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International Children's Continence Society Standardization Report on Urodynamic Studies of the Lower Urinary Tract in Children

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Aims: The objective of this document created by the ICCS standardization subcommittee is to provide a uniform guideline on measurement, quality control and documentation of urodynamic studies in children. **Methods:** This guideline was created using expert opinion and critical review of the published literature on urodynamic studies in children. Currently no standardized guideline or level 1 data exists on the proper technique for this subject matter. **Results:** The document provides a throughout explanation on how to approach a child who presents with lower urinary tract dysfunction, whether it be of neurogenic, anatomic or functional origin. Formation of an urodynamic question after a comprehensive history and physical examination is paramount in selecting the urodynamic study(ies) that will be most appropriate for each child. Appropriate application of each test with careful consideration of the needs of the child and family will provide the most accurate and reproducible results. Recommendations on how to execute each of the components of an urodynamic study as well as interpretation are included in the document. **Conclusions:** Urodynamic studies have become a major tool in evaluating lower urinary tract dysfunction in children. There are many subtleties in performing these studies in children in juxtaposition to adults; therefore, adaptations specific to children must be made to achieve accurate and reproducible results. Uniformity in how the studies are conducted from center to center will allow for healthier transparency and enhanced comparison of results in both clinical and research situations. *Neurourol. Urodynam. 34:640–647, 2015.* © 2015 Wiley Periodicals, Inc.

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INTRODUCTION

Apart from the ICS report on 'Good Urodynamic Practices' there is no validated guideline on the use of urodynamic studies (UDS) in children.[1] The basics of UDS are similar in both groups, but pediatric UDS involve different approaches and applications that are unique to this population. The ICCS presents these guidelines for measurement, quality control, and documentation of UDS in children in both clinical and research environments. This report describes the most common investigations performed in children, uroflowmetry, cystometry, and pressure flow studies. Determination of urethral pressure profilometry and ambulatory urodynamic testing will be briefly discussed, as these studies are not widely utilized in pediatrics.

The aim of UDS is to mimic a clinical scenario in a non-clinical setting while making precise measurements and obtaining reproducible results in order to characterize LUT function, identify the causes for its symptoms, and quantify related pathophysiological processes. Ultimately, UDS should provide (1) objective knowledge about LUT function and dysfunction as well as (2) an explanation for providers, patients and parents. In selected populations (e.g., spina bifida), baseline UDS evaluation is paramount as it provides guidance towards management in addition to noting changes resulting from treatment, growth and/or maturation.

METHODS

The ICCS developed a subcommittee on standardization documents to delineate what fields relating to urinary incontinence deserved standardization documents from this group. A group of 3–5 core experts in each field were appointed to author the document and provide both evidence and experience based knowledge. A complete review of the literature was performed. It was felt that there was not sufficient level I or II evidence for a meta-analysis. Therefore, recommendations set below are primarily experience based with supporting evidence from previously published papers. The document was available for review by all members of the ICCS. All critiques were considered prior to submission for peer review.

Approaching the Child Who Needs Physiologic Evaluation of the LUT

Initially it is imperative to formulate an 'urodynamic question(s)' following a comprehensive history, careful physical examination, and standard urologic investigations. Validated questionnaires are helpful in structuring history taking and providing checklists for gathering data.[2–5]

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Frequency/Volume Charts: Bladder Diary

The frequency/volume chart (FVC) or bladder diary is a detailed recording of fluid intake and urine output over specified 24-hour periods. The chart records objective information regarding number of voids, their distribution (day and night), voided volumes and episodes of urgency, leakage, and/or frank wetting. For a complete picture of the child's elimination habits, a 14-day defecation diary that includes frequency, soiling and stool consistency based on the Bristol Stool Form scale and Rome III criteria is documented.[6]

A properly recorded FVC in combination with repeated (two) uroflowmetries and measurements of post void residual (PVR) urine volume provides non-invasive, objective information that help formulate the urodynamic question and determine the need for invasive tests, that is, filling cystometry or pressure flow studies.

Initially, the clinician needs to know the mean bladder storage volume during a child's normal activities. The FVC provides the maximal storage capacity as the largest voided volume, exclusive of the first morning micturition which reflects overnight urine production and capacity, and is termed maximum voided volume (MVV).[7] MVV should be referenced during cystometry to prevent overfilling. Additionally, it can be used as an outcome measure in children with LUT dysfunction.

Unsupervised voids in children vary widely due to social circumstances and bladder activity rather than by capacity or urine production. Ideally the chart should cover 3 complete weekdays, but in reality, with difficulties inherent for registering voiding volumes during school hours, it is more suitable for weekend recordings. Thus, it is usually restricted to 2 days.[8]

Voided volumes, even in incontinent children, increase incrementally with age. The standard formula for calculating expected bladder capacity is $EBC = age\ (years) \times 30 + 30$ (expressed in ml). [9] The FVC is useful when comparing MVV and standard deviation by a child's age. Validation and test/retest data on FVCs, while sparse, indicate that voiding interval is the most variable parameter.[9–11]

FOUR-HOUR VOIDING OBSERVATIONS

The four-hour voiding observation provides information concerning voiding patterns, urine volume, bladder capacity and PVR in pre-toilet trained children. Observations are made as children perform activities that are consistent with their daily routine, starting at about 3 months of age. A dry diaper with a color-change, vibratory or alarm indicator placed at the outset, signals when it is wet. The diaper is weighed (against its dry weight) and sonographic PVR obtained to calculate bladder capacity. If no wetness indicator is available the child is checked frequently to accurately assess when voiding occurred so measurements can be taken. Interrupted voiding is considered when 2 or 3 voidings occur over a 10-minute interval. This methodology is accurate in both normal children and in those with urologic abnormalities.[12–14]

UROFLOWMETRY

Uroflowmetry is an indispensable, first-line non-invasive test for most children with suspected LUT dysfunction. Objective, quantitative information, which helps to understand both storage and voiding symptoms, is obtainable.

A private bathroom is essential. The child is instructed to void when he/she feels a "normal" desire to urinate. Children who sit to void should have a footrest supporting their feet to eliminate the possibility of a non-relaxed pelvic floor. Boys are instructed to aim their flow at a specific point in the funnelled receptacle to minimize potential misrepresentations. Afterwards, parents are asked if their child's flowmetry pattern was representative of their voiding. Maximum flow rate (Qmax) should be sustained for >2 sec to eliminate artifacts (straining). If the square of Qmax equals or exceeds the voided volume, that value is considered real. Adequate voided volumes should $\geq 50\%$ of EBC for age, based on the Koff–Hjälmås equation or that of the MVV measured on the FVC.[15,16]

Voided volumes $<50\%$ of EBC are not reliable as they may represent forced voiding on command. The bladder scan assesses volume beforehand. If not sufficiently full the child should be instructed to drink until the bladder is large enough for a reliable uroflow.[15–17]

Automated data analysis must be verified and documented by inspection of the flow curve to exclude artifacts. Results from uroflowmetry should be compared with information from the patient's FVC. Sonographic estimation of PVR volume completes the assessment. In children ≤ 6 years, a repetitive PVR of >20 ml or $>10\%$ bladder capacity is considered elevated. In children ≥ 7 years, repetitive PVR > 10ml or 6% bladder capacity is regarded as elevated.[18] Ideally 3 uroflows are representative but 2 will suffice as this maintains accuracy and consistency. First morning uroflows should be avoided as they may exceed normal voided volumes leading to aberrant flow patterns.[15,16,19]

The Normal Uroflow

Normal voiding occurs when the bladder outlet relaxes and the detrusor contracts. During a normal detrusor contraction with minimal intraurethral resistance, the *normal* flow curve is bell-shaped with a high maximum flow rate. (Fig. 1 A).

Abnormal shapes exist that are flat [*plateau*], asymmetric, or have multiple peaks (fluctuating [*staccato*] and/or intermittent with >1 complete stoppages of flow [*interrupted*]). (Fig. 1B, C) Although suggestive, these patterns do not predict a specific etiology. A normal flow does not always exclude dysfunction, nor does an abnormal pattern automatically mean LUT dysfunction, as abnormal patterns were found in a small but definite number of asymptomatic normal school children.[20,21] A minimal number of normal school children void with flattened or intermittent flow curves; most have a bell-shaped curve.[22]

Complicated flow rate patterns may result from fluctuations in detrusor contractility, abdominal straining, or varying degrees of outlet resistance. External urethral sphincter or pelvic floor contraction and relaxation, mechanical compression of the urethra or meatal stenosis can cause rapid changes in flow rate.

Bladder volume may affect uroflowmetry. As the volume increases and detrusor muscle fibers stretch, increases in potential detrusor power and work associated with a contraction are needed. This phenomenon is most evident from zero to 150 to 250 ml of filling. At higher volumes the detrusor may be overstretched decreasing contractility again. Therefore, it is theorized Q_{max} is physiologically dependent on bladder volume. Some have questioned this theorem and are working to identify other factors that may be more important in what determines Q_{max}. (I Franco, personal observation). Additionally, rapid changes in flow rate may be artifactual, when the flow rate signal is extracorporeally modified via the interference between the stream and the collecting funnel, the flowmeter, patient movements or changes in aim of the stream; thus, proper positioning and instruction are necessary.

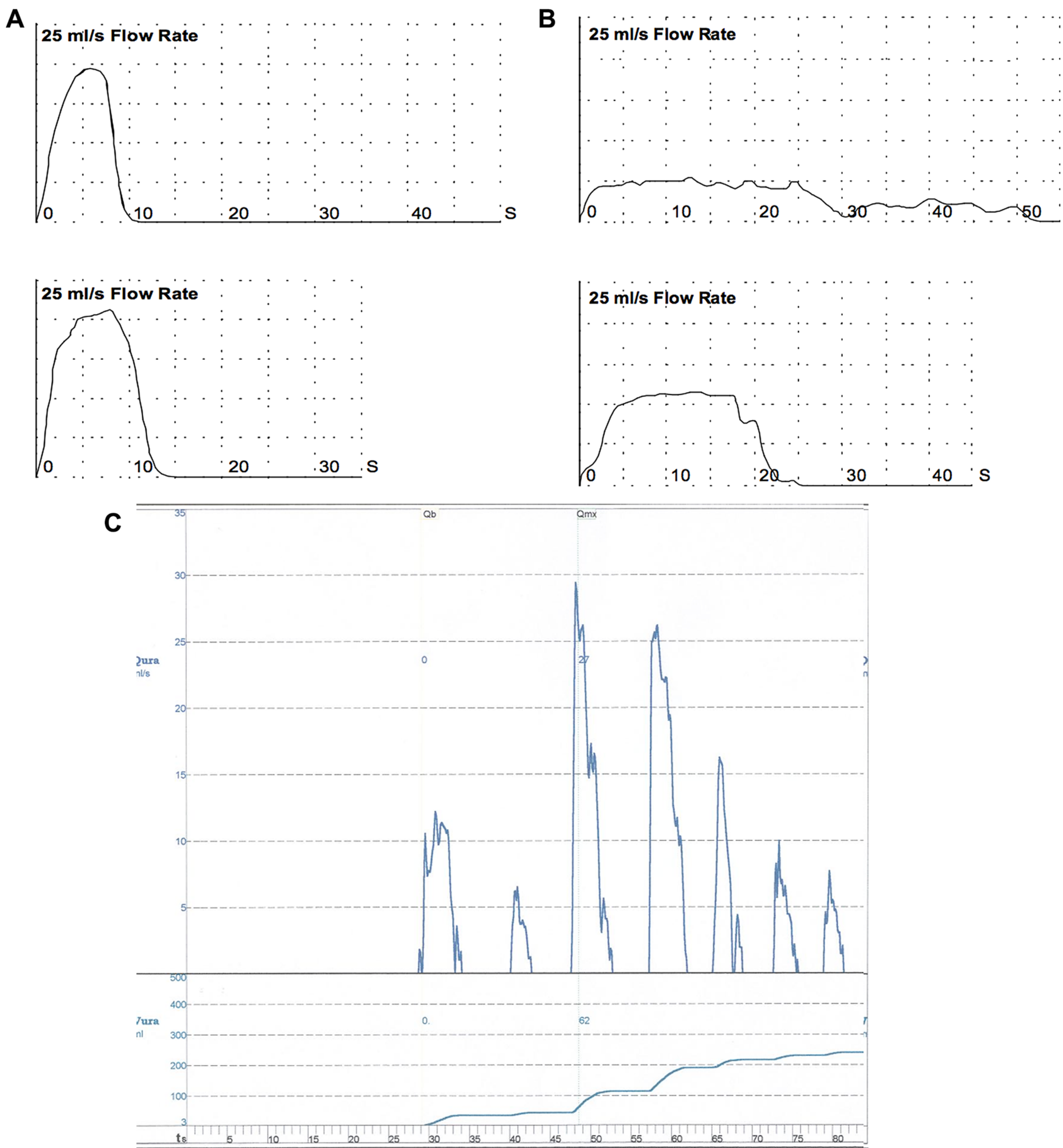

Fig. 1. A: Normal (bell shaped) urinary flow curves of 2 children. B: Flow curves of 2 children with a static, anatomic obstruction; the curve is continuous but the flow is lower than normal and extended in time. C: Interrupted flow curve in a child with either discoordination between bladder and contraction and sphincter relaxation (pelvic floor muscles) or underactive bladder with abdominal straining to empty.

Decreased detrusor power and/or consistently high urethral resistance will result in both a lower flow rate and a smooth flat flow curve. A constriction (e.g., urethral stricture), with reduced luminal size produces a plateau like flow curve (Fig. 1B).

The same parameters used to characterize a continuous flow should be applied to children with interrupted, or staccato patterns (Fig. 1C). When measuring flow time, the intervals between flow episodes are disregarded. Voiding time is the total duration of micturition, including interruptions.

Problems in Urine Flow Rate Measurement

The shape of the flow curve may suggest an abnormality, but reliable and specific information about its cause cannot be derived solely from the pattern. Only when combined with pelvic floor electromyography (EMG), intravesical and abdominal pressure recordings, the pressure-flow relationship, does it become possible to analyze the separate contributions of the detrusor and bladder outlet to the overall voiding pattern. Uroflowmetry without EMG is discouraged unless it is done for follow-up situations where only the actual curve and residual urine are needed.

Dual channel EMG with perineal AND abdominal EMG helps define if patients have abdominal straining that results in a spike in Q_{max} or changes in the shape of the curve from plateau to other forms. EMG lag time, or time between pelvic floor relaxation and the start of flow, has predictability for characterization of bladder dynamics (see below).

Recommendations for Uroflowmetry

To facilitate recording urinary flow rate characteristics and pattern recognition of curves, graphic scaling must be standardized: one millimeter = 1 sec on the x-axis and 1 ml/s and 10 ml voided volume on the y-axis. For routine clinical measurements it is useful to read flow rate values to the nearest full ml/s and volumes to the nearest 10 ml. To have electronic Q_{max} values that are reliable, internal electronic smoothing of the curve by removing positive and negative spike artifacts should be applied.

Interpretation of any dynamic variation (signal patterns) in free flow relies on personal experience, can be only descriptive, and often remains speculative.

Uroflowmetry combined with pelvic floor patch EMG differentiates an interrupted or staccato flow secondary to a non- or intermittently relaxing external sphincter from straining maneuvers to empty. When free uroflowmetry reveals these patterns a flow—patch EMG is warranted.[23]

Invasive UDS

In children UDS should be performed if the outcome is likely to affect treatment or when treatment does not lead to its intended outcome.[24,25] Testing is considered when surgical interventions are planned. Invasive UDS provides information not readily available elsewhere and which influences further management. From studies addressing this issue in children with LUTS but without neuropathy, invasive UDS rarely provides significant additional information to justify its use.[26–28] Baseline UDS in children with neurogenic bladder may not influence immediate management but when there is a change in continence, recurrent UTIs or new/worsening hydroureter or hydronephrosis, it can be used as comparison for subsequent testing.

Indications for invasive UDS in non-neurogenic conditions include: voiding frequency $\leq$3 per day, straining or manual expression during voiding, a weak urinary stream, urge incontinence unresponsive to proper elimination habits or pharmacotherapy, pronounced apparent stress incontinence, or new or worsening dilating vesicoureteral reflux (VUR, $\geq$grade 3 reflux, international classification). In children with neurogenic bladders, investigation is warranted when recurrent febrile UTI occurs where previously identified or newly diagnosed VUR may indicate a deteriorating bladder. In centers where voiding cystourethrography is performed separate from invasive UDS, an abnormal appearance to the bladder contour suggesting a neurogenic cause in an otherwise neurologically intact child, with or without VUR, should prompt these studies.

In children with neurogenic bladder dysfunction, the ICCS has recommended an initial evaluation and subsequent studies as follows:[29] in the first 2 to 3 months of life, in response to therapy, development of hydroureteronephrosis, a change in continence or a question of progressive spinal cord tethering when concomitant signs are evident.

In summary, invasive UDS are indicated when non-invasive investigation raises suspicion of neuropathic detrusor-sphincter dysfunction (occult spinal dysraphism), obstruction (i.e., posterior urethral valves), genitourinary abnormalities (i.e., exstrophy, epispadias), profound non-neuropathic detrusor-sphincter dysfunction (children with dilating VUR and recurrent febrile UTI), or significant PVR of unknown cause.

Cystometry and (Video)-Urodynamics

Intravesical pressure-volume relationships are measured during cystometry. Information is gleaned on storage function (detrusor activity, sensation, compliance, and capacity) and voiding function (outflow obstruction, flow pattern, detrusor contractility and sustainability). Abdominal pressure recordings via a small rectal balloon catheter are necessary to accurately assess changes in abdominal pressure as reflected in intravesical pressure changes. To evaluate voiding function, the patient should be in a sitting position. Children who are not yet toilet trained or unable to support themselves sitting upright, may lay supine for the voiding phase, thus excluding recording accurate flow rate data. (Fig. 2)

In newborns, only storage function can be evaluated. Voiding may be observed, but reliable pressure-flow studies are difficult to perform.

Cystometry in conjunction with fluoroscopy (video-urodynamics) records fluoroscopic images during testing that have several advantages. The shape of the bladder and bladder neck during filling and voiding, appearance of the urethra during voiding, the volume and pressure when VUR occurs, and the influence of voiding on VUR can be objectively noted. These are vital in neuropathic bladder dysfunction, where this information, unobtainable otherwise, can lead to possible causes for incontinence and/or reflux as noted by poor pelvic floor relaxation, urethral overactivity and/or elevated residual urine.

Cystometry combined with nuclear cystography precisely identifies when reflux occurs during cystometrography (volume and pressure) as the camera continuously records gamma radiation location of the nucleotide without increased radiation exposure, but it does not provide absolute anatomic detail.

Because UDS is an invasive procedure artifacts may influence accurate interpretation of results.[30] Despite all efforts to achieve normalcy, the test environment is not natural; most children are apprehensive to a degree that can influence findings; a transurethral catheter may affect voiding; and catheter 'irritation' may induce detrusor overactivity. Suprapubic catheterization may eliminate voiding abnormalities associated with a urethral catheter but detrusor overactivity may result despite a latency period for accommodation from insertion to testing.

Cystometry performed using the body's natural diuresis to fill the bladder (natural fill cystometry or ambulatory urodynamics) is time-consuming and not practical in most centers. When performed, the child is permitted to be mobile, compatible with his/her own surroundings, that theoretically produces less psychological stresses. Natural fill studies elucidate lower voided volumes, higher voiding pressures, a dampened increase in the pressure rise during filling and increased sensitivity for detecting detrusor overactivity.[31]

To reduce anxiety, the study is best performed with the child seated, watching a video or DVD accompanied by one or both parents. Only essential equipment should remain in the room. Avoiding general anesthesia is important as this affects the natural state and eliminates the chance for voiding. Intranasal midazolam may be administered in certain situations where high anxiety levels cannot be mollified, as this drug appears to be innocuous regarding outcome of the study.[32]

Both the child and his/her parents need adequate preparation about every aspect of the study before it is undertaken. If the initial investigation is inconclusive and/or inconsistent with the history or prior uroflowmetry, repeating it 2 to 3 times may be necessary.[33,34]

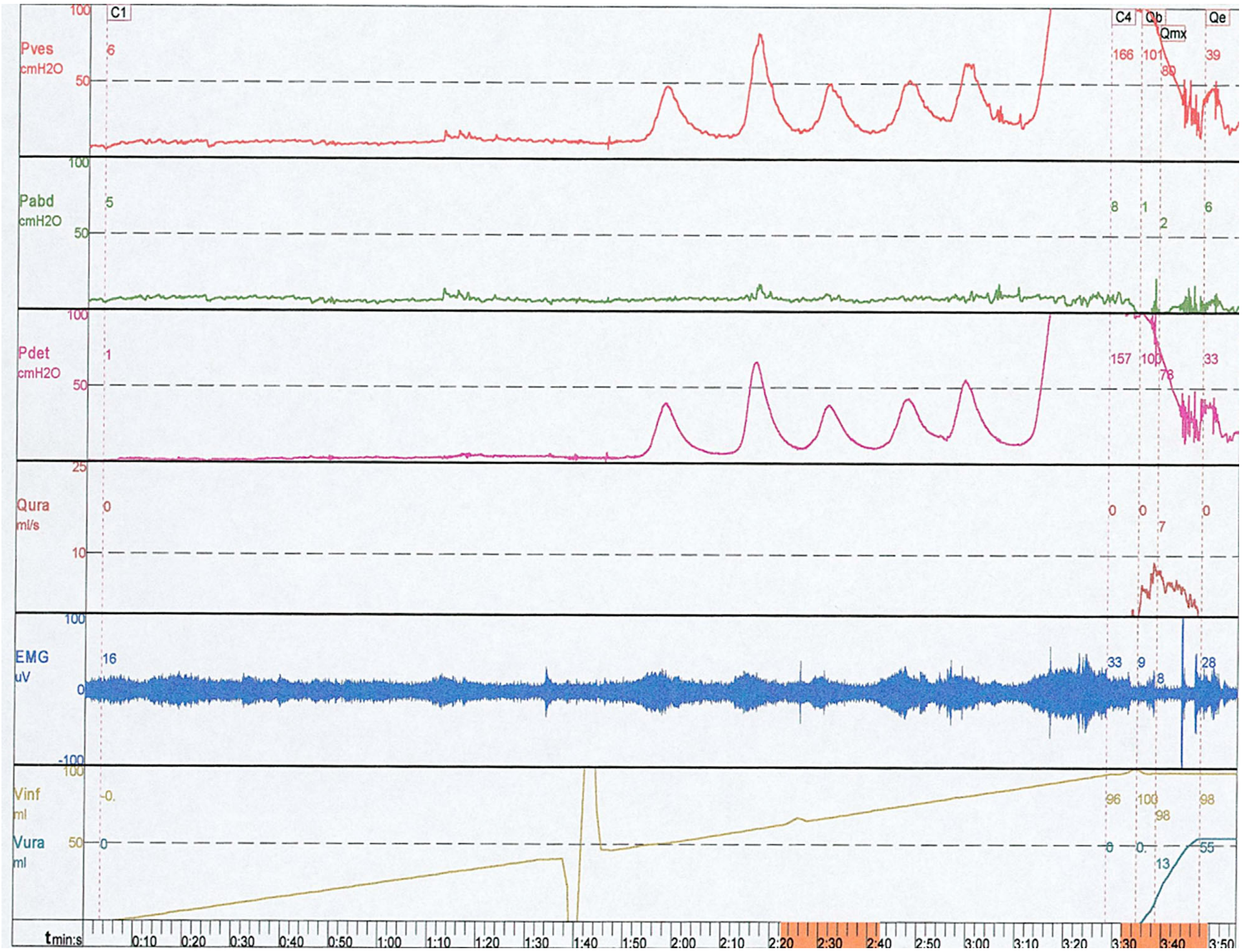

Fig. 2. UOS illustrating involuntary detrusor contractions (DO), counter action of pelvic floor muscles (guarding reflex) and incomplete relaxation during voiding results in higher than normal voiding pressures and substantial post-void urine volume (DO + dysfunctional voiding).

Most children readily accept a 6- or 7- Fr. double lumen transurethral catheter to fill the bladder and record pressure. In selected cases, a suprapubic catheter may be inserted under general anesthesia the previous day or several hours earlier on the same day, but risks need to be juxtaposed against benefits of this approach. It has been shown transurethral catheters (6 or 7 Fr.) do not significantly obstruct the urethra.[35,36]

Before inserting a catheter, a uroflow is obtained (the child is instructed to arrive with a full bladder). After voiding is completed, a transurethral catheter is inserted in a timely manner and residual urine measured and cultured. If infection is strongly suspected (this sample is cloudy, odorous, and/or has positive nitrites on analysis) the test should be delayed until a sterile urine is obtained. For children on CIC, colonization is common so a culture and appropriate antibiotics beginning 3 days prior to the study is preferable.

When the residual is substantial, recording the intravesical pressure before draining the bladder provides a simple one-time measurement that can be compared to the pressure recorded when the bladder is filled to that specific volume during cystometrography, to determine if even relatively slow but unphysiologic filling rates affect detrusor compliance.[37]

A small (8-Fr) rectal balloon catheter is inserted to record abdominal pressure changes that are then subtracted from bladder pressure channel recordings to obtain true detrusor pressure. This reduces artifacts of movement and helps denote straining to void from normal relaxed voiding. A suppository or enema is recommended the evening before the study to cleanse the rectum and increase accuracy of rectal pressure recordings.

A microtip transducer catheter may be as small as 3-Fr, but passage of this sized catheter is not easy in boys. Although once popular, it has been abandoned in most pediatric centers.

When video-urodynamics are performed images are taken at 30 or 50-ml intervals of filling, during any findings of increased pressure, when reflux is detected, at capacity and during voiding. X-ray memory features limit exposure time, currently averaging 0.45 min, making the total amount of radiation less than that of a plain abdominal radiograph.

To study pelvic floor muscles reactivity, surface electrodes are widely used. The EMG pads are positioned symmetrically, perineally, left and right of the anus. Due to resistance of electrical current across skin—electrode interface—the skin is degreased (alcohol) and exfoliated (fine abrasive paper) before applying conductive gel and electrodes patches. In cases of known or suspected neuropathic bladder, external urethral sphincter needle EMG assessing of individual motor unit action potentials is extremely valuable in detecting early or progressive signs of denervation, especially in children with suspected tethered spinal cord syndromes.[38,39]

In children, the transition from filling to voiding is not as easily managed as in adults. To avoid missing this important transition, cystometry and pressure-flow/EMG measurements are performed as one continuous study.

With retrograde filling via a catheter, 0.9% saline or contrast medium warmed to body temperature (37.5°C) is infused. In infants, temperature of the infusate may influence bladder capacity and detrusor activity; however, its clinical relevance remains unknown.[34]

When filling by catheter, slow fill cystometry (5–10 percent of EBC per minute, or <10 ml/min) is recommended, as compliance (predominantly) and overactivity (possibly) may be significantly altered by faster rates of filling.[40]

Assessment of the Storage Phase

Parameters measured during the storage phase include: intravesical pressure (Pves), abdominal pressure (Pabd) and detrusor pressure (Pdet). Pdet = Pabd (−) Pves.

In cases of sphincter incompetence or lack of bladder sensation, maximum cystometric capacity is difficult to determine. A Foley balloon catheter can occlude the bladder outlet to determine capacity and measure compliance. Presence of a sensory lesion warrants stopping filling when resting detrusor pressure reaches (exceeds) 30 cm H_2O.[41]

Bladder sensation is very difficult to evaluate: it may be a relevant parameter only in toilet-trained children. Terminology like "first desire to void," and "strong desire to void," although useful in adults, have little value in children. Normal desire to void is not relevant in infants, but can be a guide in toilet trained children $\geq$4 years. Normal desire to void should be considered as the volume at which some unrest is noted, that is, wiggling of toes usually indicates voiding is imminent. In the older child when fear of discomfort may result in smaller than expected volumes during initial cystometrography, or when DO is anticipated but not seen, $\geq$2 cycles of filling are recommended (personal observation). Bladder sensation can be classified as *normal*, *increased* (hypersensitive), *reduced* (hyposensitive), or *absent*.

Compliance indicates the change in volume for a change in pressure and is calculated by dividing the volume change (ΔV) by the change in detrusor pressure (ΔPdet) during a specific increase in bladder volume (ΔV/ΔPdet). It is expressed as ml per cm H_2O. When abundant detrusor overactivity is present, it may be difficult to determine compliance. To standardize the measurement, the most linear part of the V/P relationship should be isolated used for calculating compliance. The values for V and P at the beginning and end of this portion of the tracing are then used to calculate ΔV/ΔPdet. The usual notation for compliance is a single value, but a full characterization of compliance may be helpful, as some children have varying compliance factors throughout filling.[42]

This variability depends on several factors: rate of filling, which part of the curve is used for compliance calculation, shape (configuration) of the bladder, thickness, and mechanical properties of the bladder wall, contractility, relaxability of the detrusor, and degree of bladder outlet resistance.[33]

When little or no pressure change is noted during filling, compliance is called *normal*. There are no data available to exactly determine normal, high or low compliance values. When reporting compliance the rate of bladder filling, the volumes in between when compliance is calculated, and which part of the curve used to derive this number should be noted.

In children without neuropathic lesions, compliance should not exceed a 0.05 y ml/cm H_2O increase from baseline bladder pressure (y = cystometric bladder capacity [ml]) for age), a formula developed for adults but one that is not fully applicable to children because bladder capacity increases with advancing age, and that must be accounted for as well. There is no reported relationship between expected and cystometric bladder capacity; however, some feel Pdet should not exceed 30 cm H_2O at EBC.[41]

Detrusor activity is interpreted from measuring Pdet. During the storage phase it may be *normal*, *overactive*, or *underactive*.[15,16]

In normal children, a minimal rise in detrusor pressure occurs throughout filling. This process is called *accommodation*. Even after provocation, there should be no involuntary contractions. The *normal* detrusor is described as stable.

Involuntary detrusor contractions during filling (spontaneous or provoked) are characteristic of *"detrusor overactivity"*.[15,16] (Fig. 3) The child may not completely suppress these contractions; usually, an increase in pelvic floor EMG activity is noted as a counteractive guarding reflex.[43] Involuntary detrusor contractions may also be provoked by alterations in posture, coughing, laughing, walking, jumping, suprapubic tapping or compression and other triggering stimulants. The presence of these contractions does not necessarily imply a neuropathic disorder. In infants, detrusor contractions may occur in 10% of normal children during filling. Occasionally, overactive contractions may be seen very near capacity, which

Fig. 3. Improper position for voiding: the feet are not supported (unbalanced position) and the boy is bent forward. Support of the feet will correct this allowing the pelvic floor muscles to relax property.

should be interpreted as normal. In children with VUR, detrusor overactivity is seen in more than half the infants.[44–47]

Overactivity due to a disturbance of the nervous system is called *neuropathic detrusor overactivity*. In the absence of any neuropathology, it is called *idiopathic detrusor overactivity*. Any leakage occurring during an involuntary detrusor contraction is labelled *detrusor overactive incontinence*.[15,16]

If an underpowered or no detrusor contraction is seen at the end of filling (when filling reaches 150% of MVV), the detrusor is *underactive*. This is an arbitrary percentage agreed to by the ICCS terminology standardization committee based on MVV; it is variable for each child. When the child has the ability to completely suppress voiding for fear of discomfort with the catheter in place this may be normal but it may lead to overfilling during the study. Despite encouragement, the catheter may need to be removed to allow the child to urinate. The study is interpreted as normal detrusor function, especially if the child then empties. True *detrusor underactivity* may result from chronic bladder outlet obstruction or a neuropathic lesion leading to impairment of emptying.[15,16]

The normal urethral closing mechanism maintains a positive urethral closure pressure (guarding reflex).[43] Shortly before micturition, the normal closure pressure decreases to allow for flow. An *incompetent closure mechanism* is defined as one that allows leakage of urine in the absence of a detrusor contraction. In genuine stress incontinence, leakage occurs when Pves exceeds Purethra (intraurethral resistance) as a result of an increase in intraabdominal pressure, often in conjunction with low Purethra.[43] Although common in multiparous females, it is exceedingly rare in pediatrics but may be noted in athletically active teenage girls.[48]

To clinically define a bladder with high pressure at normal capacity, the term *detrusor leak-point pressure* has been introduced. It is measured by subtracting Pabd from Pves at the moment of leakage when the first drops of urine pass through the meatus in the absence of raised abdominal pressure or an involuntary detrusor contraction. A pressure <40 cm H_2O is considered acceptable for those with a fixed urethral resistance who cannot generate a detrusor contraction.[49]

Assessment of the Voiding Phase

During voiding the detrusor may be classified as *normal*, *underactive*, or *acontractile*.

Normal voiding is achieved by a voluntarily initiated detrusor contraction; it is sustained and cannot be suppressed easily once it has begun. In the absence of bladder outlet obstruction, a normal contraction will lead to complete emptying.

In children with normal neurologic function, when standard fill cystometry was performed the mean detrusor pressure during voiding was 127 cm H_2O in boys and 72 cm H_2O in girls at a median of 1 month of age; this exceeds adult values, considerably.[50] These pressures vary somewhat from those reported by Yeung, as he found infant boys have pressures of 118 cm H_2O and girls of 75 cm H_2O when these measurements were taken during natural fill cystometry.[4,45] The acontractile detrusor demonstrates no activity during voiding. If acontractility is neurologically induced, it is called *detrusor areflexia*. It denotes the complete absence of a centrally coordinated contraction. Terms such as hypotonic, autonomic, or flaccid are to be avoided.[15,16]

If a detrusor contraction is inadequate in magnitude and duration to effectively empty the bladder, it is referred to as *detrusor underactivity during voiding*.[15,16] The urethra during voiding may be *normal* or *obstructive*. The urethra opens during voiding to allow the bladder to empty at normal pressures without any loss of kinetic energy. Obstructive urethral function may be due to overactivity of the sphincteric mechanism or anatomical obstruction (posterior urethral valves, urethral stricture, ectopic ureterocele).

An *anatomic obstruction* is a fixed narrow diameter in a urethral segment that does not expand during voiding, resulting in a plateau shaped flow pattern, with a low and constant maximum flow, despite high detrusor pressure and complete relaxation of the external urethral sphincter (EUS). *Functional obstruction*, is the active contraction of the EUS during voiding that creates a narrowed urethral segment, either constantly or intermittently. Functional and anatomic obstructions can be differentiated by measuring EUS activity during voiding with simultaneous recordings of pressure and flow (urethral resistance at the EUS), or EMG activity of the striated EUS, using needle or patch electrodes. Video UDS is helpful, as pelvic floor muscle activity can be observed during voiding, as well as differentiating anatomic from functional obstruction.[51]

In some children fearful of voiding, "*urethral overactivity*" may be a natural reaction resulting in elevated voiding pressures, intermittent voiding and/or substantial PVR. Increased activity occurs as the child senses the need to urinate. In neuropathically induced detrusor-sphincter dyssynergia, the detrusor contraction and involuntary contraction of the urethral and/or periurethral striated muscles occur simultaneously during micturition. When overactivity of the EUS occurs during voiding in neurologically normal children, it is termed *dysfunctional* or *discoordinated voiding*.[15,16,45,52]

Investigators have looked at the time differential between relaxation of the EUS (as measured by patch perineal electrodes) and the opening of the bladder neck on video-urodynamics, calculating the normal time difference as 2 sec. This is labelled "lag time". It may be calculated from pressure flow studies that include perineal EMG when not employing videourodynamics. When shortened (≤ 2 sec) it is considered a sign of detrusor overactivity, when prolonged, >6 sec, an indication of bladder neck dysfunction.[53]

CLINICAL IMPLICATIONS

It cannot be overemphasized that invasive UDS should be conducted only if a treatment strategy has been outlined beforehand. Without such an indication, a study should not be undertaken.

UDS in children are best performed under the auspices of a knowledgeable urologist or trained urodynamacist. In order to obtain a complete picture of LUT function, presence and observation by these professionals during the investigation, seeing how the child behaves during testing and monitoring patient and parent interactions throughout the study are paramount. Family dynamics and what role they might play in etiology and persistence of the dysfunction, as well as what treatment strategies might be appropriate can be acertained. UDS are invasive, the surroundings frightening, and the whole procedure unnatural for the child. Some children will only void when everyone has temporarily left the room. Availability of a television, videotape recorder or DVD player provides a major diversionary advantage in assuaging anxiety and creating a distraction during the procedure. In very small children, parents are advised to bring a bottle and/or favourite toys.

CONCLUSION

Urodynamic investigation has become a major tool in the evaluation of LUT dysfunction in many children; however, it is invasive, time and resource consuming and far from natural. Thus, artifacts may affect to a great extent correct interpretations. Despite best intentions, these investigations may not always yield reproducible results. UDS is only one part of the diagnostic work-up that must be kept in context to the clinical setting.

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AUTHOR CONTRIBUTION

S.B.B.: Manuscript design, concept and content, with final approval. R.N.: Manuscript design, concept and content. B.A.D.: Critical review, manuscript content and construction of document. U.S., P.H.: Manuscript design, concept and content, critical review for intellectual content.

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