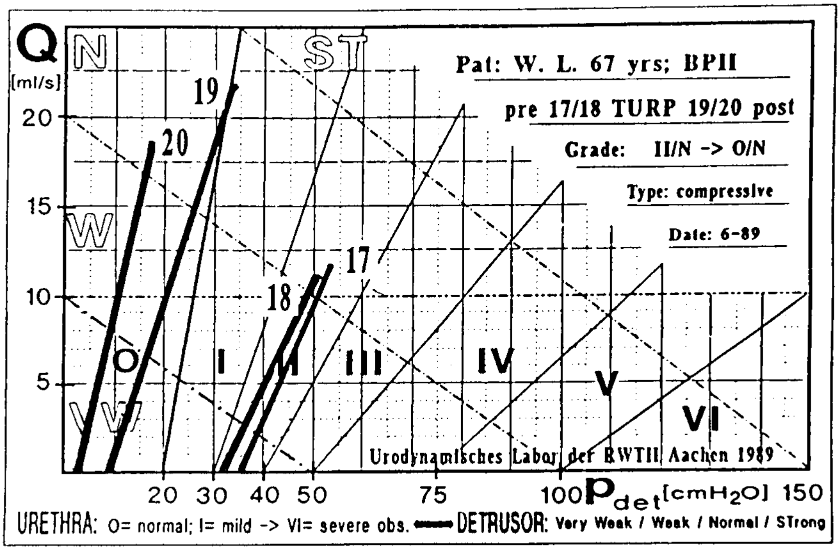


Fig. 10. Linear PURR nomogram. This nomogram developed by Schafer allows for the determination of obstruction independent of contractility. The degree of obstruction is determined by 7 zones on the pressure-flow diagram labeled 0 to VI corresponding to increasing grades of obstruction: grade 0 and I, no obstruction; grade II, equivocal or mild obstruction; grade III to VI, increasing severity of obstruction. The boundary between grades 2 and 3 corresponds to the boundary between equivocal and obstructed in Abrams-Griffiths nomogram. Contractility zones are also seen: ST, strong; N, normal; W, weak. Adapted with permission from ref. *30.*

dysfunction as outlet resistance during voiding is increased creating a functional obstruction.

Videourodynamics

In certain cases, multichannel urodynamic testing is unable to provide a precise diagnosis. In such cases videourodynamics may be necessary. Videourodynamics refers to the simultaneous measurement and display of urodynamic parameters with radiographic visualization of the lower urinary tract *(34,35).* In these cases, the bladder is filled with radiographic contrast filling during urodynamics. Because all urodynamic parameters previously mentioned are visualized simultaneously with the radiographic appearance of the lower urinary tract, the clinician can better appreciate their interrelationships and recognize artifacts. Videourodynamics is the most precise way to evaluate lower urinary

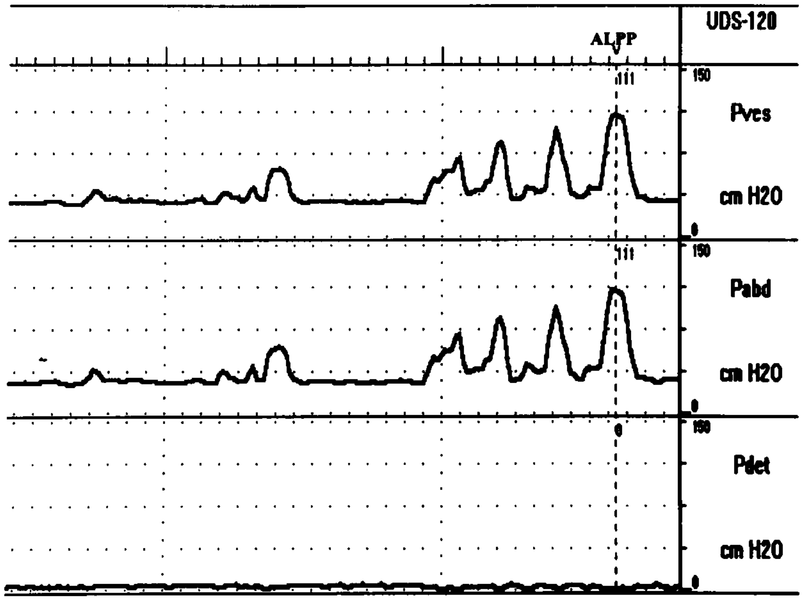


Fig. 11. Urodynamic study of a 60-year-old female with stress incontinence. The multiple spikes in Pves and Pabd represent coughing and straining. The point where leakage was demonstrated, marked by the vertical line, was at a Pves (and Pabd) of 111 cm H_2O. This is the abdominal leak point pressure (ALPP) which is usually measured on the Pabd curve.

tract function and disturbances in micturition. In cases of complex voiding dysfunction, videourodynamics can be invaluable (Fig. 14).

Bedside Cystometrics

In cases where very basic urodynamic information such as sensation, capacity, and presence of detrusor contractions (voluntary or involuntary) is desired, a very simple CMG, known as bedside or eyeball urodynamics, can be performed without any special urodynamic equipment. The urodynamic information provided, although limited, is sometimes enough to aid in making a differential diagnosis *(36)*. Bedside cystometrics are useful when sophisticated equipment is unavailable or when standard urodynamic testing would produce undue discomfort for a particular patient. Simple CMG can be done with a urethral catheter, catheter tip syringe, and filling solution (saline or water). Prior to starting the patient is asked to void, if possible. A standard straight

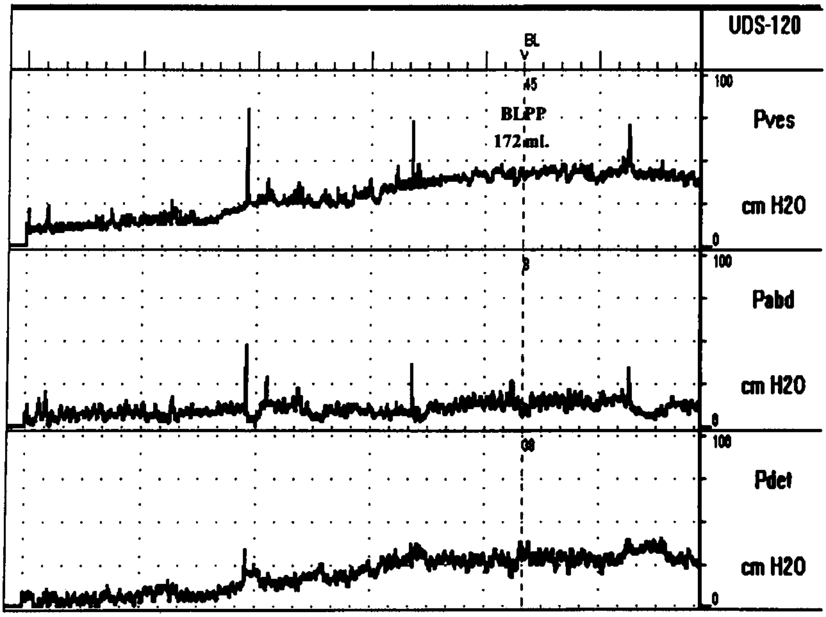


Fig. 12. Urodynamic study of a child with myelomeningocele and incontinence. The patient has a poorly compliant bladder with Pdet rising during filling. Leakage was demonstrated at a Pdet of 38 cm H_2O, marked by the vertical line. This is the bladder leak-point pressure (BLPP).

catheter 14–18 French is introduced into the bladder and postvoid residual is measured. A Foley catheter may be used if occlusion of the bladder neck is necessary or if one is already indwelling. A catheter tip syringe (usually 60 mL) is connected to the end of the catheter after its plunger is removed. The catheter and attached syringe are held directly upright and the top of the syringe is usually located about 15–20 cm above the patient's bladder (Fig. 15). The bladder is then slowly filled by gravity at 50-mL increments as water or saline is poured into the syringe. The catheter and syringe should be kept as low as possible to allow for a steady infusion. Sensations and the volumes at which they occur can be noted. If it is necessary to raise the syringe to maintain flow rate, this usually means that intravesical pressure is increasing (contraction, poor compliance, or abdominal straining). When a sudden rise in pressure occurs, fluid may be seen backing up into the syringe. This is usually indicative of an involuntary contraction and may be accompanied by an urge; however, an abrupt decrease in compliance or abdominal straining can also do this. It is

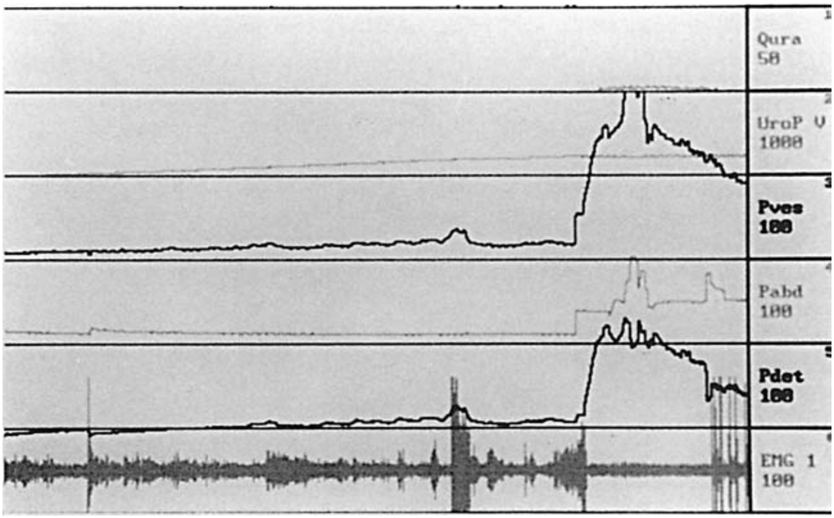


Fig. 13. Normal electromyography of the pelvic floor during a pressure flow study. Note the voluntary increase in EMG activity during the involuntary detrusor contraction and the decrease in activity during voluntary voiding. Adapted with permission from ref. *33*.

helpful to gently place a hand on the patient's abdomen and careful observe for such movement. When it is important to assess voluntary contractility, the catheter can be raised to its maximum height and with the syringe empty, the patient is asked to void. If the top of the syringe is 25 cm above the bladder and fluid is raised to that level, then at least 25 cmH_2O pressure was generated. If fluid is not seen backing up into the syringe, the catheter is slowly lowered to see if there is any increase in pressure. Again, a hand should be kept on the abdomen to rule out, as best as is possible, abdominal straining. Obviously, when a detrusor contraction coexists with abdominal straining, it is extremely difficult to sort out the two.

ENDOSCOPY

Cystourethroscopy has been used in the evaluation of patients with lower urinary tract symptoms and voiding dysfunction in order to assess the bladder, the urethra, and prostate and look for extraurethral causes of incontinence.

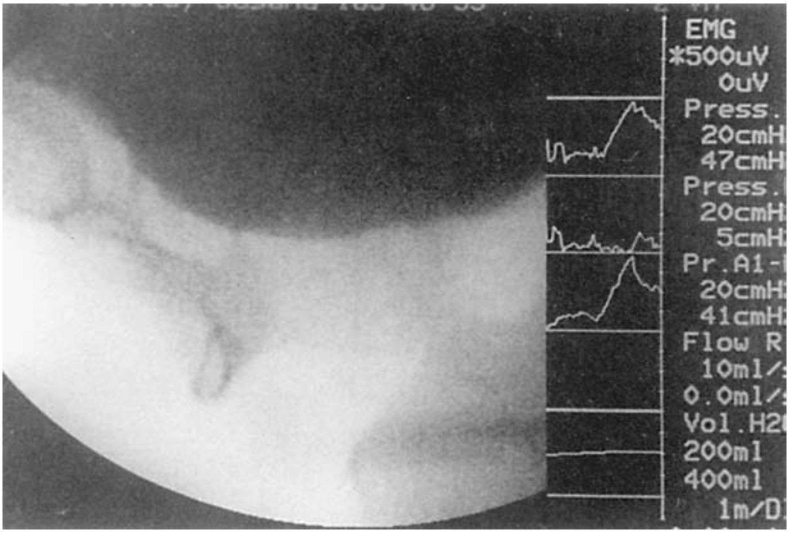


Fig. 14. Videourodynamic evaluation of a woman in retention with primary bladder neck obstruction. Figure shows urodynamic tracing (top line is vesical pressure, second is abdominal pressure, third is detrusor pressure and forth is flow) as well as fluoroscopic image during voiding. There is a sustained detrusor contraction of >40 cm H_2O with no opening of the bladder neck and no flow. Without imaging, the point of obstruction could not be localized. Adapted with permission from ref. *35*.

Evaluation of the Bladder

Cystourethroscopy to assess the bladder has been used as a routine part of the evaluation of males and females with LUTS and voiding dysfunction) to rule out intravesical pathology as a potential source of symptoms *(37)*. The bladder is examined for an intravesical lesion or process that may be causing symptoms of instability, irritability, or incontinence. However a thorough review of the literature would suggest that, in routine cases, cystourethroscopy is optional and has its greatest value in select cases *(38,39)*. There has been particular concern that irritative symptoms may be a warning of intravesical pathology such as carcinoma of the bladder. However there is no direct diagnostic value of cystourethroscopy in a patient with an unstable bladder unless microscopic hematuria is present *(40,41)*. This would support the *routine* use of cystourethroscopy for patients with irritative symptoms when clinical suspicion of an intravesical lesion is high, such as when hematuria is present or when other tests such as radiography suggest

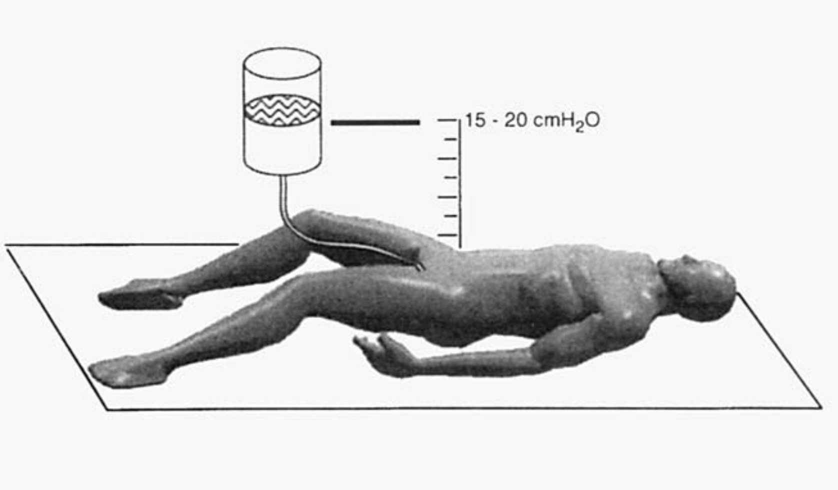


Fig. 15. Bedside or eyeball urodymanics. A urethral catheter is placed in the bladder and raised vertically. A syringe (without its plunger) is connected to the end of the catheter and the bladder is filled. Adapted with permission from ref. *26.*

intravesical pathology. However, cystourethroscopy is extremely helpful and recommended in cases where symptoms cannot be explained by other more routine diagnostic testing or in patients who have failed to respond to seemingly appropriate treatment. Cystourethroscopy should be part of routine follow-up for patients whose voiding dysfunction is managed by a chronic indwelling catheter or bladder augmentation or substitution.

Evaluation of the Female Bladder Outlet

Endoscopic evaluation of the female bladder outlet in cases of stress incontinence has been advocated by several authors *(42,43)*. However, others have found it to be inferior to other tests such as urodynamics *(44–46)*. Most experts would now agree that cystourethroscopy is inadequate to judge the functional integrity of the bladder outlet and will underestimate the presence of intrinsic sphincter deficiency. Endoscopic evaluation of the female bladder outlet is also of little value in the uncomplicated patient with urge incontinence *(47)*. In select women, cystourethroscopy to evaluate the bladder outlet can be extremely helpful; for example, in cases of urethral trauma or foreshortening, previous anti-incontinence surgery, suspected intraurethral pathology (e.g., urethral diverticulum), or bladder outlet obstruction. When evaluating the female urethra, it is extremely important to use an endoscope, which allows for complete visualization of the urethra. A rigid scope with no beak (or a short beak) to allow distension of the urethra, and a narrow lens (0–30°) or a flexible scope are optimal.

Evaluation of the Male Bladder Outlet

Lower urinary tract symptoms in men were previously thought to be caused by benign prostatic hyperplasia. However, it is now known that a variety of conditions can cause such symptoms, including bladder outlet obstruction, detrusor instability, and impaired detrusor contractility. Cystoscopic evaluation of men with LUTS used to be routine; however, now its indications are more limited. Based on the available evidence and world literature, The World Health Organization Third International Consultation on BPH made the following recommendation:

> *"Diagnostic endoscopy of the lower urinary tract is an optional test in the standard patient with symptoms of prostatism because*
> *—the outcomes of intervention are unknown,*
> *—the benefits do not outweigh the harms of the invasive study, and*
> *—the patients' preferences are expected to be divided.*
> *However, endoscopy is recommended as a guideline at the time of surgical treatment to rule out other pathology and to assess the shape and size of the prostate which may have an impact on the treatment modality chosen." (48)*

Cystourethroscopy has a more definitive role in men who have undergone surgical treatment of the prostatic for benign or malignant disease when anatomic causes of postoperative voiding dysfunction are suspected (e.g., bladder neck contracture or anastomotic stricture).

Extraurethral Incontinence

Endoscopy can be an invaluable tool in the diagnosis and treatment of extraurethral incontinence due to vesicovaginal fistula and ectopic ureter. Cystourethroscopy can precisely localize a fistula site in the bladder and help plan surgical correction. Occasionally, a small fistula that is not seen on physical exam or by radiographic studies can be diagnosed only by cystoscopy. Incontinence owing to ectopic ureter in the female is usually diagnosed by radiographic studies. However, the exact location of the ureteral orifice in the urethra or vagina can be identified by cystourethroscopy and/or vaginoscopy. This can be extremely helpful in the planning of corrective surgery.

URINARY TRACT IMAGING

In certain cases of voiding dysfunction, imaging studies, including radiography, ultrasonography, magnetic resonance, and nuclear scanning, are an important part of the evaluation. Specifically, when detrimental effects on the upper urinary tract or anatomical abnormalities of the upper and lower urinary tract are suspected, such studies can be useful. We will limit our discussion to imaging of the upper and lower urinary tract; however, there are cases where a urologic work-up of voiding dysfunction may prompt radiographic investigation of the nervous system or spine (e.g., in cases of suspected neurogenic voiding dysfunction).

Upper Urinary Tract Imaging

As mentioned previously, voiding dysfunction can be a cause of renal damage or deterioration of function. In 1981, McGuire and colleagues popularized the now universally accepted concept of the relationship between high bladder storage pressure and renal deterioration *(28)*. Thus, in cases of known or suspected high storage pressures (e.g., neurogenic voiding dysfunction) or elevated postvoid residual upper urinary tract, imaging is an important and necessary part of the evaluation. Also in certain patients with incontinence, an extra-urethral cause may be suspected (e.g., ectopic ureter or urinary tract fistula).

The upper tract imaging modalities most commonly used are intravenous urography (IVU), ultrasonography, computerized tomography (CT scan), magnetic resonance imaging (MRI), and isotope scanning. The usefulness of each individual test often depends on local expertise.

Intravenous urography (IVU) is a standard radiographic examination of the upper urinary tract. Successful examination is dependent upon adequate renal function. Renal dysfunction, obstruction, congenital anomalies, fistula, stones, and tumors may be detected. IVU is the appropriate first study when ureteral ectopia is suspected. It is also an appropriate first imaging study when ureterovaginal fistula is suspected *(49,50)*. Confirmation of the fistula, its size, and its exact location are often obtained with retrograde ureteropyelography. IVU can also be used to evaluate hydroureteronephrosis; however, ultrasound has become the procedure of choice for this because it is more cost-effective and does not expose the patient to intravenous contrast (*see* below).

Ultrasonography is an excellent tool for imaging of the upper urinary tracts. It is totally noninvasive, and successful imaging of the kidneys is independent of renal function. Ultrasound can be used to assess many features of renal anatomy including renal size and growth, hydronephrosis, segmental anomalies, stones, and tumors. In the evaluation of the patient with lower urinary tract dysfunction, the detection of hydronephrosis is extremely important and may be an indication of vesicoureteral reflux or obstruction. However, no correlation exists between the degree of dilatation and the severity of obstruction. Also renal blood flow can be detected by the Doppler technique. Ultrasound is an excellent tool to follow the degree of hydronephrosis over time or in response to treatment.

CT scanning can also provide much useful information about the anatomy of the upper urinary tract. Information can be independent of renal function; however, the addition of intravenous contrast can highlight specific anatomic characteristics (dependent on renal function). In most cases of voiding dysfunction, adequate information about renal anatomy can be obtained with ultrasonography; however, there may be select cases where CT is beneficial. MRI offers some of the same benefits as CT in the evaluation of the upper urinary tracts. It has the advantage over CT in that all planes of imaging are possible. As technology advances, MRI may play an increasing role in the evaluation of hydronephrosis and urinary tract anomalies in the future.

When it is necessary to investigate functional characteristics of the upper urinary tract, nuclear isotope scanning is useful. Renography is used to examine the differential function of the two kidneys as well as how they drain. There are many physiological factors and technical pitfalls that can influence the outcome, including the choice of radionucleotide, timing of diuretic injection, state of hydration and diuresis, fullness or back pressure from the bladder, variable renal function, and compliance of the collecting system *(51,52)*. Diuresis renography with bladder drainage may be performed when obstructive uropathy is suspected *(53)*.

Lower Urinary Tract Imaging

When anatomical factors are considered as a possible cause of voiding dysfunction, lower urinary tract imaging can be useful. A plain radiograph of the abdomen and pelvis (KUB) can determine the presence of stones or foreign bodies, which can be contributing to LUTS and voiding dysfunction. The lower spine can also be evaluated (spina bifida occulta or sacral agenesis). A cystogram, with stress and oblique views, can be useful in select cases of pelvic prolapse (especially when the degree of cystocele is difficult to determine on a physical exam) and stress incontinence in women to determine support defects *(54)*. Voiding cystourethrography (VCUG) may detect abnormalities such as posterior urethral valves, urethral diverticulum, urethral stricture, or other anatomic abnormalities of the urethra. In cases where female bladder outlet obstruction is suspected the VCUG in addition to urodynamic studies is important. We prefer videourodynamics in such cases *(55)*; however, when not available the VCUG can be done separately. The VCUG can also determine the presence of vesicoureteral reflux. Ultrasound of the bladder has become a convenient, noninvasive way to determine postvoid residual, especially with the introduction of small portable devices made specifically for determination of bladder volume.

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Voiding Dysfunction
Diagnosis and Treatment
Appell, R.A. (Ed.)
2000, X, 342 p. 68 illus., Hardcover
ISBN: 978-0-89603-659-8
A product of Humana Press