Urodynamic studies in pediatric urology

Tom P. V. M. de Jong and Aart J. Klijn

Abstract | In any type of lower urinary tract dysfunction it is mandatory to obtain as much information as possible on the function of the urinary tract. By definition of the International Continence Society, any investigation that produces such information is part of urodynamics. Thus, voiding and defecation history, physical examination, voiding frequency charts and defecation diaries are all essential parts of urodynamics. Repeated free uroflowmetry is considered an essential routine investigation by the International Children's Continence Society. Static and dynamic ultrasonography of the lower urinary tract and the pelvic floor can give important information on lower urinary tract anatomy and function, in a noninvasive manner. Invasive urodynamic studies such as voiding cystourethrography and cystometry are reserved for patients for whom the outcome of such studies is expected to change the therapeutic regime. Invasive urodynamic tests are performed primarily for one of two reasons. First, to confirm an expected diagnosis in new patients. Second, to ensure that the storage pressures in the bladder remain safe for normal functioning of the kidneys in children with chronic disease.

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Learning objectives

Upon completion of this activity, participants should be able to:

1. Identify the most important diagnostic tool for lower urinary tract symptoms in children.
2. Describe the clinical characteristics of diagnoses affecting urinary function in children.
3. Apply urodynamic studies effectively in children.
4. Interpret findings from urodynamic studies in children.

Introduction

Between 7% and 10% of school-age children are seen by a specialist for investigation of recurrent urinary tract infections (UTIs) or urinary incontinence. Some patients come to medical attention at neonatal age because of abnormal findings on intrauterine ultrasonography. Children with manifest (spina bifida aperta) or occult (partial sacral agenesis, tethered spinal cord) spinal dysraphism need life-long attention to the function of their lower urinary and gastrointestinal tracts. The same is true for children with severe obstructive uropathy, such as posterior urethral valves (PUVs) or large ectopic ureteroceles. Here, we attempt to clarify the urodynamic aspects of managing these children.

According to the International Continence Society definition, any method to measure the function of the lower urinary tract is part of urodynamics. Thus, urodynamic information can be obtained from multiple sources: voiding history, physical examination, micturition and defecation diaries, static and dynamic ultrasonography of the lower urinary tract, uroflowmetry with ultrasonographic measurement of residual urine volumes, and finally, invasive studies such as voiding cystourethrography and urodynamic studies (UDS). The second report of the International Consultation on Incontinence also includes measurements of the function of the lower gastrointestinal tract in this definition.[1] A voiding and defecation history and voiding and defecation diaries are, therefore, the most important sources of information on the function of the lower urinary and gastrointestinal tracts,[2–5] and can direct the course of subsequent investigations.

UDS are invasive procedures, in which bladder and abdominal pressures are recorded during filling of the bladder, and the relationship between pressure in the bladder and urinary flow during emptying of the bladder is evaluated. Recordings are done with an indwelling catheter in the bladder and a pressure recording catheter in the rectum, together with measurement of the pelvic floor muscle activity by surface electromyographic (EMG) electrodes.

This Review attempts to provide insight into the diagnostic process in children with functional or congenital

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Department of Pediatric Urology, University Children's Hospitals, University Medical Center, Utrecht and Academic Medical Center, Amsterdam, The Netherlands (**T. P. V. M. de Jong, A. J. Klijn**).

Correspondence: T. P. V. M. de Jong, Department of Pediatric Urology, University Children's Hospital UMC Utrecht, Lundlaan 6, 3584 CX Utrecht, The Netherlands t.p.v.m.dejong@umcutrecht.nl

Key points

- Any information on the function of the urinary tract is part of urodynamics; a meticulous micturition and defecation history with voiding and defecation diary are invaluable in pediatric patients
- Invasive urodynamic studies are done to obtain information that directs or changes the treatment of the individual child
- When diagnosis is done properly, straightforward therapy can be given and the psychological trauma associated with failure to respond to ill-defined treatment strategies can be avoided
- In patients with chronic lower urinary tract dysfunction of neurogenic origin or after severe obstructive uropathy, invasive urodynamic studies ensure that bladder pressures remain safe, to protect kidney function
- In a patient with lower urinary tract symptoms, any sign of structural anomalies must be investigated to exclude neurogenic bladder dysfunction

problems of the urinary tract, with an emphasis on the role of invasive urodynamic testing. We first discuss the different aspects of diagnosis in the distinct groups of patients encountered in this setting: the huge group of children with functional lower urinary tract symptoms (LUTS), the group with neurogenic bladder and sphincter disorders, and the group with obstructive uropathy such as PUVs and ectopic ureteroceles. We will then highlight some of the important aspects of performing invasive UDS in pediatric patients, and will discuss how the results of these studies can lead to the correct diagnosis.

Indications for urodynamic studies

Any initial diagnostic investigations on children that wet during the day or suffer recurrent UTI are done to discriminate between those children with functional voiding problems, those with neuropathic bladders and those with anatomic anomalies who may need surgery. Neuropathic conditions should be ruled out at the first clinical visit by physical examination and any suspect finding must lead to UDS.[6,7] In boys with overactive bladder (OAB) and incontinence, urethral obstruction must be evaluated as the possible cause. Incontinence resulting from functional LUTS is very common in girls and can be accompanied by UTI. In girls with dysfunctional voiding or underactive bladder (UAB), exclusion of other anomalies by UDS is strongly recommended because for many of these girls LUTS is a chronic condition that needs life-long attention to their voiding behavior.

In children with complex obstructive uropathy, such as those treated for PUVs or large ectopic ureteroceles, and in children with neurogenic bladders, UDS are mainly done to ensure the safety of the upper urinary tracts. Maintenance of low storage pressures throughout most of the day and the night is needed to preserve kidney function.[8,9] When previous investigations or clinical history raise suspicion for additional anatomic anomalies such as vesicoureteral reflux or diverticula, UDS are ideally combined with fluoroscopy into one videourodynamic study. As a general rule, UDS should only be done in children when the outcome will affect the choice of treatment regime.[10–12]

Functional LUTS

Between 7% and 10% of children at school age have functional LUTS.[13,14] LUTS can manifest as urgency, frequency, incontinence or recurrent UTI. A 3-day voiding diary and a 2-week defecation diary are recommended before the first visit to a pediatric urologist. A complete voiding and defecation history, a physical examination with special attention to lumbosacral neurological function, and at least two free uroflowmetry assessments with ultrasonographic measurement of the postvoid residual urine volume should be done. Ultrasonography of the urinary tract is routinely advised;[2,15–17] in the upper tract, this technique can indicate double systems or can show dilatation or scarring. Bladder ultrasonography gives information on wall thickness; a thick-walled bladder raises suspicion of anatomic or functional obstruction, while an open bladder neck in girls is commonly present in dysfunctional voiding.[15–17]

The transverse diameter of the rectum can be determined on bladder ultrasonography and a dimension of >3 cm in the absence of an urge to defecate is a strong sign of constipation.[18,19] Advanced static and dynamic ultrasonography of the perineum gives additional information on the mobility of the bladder neck, the ability to contract the puborectalis muscle and sphincter at will, the guarding reflex (S3 neurological pathway) and the length of the urethra.[20–22] Hypermobility of the bladder neck can be seen in the 15% of children with generalized hyperlaxity of joints and might be associated with congenital stress incontinence. Inability to control the pelvic floor might be an indication for physical therapy before urotherapy (defined as nonsurgical, nonpharmacologic treatment for lower urinary tract malfunction, synonymous with the term 'lower urinary tract rehabilitation' used in adults[2,23]), while the absence of S3 reflexes might point to spinal dysraphism. Rarely, a congenital very short urethra of less than 15 mm can predict failure of conservative therapy.

The possible diagnoses in children with LUTS are OAB, dysfunctional voiding, UAB and incontinence with UTI caused by voiding postponement. UDS can be used to identify subsets of OAB and UAB characterized by an overactive or underactive detrusor muscle, respectively.[2] An overview of the diagnostic steps in children with LUTS is provided in Figure 1. Most children with LUTS need to be treated by urotherapy, supported by pharmacologic therapy when necessary.

Overactive bladder

In school-aged boys with urge complaints and incontinence resulting from OAB, the major differentiation is between secondary overactivity caused by urethral obstruction and primary loss of central control of bladder behavior, which probably both present with a small voided volume compared to expected bladder capacity for age.[24] Obstruction in boys can occur anywhere from the bladder neck to the tip of the urethra, and will generally not be detected by voiding cystourethrography.[24–26]

A positive reaction—in terms of relief of symptoms—to antimuscarinic therapy, even when it only lasts a few weeks, is a strong predictor of urethral obstruction being the primary cause of OAB in boys.[27] On the basis of this study, we routinely recommend a 3-month period of antimuscarinic pharmacotherapy to identify obstruction before deciding whether a boy needs to undergo UDS (and potentially endoscopic surgery) or needs alternative treatments for bladder overactivity.

Girls with LUTS predominantly need pharmacologic and behavioral therapy. Up to one-third of these girls might have a urethral meatus anomaly that prohibits its relaxed voiding in the ideal toileting position. Girls with such anomalies wet the toilet rim and buttocks because of an anteriorly deflected urinary stream and thus may need meatus correction before urotherapy.[28,29] Sometimes, UDS are needed to identify meatal anomalies and a strongly elevated maximal detrusor pressure during voiding can typically be found in these cases.

Dysfunctional voiding

Dysfunctional voiding occurs often in girls and rarely in boys. Inappropriate relaxation of the pelvic floor during voiding results in staccato and interrupted streams on uroflowmetry with residual urine seen on ultrasonography. Loss of feeling of the filling state of both the bladder and the rectum characterizes dysfunctional voiding, and incontinence caused by voiding postponement is frequently observed.[2] Urethral meatus anomalies, as described earlier, can be present; approximately half of girls will be free of complaints after treatment of the meatus deformity while the other half will require cognitive and biofeedback training.

Underactive bladder

UAB presents as a decompensated form of dysfunctional voiding that occurs predominantly in girls, but sometimes in otherwise healthy boys.[30] In boys with a history of severe urethral obstruction, loss of feeling of the filling state of the bladder and loss of sensation of the full bladder combined with low bladder compliance can be dangerous for the upper tracts, especially when nighttime polyuria is present. UDS can prove the need for a nightly indwelling catheter in boys with a history of PUVs. The same problem can be present in girls after severe obstruction by a large ureterocele.[8,9,31–33]

Neurogenic bladder

In contrast to children with severe anatomical urethral obstruction, nearly all patients with a neurogenic bladder are born with normal kidneys. Shortly after birth, children with detrusor sphincter dyssynergia are at high risk of developing severe renal damage when treated inappropriately.[34] The change in behavior of pelvic floor and bladder in the first months after birth have led us to routinely start treatment with clean intermittent catheterization and antimuscarinic drugs immediately after birth in these patients, and to postpone the first UDS to the age of 3 months.[35,36] Routine UDS are repeated annually—to ensure safe bladder pressures and thus protect normal function of the kidneys—in the first years of life or when changes in bladder and sphincter behavior are suspected. In a proactive setting, no place exists for postponement of UDS to after dilatation of the upper tract has occurred.[37] For incontinent patients with a paralytic sphincter, UDS are needed to judge the closure function of the sphincter,

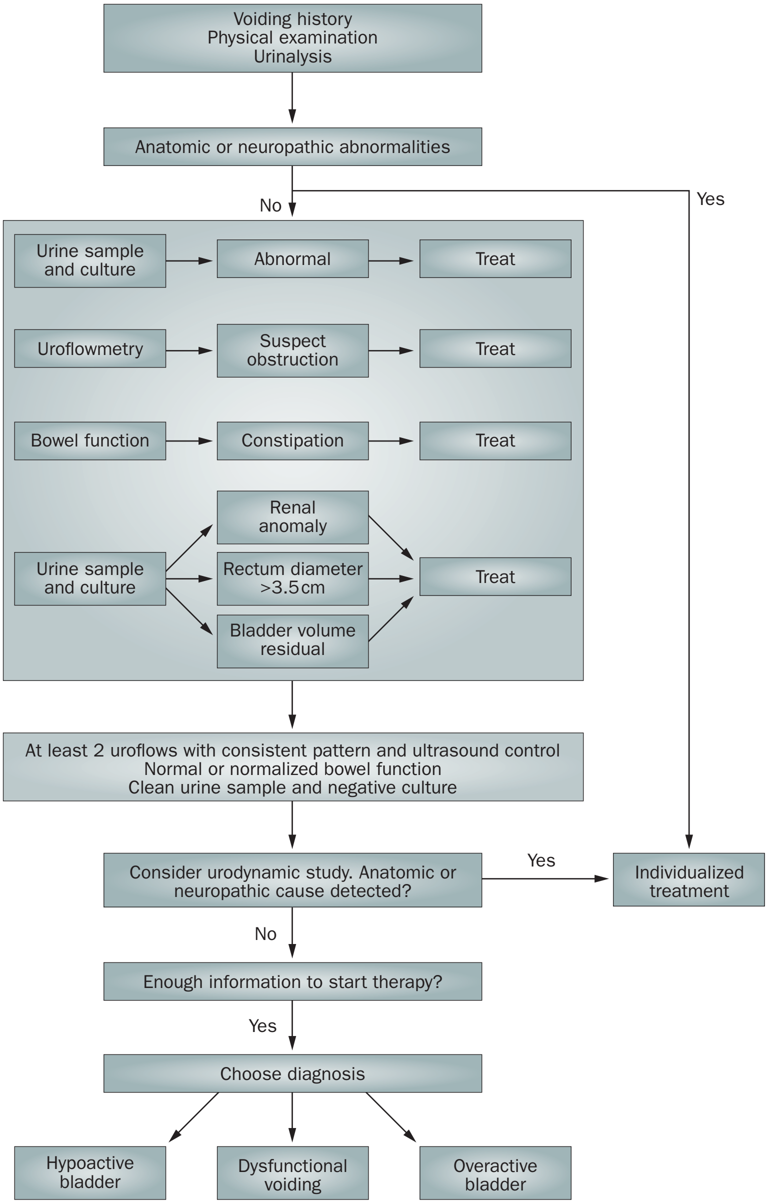

Figure 1 | Diagnosis of children who present with functional lower urinary tract symptoms (LUTS). All patients should provide a voiding history, and undergo physical examination and urinalysis. Any anatomic or neuropathic abnormalities identified on these tests should prompt appropriate individualized treatment. If LUTS persist after treatment of comorbidities such as constipation and urinary tract infection, urodynamic studies can be considered. These can identify previously undetected anatomic or neurologic abnormalities, or can identify the correct LUTS diagnosis and direct appropriate pharmacological or behavioral and biofeedback treatment.

the quality of the bladder reservoir and to decide what surgery is needed to become dry. UDS are needed after continence surgery and bladder augmentation to ensure that the pressures in the bladder remain safe, and do not pose a risk to the upper urinary tracts.[35,36]

Congenital abnormalities

Another important group of children who require UDS are newborn babies with severe congenital obstructive abnormalities of both the upper and lower urinary tracts. Especially in cases of severe PUVs with upper tract dilatation or reflux, and in children with large ureteroceles, UDS findings might dictate the need for surgery. In these children, as in those with neuropathic bladder, follow-up UDS are performed to ensure that low storage pressures are maintained to protect the upper tract. Bladder dysfunction after severe PUVs is a life-long disease and deterioration of the relationship between urine production, polyuria and low-pressure bladder capacity can occur at any age.[9,38,39] Any rise in serum creatinine level in a patient with PUVs at any age might indicate a need for UDS to determine whether the patient's compliance with instructions to void regularly needs to be controlled or adjusted and whether clean intermittent catheterization or a nightly indwelling catheter must be introduced, all to prevent end-stage renal failure. Patients with high-grade vesicoureteral reflux tend to have large bladders for their age. Fortunately, this abnormalcy often causes no specific problems. Patients with vesicoureteral reflux and ureterocele have a high prevalence (up to 40%) of dysfunctional voiding.[31,32] This disorder is part of the congenital abnormalcy rather than a complication of open bladder surgery, as it is also found in patients who had only endoscopic incision of the ureterocele, or upper pole nephrectomy without lower urinary tract surgery. The paradigm that early surgery of the bladder and trigone influences the urodynamic properties of the bladder has been proven untrue.[40]

The urodynamic system

For pediatric UDS a standard system is used, ideally with reliable EMG sampling of at least 1,000 Hz. Many older digital systems have insufficient EMG quality to enable differentiation between true sphincter dyssynergia and movement artifacts in children with LUTS or neurogenic bladder.

The UDS are done with pressure recording of both the bladder and the rectum. Rectal pressure is constantly subtracted from intravesical pressure to correct for changes in abdominal pressure. This correction is especially important in children because many will cry, laugh or chat during the investigation, leading to constantly changing abdominal pressures. In adult urology, urethral pressures are recorded as well, sometimes with pressure-sensor catheters fitted with 2–3 pressure transducers. Few pediatric urologists do the same in children.[41] In our experience, this investigation has proven to be unreliable because of movements of the child during the study.

Double-lumen 6 Fr (2.5 mm) disposable catheters are now available for pediatric urodynamics and, for safety reasons, a wise course of action is to opt for pressure recording with open fluid-filled double lumen catheters instead of pressure-sensor catheters.[41–44]

Performing UDS in children

Most children with LUTS will be old enough to understand that they can gain from the study and, therefore, will cooperate. Patients with spina bifida are usually on a regime of clean intermittent catheterization and will accept the study without any problem. Infants and toddlers with congenital anomalies between the ages of 8 months and 4–5 years can be problematic. In our experience, specialized personnel are needed to obtain good study results. We obtain reliable results in 490 of 500 pediatric UDS conducted each year owing to very dedicated and experienced nurses. They need up to 30 min to convince the child to accept catheterization and apply urethral and rectal catheters and EMG electrodes. A special catheterizable doll and pictures of the urinary tract are used to explain what is going to happen and why. The room used is child-friendly, with posters, stickers and books, and DVD movies available.[42]

Evaluating bladder function with UDS

UDS can be divided into two parts. During filling and storage the properties of the bladder wall and the patency of the closure mechanism of the urethra are recorded. During bladder emptying, urethral resistance and the function of the musculature of the pelvic floor and sphincter can be evaluated. In patients with chronic disease who empty their bladder by clean intermittent catheterization, only the first part can be done.

Function in the filling and storage phase

Filling and storage phase function is assessed by cystometry, which measures how the pressure changes with increasing volumes of the bladder. Cystometry measures detrusor activity, volume at bladder sensation, maximal volume, and compliance. In children with neurogenic bladder and a paralyzed sphincter, cystometry can be done with the bladder neck occluded by a balloon catheter in order to assess bladder function before bladder neck surgery—so-called closed cystometry. In children under the age of 6 years, filling and voiding are performed as one continuous study because the start of micturition is often not marked. EMG recording is generally done with surface electrodes and evaluates the function of the pelvic floor muscles during filling and voiding. Needle electrodes for specific sphincter EMG studies are not recommended in children.

Both intravesical pressure (suprapubic or urethral route) and abdominal (rectal) pressures are recorded, and the abdominal pressure is subtracted from the intravesical pressure to yield the detrusor pressure. During cystometry the child should be reasonably at ease, distracted by a DVD film or by the parents. The child should be awake, without sedation, and not on any drugs that affect bladder function (except for antimuscarinic drugs in cases of neuropathic bladder). Usually two cycles of filling are observed, with a third if the first two are not conclusive.[45]

Filling the bladder can be achieved by diuresis, natural filling, or retrogradely by catheter. For retrograde filling, saline 0.9% at 25–36 °C is recommended in children, without additives. Filling with cold solution can provoke detrusor overactivity. When fluoroscopy is included, contrast medium is used for filling the bladder. A filling rate of 10% of the expected volume for age per minute is used. The expected volume for age is calculated by the formula 30 + (30 × age[years]) = volume [ml].[11] When detrusor overactivity or a low compliant bladder is noted, the second filling is done with a filling speed <10 ml/min.

Detrusor function

Detrusor activity is inferred from detrusor pressure (P_{det}), which is estimated by real-time subtraction of the measured pressure in the rectum from the measured pressure in the bladder. Detrusor activity can be normal, overactive, or underactive. For normal function, the bladder volume increases during the filling phase without a significant rise in bladder pressure. No overactive contractions are registered during filling, or when provoked by coughing or hold-up maneuvers.

Overactive detrusor function is characterized by repeated detrusor contractions during filling, which the patient, in many cases, will not feel or recognize. Detrusor overactivity can be provoked by rapid filling, use of cold saline for filling, alterations of posture and coughing. Detrusor overactivity can occur in patients with an overactive bladder or in neuropathic bladders. In non-neuropathic bladder, it can go unnoticed by the patient or might be felt as urgency. Any detrusor activity in infants and children before voiding should be considered pathological. Detrusor overactivity is often compensated for by simultaneous activity of the pelvic floor (Figure 2). In children, detrusor overactivity can often be seen during the first filling but is completely absent during subsequent fillings. The reason for this phenomenon is unclear but it underscores the need for repeated fillings, especially when overactivity is present. Also, because of the patient's anxiety and discomfort, the volume used in the first filling cycle can be relatively small, which is another reason for repeated filling.

Underactive detrusor function is not readily visible in the filling phase, but this phenomenon occurs in children with UAB or those with an overdistended, post-obstructive bladder. Underactive detrusor will present as a large bladder volume for age and absent or unsustained detrusor action during emptying.

Bladder sensation

Bladder sensation is difficult to evaluate in children. Only in toilet-trained, cooperative children is it a relevant parameter. Terms like 'first desire to void' are not relevant in the infant, but can be used as a guideline in children aged 4 years and older. In infants, the desire to void should normally be considered the volume at which some unrest is noted; for example, wriggling the toes, which usually indicates that voiding is imminent. In older children, the terms 'strong desire to void'—a persistent desire to void, without fear of leakage—and 'urgency'—strong desire to void accompanied by fear of leakage or pain—might be used, although the difference between strong desire to void and urgency can be too subtle for children to perceive.

Reduced or absent bladder sensation is indicated by a lack of urgency at greater than the expected volume for age. This symptom occurs predominantly in patients with dysfunctional voiding and UAB. Sometimes, by the end of bladder filling, children complain about abdominal pain instead of desire to void. For the older child with dysfunctional voiding or UAB, this phenomenon can sometimes act as an eye-opener during UDS, and provide the motivation to start timed voiding.

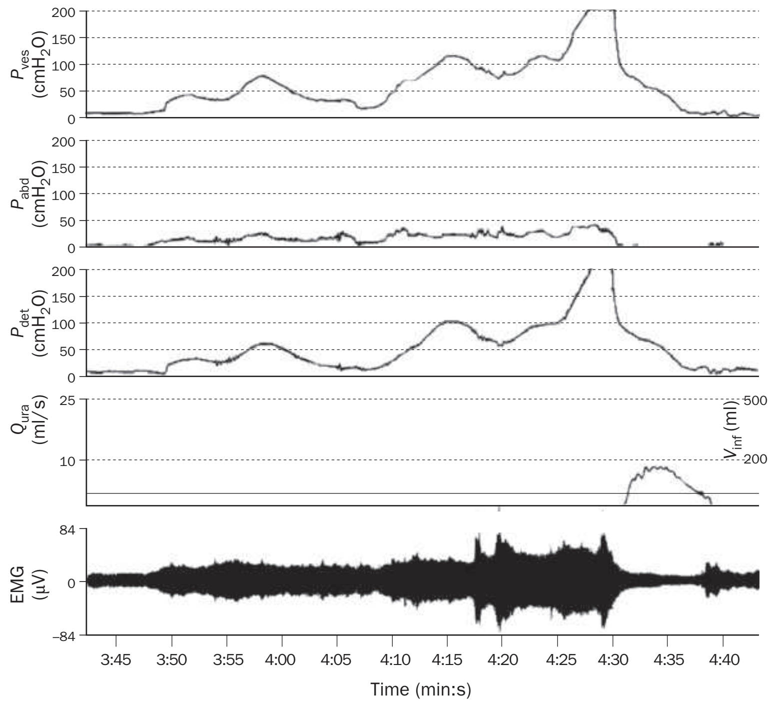

Figure 2 | A patient with overactive detrusor and urge complaints. Detrusor contractions are countered by pelvic floor activity. During the last detrusor contraction the patient relaxes the pelvic floor, which results in micturition. Abbreviations: EMG, pelvic-floor electromyography; P_{abd}, abdominal pressure; P_{det}, detrusor pressure; P_{ves}, bladder pressure; Q_{ura}, urine flow rate; V_{inf}, infused volume (solid horizontal line).

Bladder capacity and volume

The volume in the bladder at which the infant or child normally starts voiding is termed the maximum cystometric volume (MCV); it is calculated from volume voided plus residual volume. MCV values should be

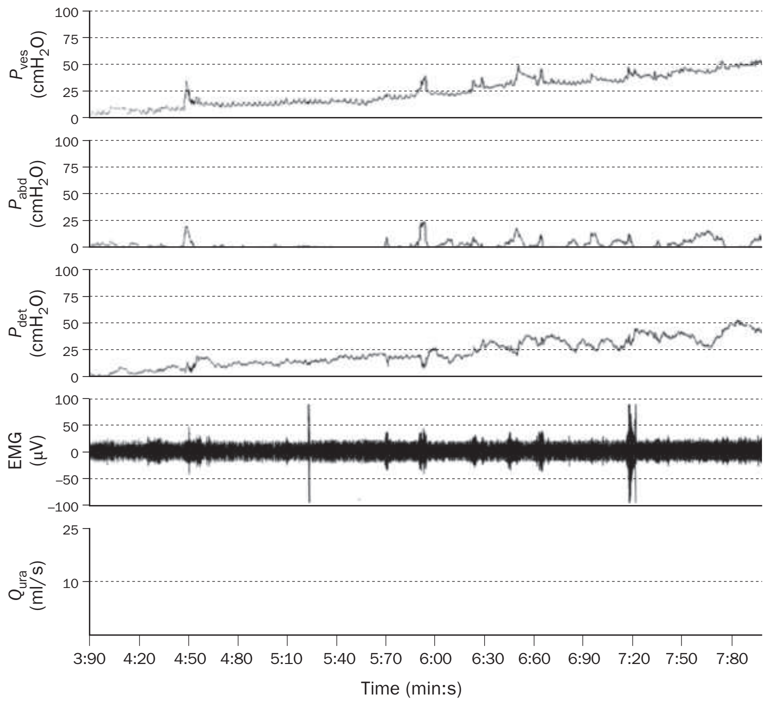

Figure 3 | A patient with neurogenic bladder under antimuscarinic treatment. The filling pressures are too high to maintain normal kidney function, and bladder augmentation surgery is indicated. Abbreviations: EMG, pelvic-floor electromyography; P_{abd}, abdominal pressure; P_{det}, detrusor pressure; P_{ves}, bladder pressure; Q_{ura}, urine flow rate.

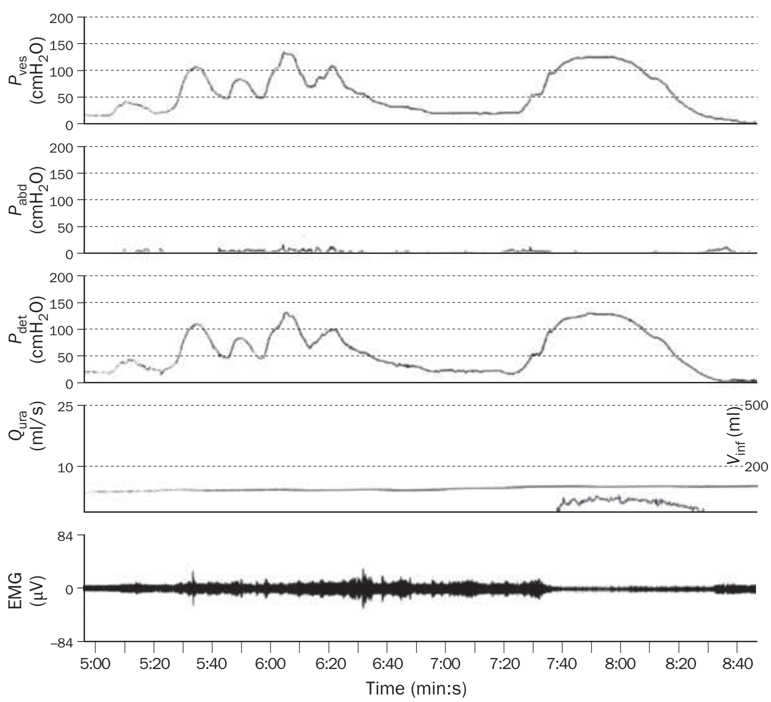

Figure 4 | A patient with an obstructed urethra. During emptying, a high detrusor pressure and prolonged, low flow are seen. Abbreviations: EMG, pelvic-floor electromyography; P_{abd}, abdominal pressure; P_{det}, detrusor pressure; P_{ves}, bladder pressure; Q_{ura}, urine flow rate; V_{inf}, infused volume (solid horizontal line).

interpreted in relation to normal values for age. Although a variety of formulas for normal volume have been described for girls and boys, in general most clinicians apply the simple formula 30 + (30 × age [years]) = volume [ml].[46,47] Abnormal values are expressed as percentage differences, positive or negative, from the normal volume for age.

Functional bladder volume is, clinically, a more relevant parameter than MCV. The functional bladder volume is equivalent to the voided volume, and is estimated from the patient's frequency–volume bladder diary. This method may give a very wide range of values for volume, as the voidings are unobserved. The consistency of values can be improved by supervised measurement of free voiding, in which the child voids only at a genuine desire to void.

Maximum (anesthetic) bladder volume is measured after filling during anesthesia at 40 cmH_2O pressure; this method is difficult to standardize and gives unreliable results in children.[2]

Compliance

Compliance refers to the change in bladder volume for a given change in pressure. It can be calculated by dividing the change in volume (ΔV) by the change in detrusor pressure (ΔP_{det}). In children, for whom it is important to know the volume increase as well as the pressure increase, the full notation, in ml/cmH_2O or as end-filling pressure, has advantages.[48,49]

For normal compliance, one can use the simple rule that pressure at the expected volume for age should not exceed 10 cmH_2O. For abnormal pressures, the shape of the $\Delta V/\Delta P_{det}$ curve is important: is it linear or does pressure rise only near maximum volume? In general, storage pressures over 30 cmH_2O are considered dangerous for the upper tract (Figure 3). In patients with neuropathic disorders and in those with postobstructed bladders, the proportion of the day during which pressure is greater than 30 cmH_2O can provide important information.[50] Rarely, a poorly compliant bladder during UDS indicates the need for 24 h recordings to determine the duration of the episodes of high pressure in the bladder. In general, the utility of 12 h or 24 h recording is limited. We confine it to children with postobstructive poorly compliant bladders and renal dysfunction. Also, investigation of poor compliance in patients with neurogenic bladder and dilatation of the upper tract can require 24 h recording. Notably, the combination of lack of bladder filling sensation, poor compliance and renal transplantation in patients with obstructive uropathy, for example PUVs, needs very meticulous UDS to safeguard the transplant kidney, especially when nightly polyuria coexists.[39,49]

Urethral function

The urethral closure mechanism during filling can be normal or insufficient. When normal, urethral closure pressure is maintained during filling, and also during coughing and straining (the S3 guarding reflex). At the start of voiding, the sphincter and pelvic floor relax and the urethra opens to pass urine. Insufficient urethral closure results in leakage of urine without detrusor activity. Genuine stress incontinence is rare in pediatric patients. Incontinence due to involuntary urethral relaxation without detrusor activity or abdominal pressure rise is observed rarely in children.[51] In children with neurogenic bladder dysfunction, sphincter paralysis will be the major sign to assess urethral function before bladder neck surgery.[52]

Function in the voiding phase

Measurement of urinary flow is performed as a solitary procedure, with bladder filling by diuresis (spontaneous or forced), or as part of a pressure–flow study, with bladder filling by catheter. In general, voided volumes of less than 100 ml, or less than 50% of the expected functional volume for age, cannot be interpreted reliably. In all cases, the voided volume, the recorded urinary flow and the flow time are important to report. Urinary flow can be described in terms of rate and pattern and can be continuous, interrupted (fractionated), or staccato (fluctuating with peaks and troughs). The calculation of average flow rate (voided volume divided by flow time) is only meaningful if flow is continuous. The parameters used to characterize continuous flow can be applicable, if care is exercised, in children with fractionated or staccato flow patterns. Patterns and rates should be consistent over repeated studies to allow evaluation, and several recordings are, therefore, needed to attain consistency.

Low rate, continuous flow with an extended flow time can point to anatomical infravesical obstruction.[53] Staccato and interrupted flows are seen in patients with dysfunctional voiding and UAB.[2] A normal, continuous flow rate within the expected flow time does not preclude the presence of urethral obstruction, however, because no information is present on the pressure that the detrusor generates to produce this flow. Specific literature on this subject, other than expert opinion, is sparse.[3,54–56]

Pressure–flow studies

During the voiding phase of UDS, the relationship between the pressure that the detrusor generates to empty the bladder and the flow rate gives an indication of the urethral resistance. High voiding pressures and a low flow rate indicate an urethral obstruction, which can be caused by either anatomical or functional conditions. Anatomical obstruction results in high detrusor pressures with constant low flow rates combined with good relaxation of the urethral sphincter and pelvic floor muscles (Figure 4). In functional obstruction, the active contraction of the pelvic floor or urethral sphincter during voiding causes obstruction that, in the majority of cases, is intermittent—as evinced by the resulting staccato or interrupted flow. To diagnose functional obstruction, an EMG recording of the activity of the pelvic floor and sphincter muscles during voiding is needed. In practice, only registration of the pelvic floor muscles

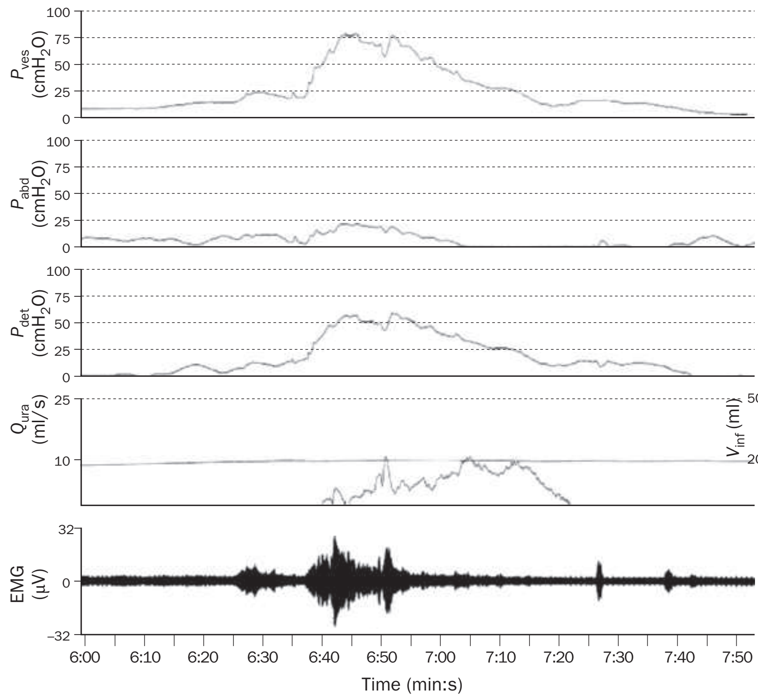

Figure 5 | Voiding phase in a girl with dysfunctional voiding. Pelvic floor activity during voiding results in a staccato flow pattern, and detrusor contraction is unsustained. Abbreviations: EMG, pelvic-floor electromyography; P_{abd}, abdominal pressure; P_{det}, detrusor pressure; P_{ves}, bladder pressure; Q_{ura}, urine flow rate; V_{inf}, infused volume (solid horizontal line).

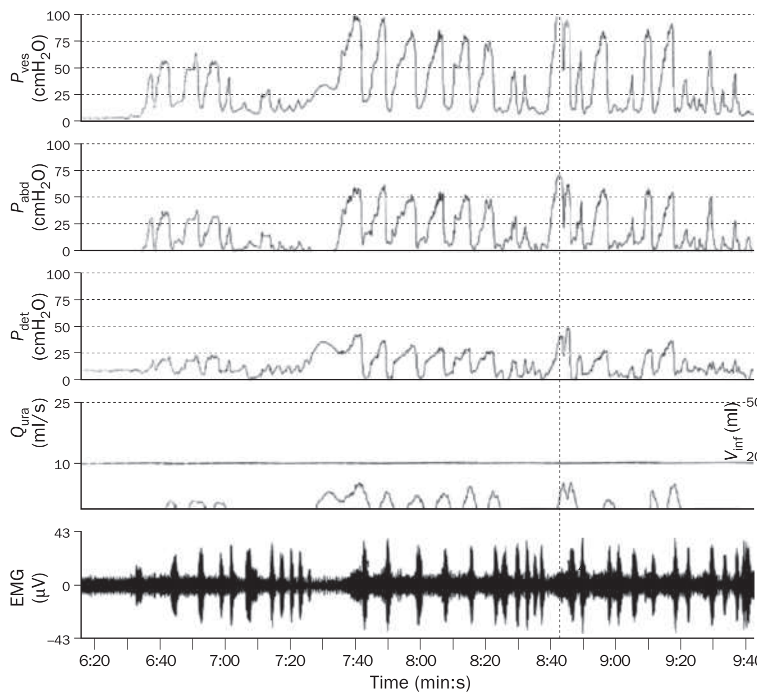

Figure 6 | Voiding phase in a patient with underactive bladder, emptied by straining. Abbreviations: EMG, pelvic-floor electromyography; P_{abd}, abdominal pressure; P_{det}, detrusor pressure; P_{ves}, bladder pressure; Q_{ura}, urine flow rate; V_{inf}, infused volume (solid horizontal line).

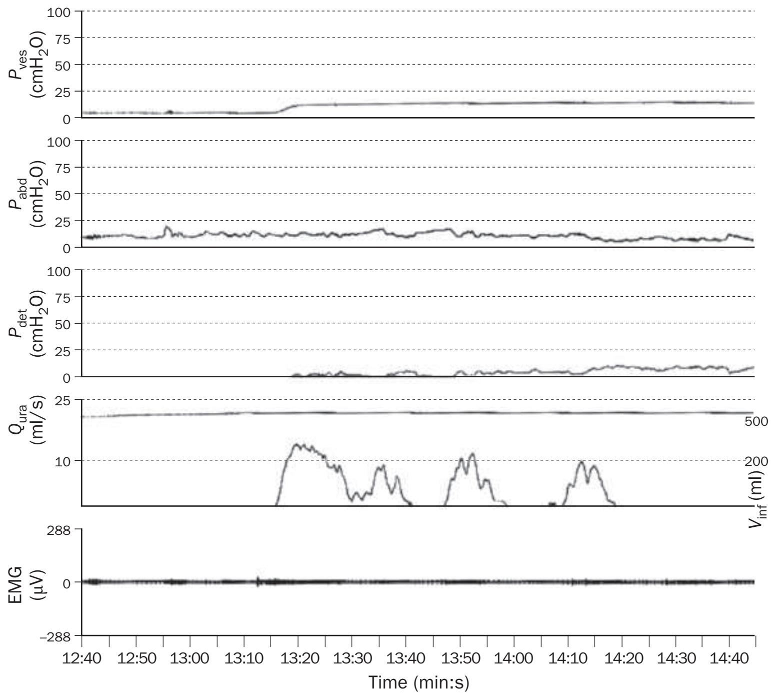

Figure 7 | Voiding phase in a patient with underactive bladder, emptied by gravity. Abbreviations: EMG, pelvic-floor electromyography; P_{abd}, abdominal pressure; P_{det}, detrusor pressure; P_{ves}, bladder pressure; Q_{ura}, urine flow rate; V_{inf}, infused volume (solid horizontal line).

and anal sphincter is done because these can be evaluated using external skin electrodes, rather than requiring needle electrodes.

Urethral resistance is represented by the relationship between pressure and flow rate: the urethral resistance relation. An indication of this resistance can be obtained by plotting detrusor pressure against flow rate, continuously or with just 2–3 pressure–flow points connected by straight lines. The most important point to plot is the detrusor pressure at maximum flow rate. No matter how the plot is made, flow delay should be considered: more than 1 s may elapse between the passage of urine through the sphincter and the recording by the uroflowmeter. Normal pressures in children are similar to those in adults. Mean maximal normal pressure is 66 cmH_2O in boys and 57 cmH_2O in girls.[57–59] In newborn and infant boys, these pressures are greatly increased by insertion of a 6 Fr (2.5 mm) transurethral catheter—to 118 cmH_2O and 75 cmH_2O, respectively.[60,61] Pressures above these levels are suspicious for anatomical urethral obstruction.

The most common non-neurogenic functional urethral obstruction is dysfunctional voiding—repeated fast contractions of the pelvic floor during voiding, which manifest with strong fluctuations in detrusor pressure, staccato or interrupted flow rate and strong fluctuations in EMG activity (Figure 5). Activity of the pelvic floor muscles and external sphincter also occurs in the absence of detrusor contraction. This activity represents the guarding reflex (S3), which operates during coughing, straining and tapping of the abdomen.[2,3,11]

Detrusor function

Micturition in a patient with a normal functioning lower urinary tract starts with a detrusor contraction that is consciously initiated and is sustained during emptying of the bladder. Detrusor underactivity is the absence of this contraction during voiding. Such underactivity may result from a neuropathic problem, or might represent secondary decompensation of the detrusor after long-standing anatomical or functional obstruction. Underactivity can present at late age, for example after puberty, in boys with a history of PUVs.[8,9,62] Mild forms of underactivity can present urodynamically as unsustained detrusor contraction, with a gradual decrease of pressure during voiding. Unsustained contractions are insufficient in duration (but not magnitude) to empty the bladder completely.[3,11] On UDS, detrusor underactivity during voiding manifests either as fractionated flow and abdominal straining (Figure 6) or as fractionated flow with short episodes of pelvic floor relaxation that enable emptying due to the effect of gravity (Figure 7).

Conclusions

Meticulous assessment of all aspects of the function of the lower urinary tract and the bowel by history, physical examination, ultrasonography and UDS will provide a diagnosis and a plan for treatment in any child with LUTS. When done properly, straightforward therapy can be given and the psychological trauma associated with failure to respond to ill-defined treatment strategies can be avoided. Sometimes a period of therapeutic trial and error is unavoidable in children with LUTS. This approach is fine, as long as the treatment plan is adequately communicated to both the parents and the child. Persevering with a treatment approach that fails to show a benefit is a serious failure of care, as is referring a child for psychiatric evaluation because the doctor does not have the means to investigate all possible urodynamic data on the function of the child's lower urinary tract. Such children should be referred to centers that can perform state-of-the-art UDS and urotherapy. Any tertiary referral center that deals with functional and structural LUTS in pediatric patients should have the facility to perform invasive UDS in children, including, in selected cases, fluoroscopy.

Review criteria

To obtain material for this Review, we searched PubMed for articles published since 1978, when the term urodynamics began to be used. We also searched the Scopus database for articles published since 2000. Search terms were "urodynamics", "urodynamics" AND "reference values", "urodynamics" AND "pediatric", "urodynamics" AND "spina bifida", "urodynamics" AND "posterior urethral valves", and "pediatric incontinence".

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