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Standardization and definitions in lower urinary tract dysfunction in children

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Introduction

In 1973, the 3-year-old International Continence Society (ICS) established a committee for the standardization of terminology of lower urinary tract function. This committee published seven reports [1–7], approved by the Society, and these reports became accepted and important tools in clinical practice and research.

In children, the complex composite structure of the lower urinary tract is functionally controlled at several levels of the central nervous system; co-ordination and communication between these levels are not fully developed until the age of 4 years. Furthermore, owing to the impact of sociocultural differences, the age-dependent neural control over lower urinary tract function in children is far less standard than in adults.

With interest in paediatric urodynamics growing rapidly, the need for a separate report on standardization and definitions for lower urinary tract dysfunction in children became obvious. Using the International Children's Continence Society (ICCS) as body of reference, and the format of the Standardization Committee of the ICS, the present report was created. The full draft was ratified at the first annual meeting of the ICCS, in 1997, and a shortened version will be adopted and published by the Standardization Committee of the ICS.

Standardization of terminology and methodology should facilitate comparison of results by investigators using urodynamic methods in children. The report's standardized definitions of dysfunctional entities in children avoid the confusion caused by the many diagnostic labels for syndromes and types of incontinence reported in the literature. Future investigations of therapy and outcome will benefit from clear and standard definitions.

We hope that acknowledgement of these standards in relevant written publications will be indicated by a footnote, or its equivalent, as follows: *Methods, definitions and units conform to the standards recommended by the International Children's Continence Society, except where specifically noted.*

Classification of enuresis and incontinence

Enuresis nocturna

According to Liddell and Scott's Greek–English Lexicon [8], enuresis is derived from the Greek verb ενουρειν, which literally means 'to make water in', and ενουρηκοτες are 'piss-a-beds'. In paediatrics, enuresis is defined as a normal void occurring at an inappropriate or socially unacceptable time or place. Children with nocturnal enuresis void in bed while asleep and are generally not aroused by the wetting. The condition is monosymptomatic and has a clear familial tendency.

Quantification of nocturnal enuresis

Age. After infancy, there is a gradual evolution to nocturnal continence. The definition of nocturnal enuresis implies social unacceptability; rarely, the condition is distressing to children under the age of 5 years.

Frequency. The number of wet nights is ascertained, per month or per week, and if possible the number of wetting episodes per night as well. It is also important to determine the time of night of wetting: early (first 2 h of sleep), late (2 h before arising), or randomly timed. Generally, nocturnal enuresis is not considered a clinical problem when the number of wet nights is $\leqslant 1$ per month. However, teenagers and older patients may find one wet night per month unacceptable.

Amount of wettings. As a rule, the bed will be soaking wet; smaller amounts should raise suspicion of other causes of wetting.

Arousability. It is important to know whether an individual with monosymptomatic bedwetting wakes up to a full bladder. Without sleep studies the assessment of arousability is not possible.

Subtypes of nocturnal enuresis

Several subtypes of nocturnal enuresis have been defined

[9] and are mentioned because of their varying therapeutic implications.

Primary nocturnal enuresis. Monosymptomatic bedwetting in individuals who never have been dry at night for an uninterrupted period of at least 6 months. Primary nocturnal enuresis may coexist with the daytime wetting of urge syndrome or dysfunctional voiding; both conditions have a very high prevalence in children.

Onset nocturnal enuresis. Monosymptomatic bedwetting in individuals who have been dry at night for an uninterrupted period of 6 months or more.

Familial nocturnal enuresis. Monosymptomatic bedwetting in individuals with first-degree relatives who have (had) the same condition.

Nocturnal polyuria enuresis. Monosymptomatic bedwetting in individuals who have, on wet nights, urine production in excess of their functional bladder capacity, as shown by voiding charts. On dry nights, these individuals will have nocturia.

Urinary incontinence

This is defined as the involuntary loss of urine, objectively demonstrable, and constituting a social or hygienic problem. Loss of urine through channels other than the urethra is extraurethral incontinence. Urinary incontinence denotes a symptom, a sign, or a condition.

The *symptom* indicates the patient's recognition of involuntary urine loss, the *sign* is the objective demonstration of urine loss and the *condition* is the urodynamic demonstration of urine loss. Urodynamic diagnoses should correlate with the patient's symptoms and signs. For example, the presence of an unstable contraction in an asymptomatic continent patient does not warrant the urodynamic diagnosis of detrusor overactivity.

Symptoms, signs, and conditions

The symptom of stress incontinence is the patient's statement of involuntary loss of urine during physical exertion. The sign of stress incontinence denotes the observation of loss of urine from the urethra synchronously with physical exertion (e.g. coughing). Incontinence may also be observed without physical exercise. Post-micturition dribble and continuous leakage denote other signs of incontinence.

Conditions. Genuine stress incontinence is the involuntary loss of urine occurring when, in the absence of a detrusor contraction, the intravesical pressure exceeds the maximum urethral pressure. Reflex incontinence is loss of urine due to detrusor hyper-reflexia and/or involuntary urethral relaxation in the absence of the sensation usually associated with the desire to micturate. This condition is only seen in patients with neuropathic bladder/urethral disorders. Overflow incontinence is any involuntary loss of urine associated with overdistension of the bladder. Urge incontinence is the involuntary loss of urine associated with a strong desire to void (urgency).

Urge syndrome and dysfunctional voiding

Urge syndrome and dysfunctional voiding are characteristic paediatric disorders, classified as functional incontinence; they merit separate discussion, because they have a very high association with recurrent urinary tract infections and occur predominantly in girls. The disorders might not be the separate entities they seem, as transitional phases between urge syndrome and dysfunctional voiding do occur. The complex of functional incontinence and recurrent urinary tract infections may start with detrusor overactivity and hold-manoeuvres (Fig. 1), with a gradual evolution to fractionated and incomplete voiding [9]. Data from prospective studies are needed to validate this concept.

Urge syndrome and urge incontinence

The frequent attacks of imperative urge to void, countered by hold-manoeuvres such as squatting are characteristic symptoms; children have to be asked specifically about this. Urge incontinence usually peaks in the afternoon and consists of small amounts of urine loss. Urge incontinence may also have a nocturnal component, in the form of an incomplete bladder emptying, which may or may not wake the child. By this definition, bedwetting in a child with urge syndrome and urge incontinence is not categorized as enuresis but as incontinence; the wetting at night is caused by the same dysfunction as its daytime counterpart.

The problem is caused by overactive detrusor contractions, early in the filling phase, countered by the emergency 'brake' of voluntary pelvic floor contraction. Hold manoeuvres, aiming at external compression of the urethra, are added to this. Usually the bladder capacity is small for the child's age, resulting in a high voiding frequency. Micturition is essentially normal, with complete relaxation of the pelvic floor.

The habit of countering every urge to void with voluntary pelvic floor contraction also inevitably leads to inappropriate postponement of defecation; constipation and fecal soiling are very common signs and symptoms in children with urge syndrome.

Dysfunctional voiding

Several patterns of dysfunctional voiding have a

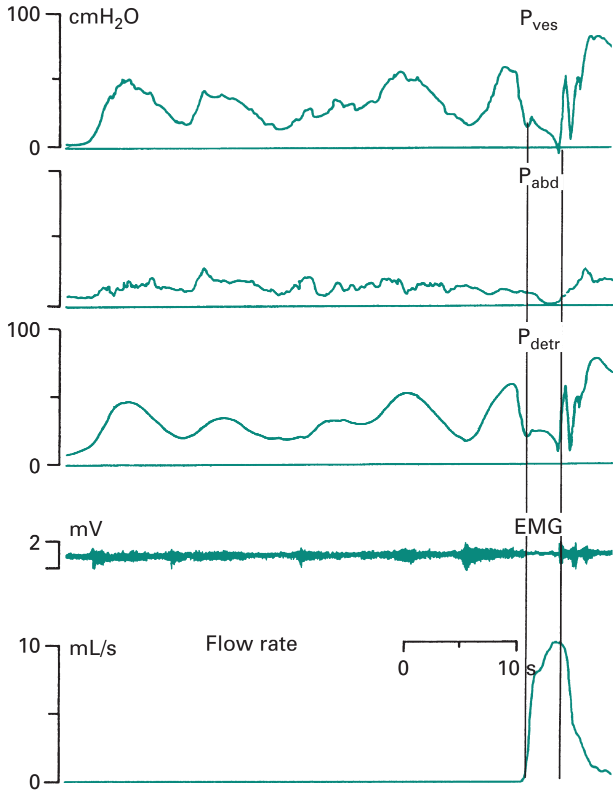

Fig. 1. Filling phase and voiding phase in a 5-year-old girl with urge syndrome, daytime wetting and recurrent urinary tract infections. Overactive detrusor contractions during filling are countered deliberately with pelvic floor contractions, until voiding can no longer be postponed. The actual voiding phase is normal, although the flow rate rises steeply (see Fig 5c) and flow may be stopped too soon.

common denominator, i.e. overactivity of the pelvic floor muscles during micturition. *Staccato voiding* is a peculiar rhythmic voiding pattern caused by bursts of pelvic floor activity during micturition, resulting in peaks in bladder pressure coinciding with (in)complete interruptions in flow (Fig. 2a). A flow rate above a certain threshold seems to trigger the pelvic floor muscles into contraction; as soon as this contraction has reduced the flow rate, the pelvic floor relaxes again and the flow rate regains the threshold. Flow duration is prolonged and bladder emptying tends to be incomplete.

Fractionated voiding is a micturition that occurs in several small fractions, with incomplete bladder emptying. The condition is caused by hypo-activity of the detrusor muscle, and the voiding consists of several unsustained detrusor contractions, each with its own flow. Often, abdominal pressure is exerted to speed up the voiding. The flow rate is highly irregular, because reflex activity of the pelvic floor muscles is triggered by each increase in abdominal pressure. Voiding frequency tends to be very low, bladder capacity is large for the child's age and the wetting in this pattern is intrinsically a form of overflow incontinence. Occasionally, children may have a low voiding frequency with no fractionated voiding; in typical situations, or because of extreme dysuria, micturition is postponed as long as possible, until urge is so imperative that voiding irrevocably takes place, usually in the pants.

Lazy bladder syndrome is the result of long-term dysfunctional voiding. Secondary to detrusor decompensation, detrusor contractions are absent and abdominal pressure is the driving force for voiding (Fig. 2b). Large residual volumes and recurrent urinary tract infections are the rule. Symptoms and signs of fractionated voiding may also relate to *vaginal regurgitation* (*vaginal reflux*) of urine.

Wetting in attention-deficit disorders

In some children with diurnal enuresis the incidence of wetting varies greatly, as does the amount. These children void predominantly in the pants and sometimes in bed. Voiding is complete and there is no history of urinary tract infections. These children typically have symptoms belonging to the complex of attention-deficit disorders (ADDs), which may explain the marked variability in wetting. In these children, bladder and urethral function are completely normal.

Clinical assessment

The clinical assessment of children with lower urinary tract dysfunction should consist of a detailed and structured history, a frequency/volume chart, and a physical examination. In urinary incontinence, leakage should be assessed objectively and quantified. In nocturnal or diurnal enuresis, volume and time of urine loss should be noted.

History

For the paediatric age group, where the history is obtained from both parents and child, and where the development of bladder control generates specific problems, a structured approach is recommended. A questionnaire [10], completed by the parents before the first visit to the clinic, is essential. General history-taking should include questions relevant to neurological and congenital abnormalities, and information on previous urinary infections and relevant surgery. History-taking should assess bowel function, menstrual and sexual function. Specific questions should focus on symptoms related to both the storage and the evacuation of urine. Medications with known or possible effects on the lower urinary tract should be ascertained.

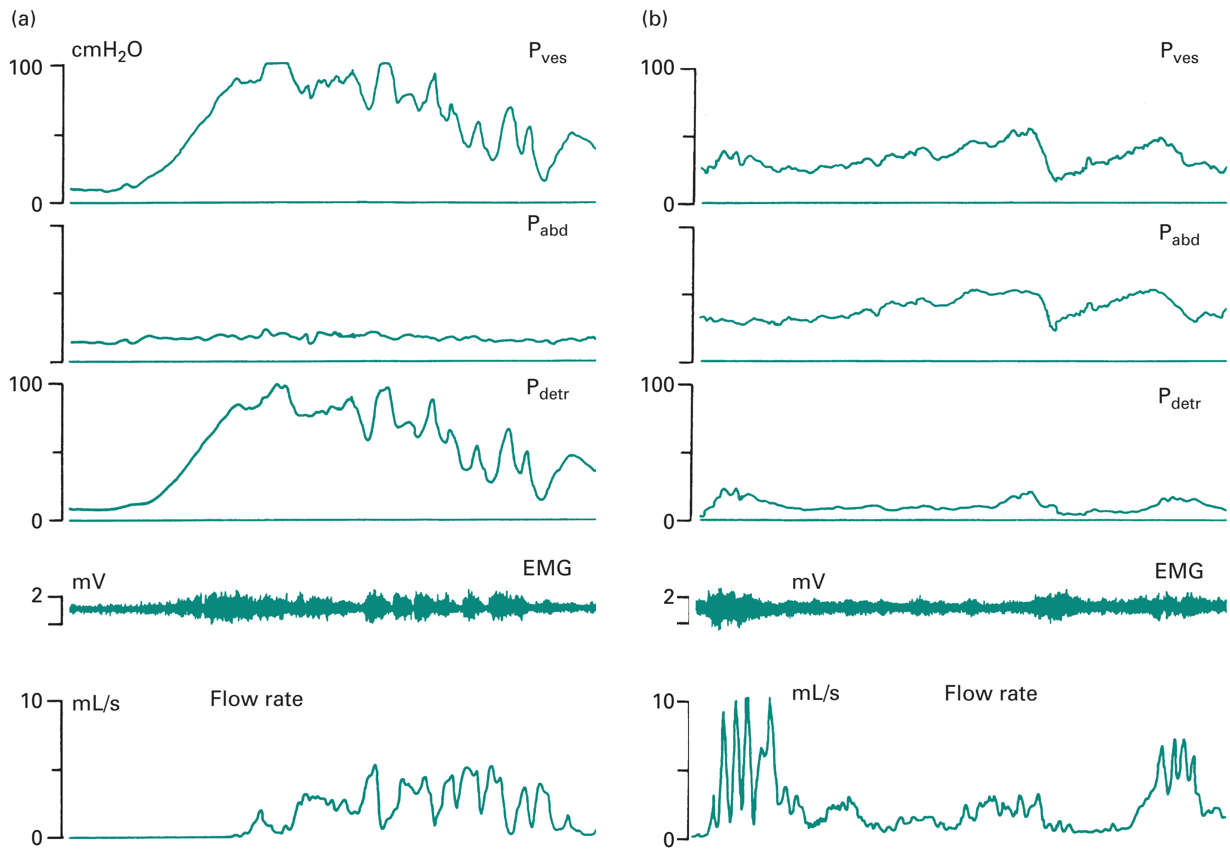

Fig. 2. Urodynamic recording of (a) staccato voiding in a 9-year-old girl. Flow is interrupted by short bursts of pelvic floor activity, resulting in high bladder pressures, prolonged flow time and poor flow rate; and (b) voiding in 'lazy bladder syndrome'. Abdominal pressure is the driving force, resulting in a very fractionated flow pattern, caused by reflex activity of the pelvic floor muscles with each abdominal 'push'. The recording was made during the urodynamic investigation of a 6-year-old girl with daytime and night-time wetting, who tried to comply with every parental demand to void.

Frequency–volume diary

The frequency/volume chart is a detailed diary recording fluid intake and urine output over several 24-h periods. The diary should provide the number of voidings, the times of voiding and voided volumes. The chart can record episodes of urgency and leakage. These charts are useful in assessing voiding disorders and in the follow-up of treatment. Whenever possible, the diary is the responsibility of the child; the parents should assist and support.

Physical examination

Besides a general paediatric examination, a physical examination should assess perineal sensation, the lumbosacral reflexes (standing on toes, anal reflex and tone, bulbocavernosus reflex). Special attention should be paid to inspection of the male or female genital region and of the urethral meatus. Asymmetry of buttocks, legs or feet, as well as other signs of occult neurospinal dysraphism in the lumbosacral area (subcutaneous lipoma, skin discoloration, hair growth) should be sought. The physical examination must include urine analysis, to exclude hyposthenuria, glucosuria, proteinuria and bacteriuria.

Quantification of urine loss

The subjective grading of incontinence may not reliably indicate the degree of abnormality. However, it is important to relate the management of the individual child to objective signs and measurements as well as to complaints and personal circumstances. For objective grading, the 12-h pad test [11] and frequency/volume charts [12] are validated instruments. In children, the 12-h pad test should also include fluid intake. The pad test complements the frequency/volume chart, which registers the quality of incontinence and the distribution of wetting episodes more than the quantities of urine lost. Children take the 12-h pad test very seriously as a benchmark for their overall performance; the suspiciously excellent scores found in functional incontinence will not be produced by children with structural incontinence.

The amount of urine lost during sleep can be measured by weighing a collecting device, such as an absorbent pad, before and after sleep. To obtain a measure of the total nocturnal urine output, the volume of the early morning voiding should be added to the amount lost during sleep.

Aetiological classification of lower urinary tract dysfunction

The bladder and urethra form a functional unit and their interaction cannot be ignored. The unit has two opposed and alternating functions, i.e. storage and evacuation of urine. When reference is made to the hydrodynamic function or to the whole anatomical unit as a storage organ, *vesica urinaria*, the correct term is 'bladder'. When the smooth muscle structure known as *muscularis detrusor vesicae* is being discussed, then the correct term is 'detrusor'. For simplicity, bladder/detrusor and urethra will be considered separately in the classification of lower urinary tract dysfunction.

Terms should be objective and definable, and should apply to the whole range of abnormality. If other investigators disagree with the classification presented below, or prefer to use terms that are not defined herein, they should ensure that their terminology is clear. In the present classification, nocturnal enuresis has been excluded, as this condition is not related to any specific lower urinary tract dysfunction.

Disturbance of pertinent nervous or psychological control

Congenital malformations of the CNS. These include; myelomeningocele; occult spinal dysraphism; caudal regression sequence (e.g. syringocele, diastematomyelia, sacral malformations, certain cases of anal atresia); tethered cord syndrome.

Developmental disturbances. Urge syndrome; dysfunctional voiding; mental retardation and delayed psychomotor development; ADD–like syndromes.

Acquired conditions. Cerebral spasticity (perinatal asphyxia); progressively degenerative diseases of the CNS associated with central spasticity (e.g. Hallervorden-Spatz disease); multiple sclerosis; Guillain–Barré syndrome; radiculitis; transverse myelitis; spinal cord trauma; spinal cord infections (e.g. schistosomiasis); tumours (e.g. sacrococcygeal teratoma); vascular malformations of the spinal cord; iatrogenic trauma to the pelvic plexus.

Disorders of smooth and striated muscle function

Congenital conditions. Duchenne's muscular dystrophy, spinal muscular atrophy, neuronal dysplasia (megacolon–megacystis syndrome).

Acquired conditions. Chronic bladder distension; overdistension injury; fibrosis of detrusor and bladder wall.

Structural abnormalities

Congenital conditions. Exstrophy, epispadias, hypospadias; caudal regression sequence (e.g. cloaca); ureteroceles and other abnormalities of bladder, trigone and bladder neck; posterior urethral valves and other urethral abnormalities; prune-belly syndrome; ectodermal dysplasia; disorders of collagen (e.g. Ehlers-Danlos).

Acquired conditions. Trauma (causing stricture or damage to the sphincter); iatrogenic (e.g. Otis urethrotomy); hypercalciuria.

Unclassified conditions

Giggle incontinence; Hinman syndrome; Ochoa syndrome.

Outcome and results of treatment for enuresis

The outcome of pharmacological treatment for nocturnal enuresis is expressed as either complete cure or improvement while on the prescribed medication. Complete cure (*responder*) is defined as a reduction in wet nights of at least 90% and improvement (*partial responder*) as a reduction in wet nights of $>50\%$ [13].

With other forms of therapy (bell-and-pad, dry-bed training), the outcome is noted *after* the therapeutic period. With a follow-up of at least 6 months, outcome can be a lasting complete cure ($>90\%$ reduction) or a lasting improvement ($>50\%$ reduction, but $<90\%$). In reports on the outcome of nocturnal enuresis, it should be ascertained whether nocturia replaced the night-time wetting.

Outcome and results of treatment for incontinence

Statistics. When statistically analysing urine loss in a group of subjects, nonparametric statistics should be used, as the values are not normally distributed.

Outcome. 'Complete cure' is achieved with pharmacological treatment when the reduction in wetting incidents is at least 90% while on medication. Improvement is restricted to a reduction of at least 50% while on medication. With a follow-up of at least 6 months after discontinuing the prescribed drug, cure or improvement may be termed lasting. For other forms of treatment (biofeedback training), cure or improvement can be noted immediately *after* the end of treatment, or cure and improvement may be scored as lasting when there has been a follow-up of at least 6 months after the treatment period. Outcome can also be judged by 'bother' scores before and after treatment, but inter-individual variations in 'bother' scores are large and vary widely.

Questionnaires and voiding charts, used in the diagnosis of incontinence, are the most important tools in reporting on outcome and results of therapeutic interventions. Medical ethics would limit the use of repeat urodynamic studies to strict indications, e.g. in individual patients, or with full parental consent in prospective studies.

Assessment of urine storage

Cystometry

Cystometry is the method by which the pressure/volume relationship of the bladder is measured; it is used to assess detrusor activity, sensation, capacity and compliance. Cystometry performed with a balloon catheter occluding the bladder outlet is termed 'isometric'.

In children, the transition from filling phase to voiding phase is not as marked as in adults. To avoid missing this important transition, cystometry and pressure-flow/EMG measurements are performed as one continuous study in paediatric urodynamics. Electromyography of the pelvic floor muscles evaluates the activity of the striated urethral sphincter, in the filling phase and in the voiding phase. Before starting to fill the bladder, residual urine should be aspirated. Any post-void residual volume should always be confirmed by repetitive investigations.

Before cystometry, all systems are zeroed at atmospheric pressure; for external transducers the reference point is the level of the superior edge of the symphysis pubis. For microtip-transducer catheters (MTCs) the reference point is the transducer; these catheters have an integral reference channel open to the atmospheric pressure and the pressure in the bladder at the start of the study can be taken as zero. Whenever the patient's position changes during the investigation, e.g. from supine to sitting, external transducers must follow the level of the symphysis pubis to maintain zero at the preset level.

During cystometry the child should ideally be at ease, with assistance from the parents in attendance. Anxiousness or distress can be avoided by familiarising the child with the urodynamic laboratory, the doctor and the technician(s), before the actual investigation takes place. Any distress during the investigation should be noted. Furthermore, the child should be awake, not anaesthetised and neither sedated nor taking any drugs that affect bladder function. Any variation should be specified. As a rule, at least two cycles of filling are recorded.

Specifications and technique

Access may be suprapubic or transurethral.

Catheters. Specify catheter type, number of catheters, single or multiple lumina, type of catheter (polyethylene, polyurethane), and size in French. With suprapubic catheters specify the mode of insertion; local or general anaesthesia, and time of insertion in relation to urodynamic investigation. Also note any urethral catheterization or retrograde filling of the bladder before placement of the urodynamic catheter. For MTCs, list the manufacturer and specifications.

Fluid medium and temperature of fluid; saline 0.9% at 25–36°C is recommended in children, with no additives; CO_2 is not recommended.

Position of patient, supine or sitting.

Filling by diuresis, or retrograde by catheter. When filling by catheter, the precise filling rate should be stated. The following terms for the rate of filling may be used; up to 10 mL/min is *slow-fill cystometry* ('physiological filling'), any rate between 10 and 25 mL/min is *medium-fill cystometry*. Slow-fill cystometry is recommended in children, as certain cystometric variables, notably compliance, may be significantly altered by the speed of bladder filling. Filling pumps should have a preset safety switch, which makes the pump inoperative at bladder pressures of >100 cmH_2O.

Definitions

Intravesical pressure is the pressure within the bladder.

Abdominal pressure is taken to be the pressure around the bladder. A good estimate is derived from rectal pressure, obtained by a perfused infant feeding tube, or an MTC catheter, placed in the rectum.

Detrusor pressure is that component of intravesical pressure that is created by active or passive forces in the bladder proper. It is a calculated estimate obtained by subtracting abdominal pressure from intravesical pressure. The hydrostatic pressure exerted by the abdominal contents on the transducer membrane is about 10–15 cmH_2O higher in when sitting than when supine; both intravesical and abdominal pressure transducers (external or catheter-mounted) will record this difference, and it should not appear on the detrusor pressure tracing. Especially in children it is considered of utmost importance to obtain an estimate of detrusor pressure, as abdominal straining caused by anxiety or discomfort could simulate or even camouflage bladder contractions. 'Negative' detrusor pressures should be regarded as artefacts generated by intrinsic rectal activity.

Bladder sensation is difficult to evaluate in children. Only in toilet-trained cooperative children is it a relevant variable. Commonly used descriptive terms include;

First desire to void; is not relevant in the infant, but can be used as a guideline in children of 4 years and older.

Normal desire to void. In the infant this should be considered the volume at which some unrest is noted, e.g. wriggling with the toes; this usually indicates voiding is imminent. In the older child, the volume may be small with the first cystometry, for fear of discomfort; this is the reason that least two cycles of filling are recommended in paediatric urodynamics.

Strong desire to void is defined as a persistent desire to void, without the fear of leakage.

Urgency is defined as a strong desire to void accompanied by fear of leakage or fear of pain. The difference between strong desire to void and urgency may be too subtle for children to perceive.

Maximum cystometric capacity or *cystometric bladder capacity* (CBC) is the volume in the bladder at which the infant or child starts voiding. In the absence of bladder sensation the clinician decides when to terminate filling, e.g. as soon as the resting pressure in the bladder has reached 30 cmH_2O. In the presence of sphincter incompetence the maximum cystometric capacity will be significantly increased by occlusion of the urethra (Foley catheter). The value for maximum cystometric capacity is derived from volume voided plus residual volume. Values for the CBC should be interpreted in relation to normal values for age, given by the formula $y = 30 + (30x)$, where y is the capacity in mL and x is the age in years. In infant boys, $y = 24.8x + 31.6$ and in infant girls $y = 22.\mathrm{b}x + 37.4$ [13]. Abnormal values are expressed as percentage differences (positive or negative) from normal, using the formula;

$$[(CBC_{obs} - CBC_{norm})/CBC_{norm}[\times 100] \quad (1)$$

where CBC_{obs} is the observed value and CBC_{norm} the normal value calculated from the child's age

Functional bladder capacity is a more clinically relevant variable and is defined as the voided volume, estimated from the frequency/volume chart. This may give a very wide range of values, as the voidings are unobserved. More consistency can be obtained by measuring supervised free voiding, where the child voids only at a genuine desire to void.

Maximum (anaesthetic) bladder capacity is the volume measured after filling during a deep general or spinal/epidural anaesthesia, specifying fluid temperature, filling pressure and filling time. Without standardization, this method tends to give unreliable results in children.

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 (Δp_{det}) during that change in bladder volume ($\Delta V/\Delta p_{det}$). Compliance is expressed as mL/cmH_2O. Ideally, the total volume increment, as measured from empty bladder to the point immediately preceding voiding, should be divided by the increment in detrusor pressure between these points. However, many factors may contribute to the detrusor pressure increment as specified. To standardize the reading of the pressure increment, the most linear part of the V/p relationship should be delineated on the cystometrogram (Fig. 3); the values for V and p at beginning and end of that section are used to capture $\Delta V/\Delta p_{det}$. The usual notation for compliance is the single value. In children, where it is important to know to what volume increment a certain pressure increment is related, the full notation, in mL/cmH_2O, has advantages.

Urethral pressure profile (UPP)

There are few data justifying the use of this measurement in children; pulling a catheter along the length of the urethral lumen at best provokes strong reflex activity of the pelvic floor muscles. In children with neuropathic bladder dysfunction, the UPP can be helpful to discover sphincter incompetence in the presence of electromyographically normal pelvic floor activity. Urethral pressure and urethral closure pressure are idealized concepts of the ability of the urethra to prevent leakage. In current urodynamic practice the urethral pressure is measured by several different techniques which do not always yield consistent values. Not only do the values differ with the method of measurement, but there is often lack of consistency for a single method (consider the effect of catheter rotation when urethral pressure is measured by using a MTC).

Classification of function in the storage phase

This may be described according to detrusor activity, bladder sensation, bladder capacity, and compliance.

Detrusor activity. In this context, detrusor activity is interpreted from the measurement of detrusor pressure (p_{det}). Detrusor activity may be normal, overactive or underactive. In normal detrusor function, the bladder volume increases during the filling phase with on signifi-

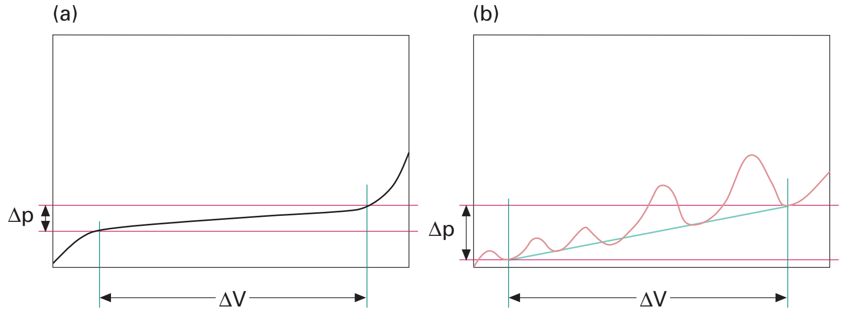

Fig. 3. (a) A standardized reading of detrusor pressures and bladder volumes to calculate $\Delta V/\Delta p_{det}$ in a normal cystometrogram. The non-linear portions at the beginning and end of the V/p diagram do not contribute to compliance. (b) The method for reading detrusor pressures and bladder volumes in a cystometrogram with detrusor overactivity; $\Delta V/\Delta p_{det}$ essentially captures the angle of the line describing the increment in resting pressure.

cant rise in pressure (accommodation). No involuntary contractions occur despite provocation. A normal detrusor so defined may be described as 'stable'.

Overactive detrusor function is characterized by phasic (Fig. 3b) involuntary detrusor contractions during the filling phase, which may be spontaneous or provoked, and which the patient cannot completely suppress. Involuntary detrusor contractions may be provoked by rapid filling, alterations of posture, coughing, walking, jumping and other triggering procedures. Various terms have been used to describe these features and they are defined as follows.

The unstable detrusor is one that is shown objectively to contract, spontaneously or on provocation, during the filling phase. Unstable detrusor contractions may be asymptomatic or may be interpreted as a normal desire to void. The presence of these contractions does not necessarily imply a neurological disorder. In infants, detrusor contractions often occur throughout the filling phase. Unstable contractions are phasic and occur throughout filling (Fig. 3b). Phasic contractions occurring only before voiding denote a lesser degree of instability. A gradual increase in detrusor pressure with no subsequent decrease is best regarded as a change of compliance (Fig. 3a).

Detrusor hyper-reflexia is defined as overactivity arising from disturbance of neurological control mechanisms. The term 'detrusor hyper-reflexia' should only be used when there is objective evidence of a relevant neurological disorder. The use of conceptual and undefined terms such as hypertonic, systolic, uninhibited, spastic and automatic should be avoided.

Underactive detrusor activity is not readily visible in the filling phase, but occurs in the overdistended post-obstructive bladder, leading to a risk of overfilling the bladder during cystometry.

Bladder sensation

During filling, bladder sensation can be classified in qualitative terms and by objective measurement. Sensation can be classified broadly as normal, increased (hypersensitive), reduced (hyposensitive), or absent.

Bladder capacity [12,14–16] and Eqn 1.

Compliance (Fig. 3). Changes in compliance during one cystometric examination are common; the compliance is (variably) dependent upon several factors, including (i) the rate of filling, (ii) the part of the cystometrogram used in the calculation of compliance, (iii) the geometry (shape) of the bladder, (iv) the thickness of the bladder wall, (v) the mechanical properties of the bladder wall, and (vi) the contractile/relaxant properties of the detrusor.

During normal bladder filling, little or no pressure change occurs and this is termed normal compliance. However, at present there are insufficient data to define normal, high and low compliance, except in clearly defined and standardized situations.

When reporting compliance, specify (i) the rate of filling, (ii) the volume increment over which compliance is calculated (preferably this should approximate the bladder capacity for age), (iii) the part of the cystometrogram used for the calculation of compliance (preferably the part where V/p is almost linear) [17].

In children, compliance should relate to normal cystometric bladder capacity for age. Provisionally, a lower limit for normal compliance might be $0.05y$ mL/cmH_2O increase in the baseline bladder pressure (where y is the CBC for age). For children with neuropathic bladder, data are available relating poor compliance to the risk of upper urinary tract damage [18].

Urethral function during storage

The urethral closure mechanism during storage may be normal or incompetent. The normal urethral closure mechanism maintains a positive urethral closure pressure during filling, even in the presence of increased abdominal pressure (guarding reflex). Immediately before micturition the normal closure pressure decreases to allow flow. An incompetent urethral closure mechanism is defined as one which allows leakage of urine in the absence of a detrusor contraction. Leakage may occur whenever intravesical pressure exceeds intraurethral pressure (genuine stress incontinence) or when there is an uninhibited micturition reflex with an involuntary fall in urethral pressure. Terms such as ‘the unstable urethra’ await further data and precise definition.

Leak-point pressure

To clinically define the bladder with high pressures at small capacity, which risks upper urinary tract function, leak-point pressure has been introduced [17]. This is the pressure in the bladder, at any given volume during filling, at which the first drops of urine pass the urethra. Leak-point pressures are a worst-case estimate of bladder storage in patients with neuropathic bladder/sphincter dysfunction. Safe leak-point pressures should be well below 40 cmH_2O.

Assessment of urine evacuation

Measurement of urinary flow

Urinary flow pattern may be continuous, intermittent (in fractions), or staccato (interrupted). The flow rate is the volume of fluid expelled via the urethra per unit time and is expressed in millilitres per second (mL/s). Urinary flow is measured 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. Patterns and rates should be consistent to allow for evaluation, and several recordings are needed to obtain consistency ((Fig. 4).

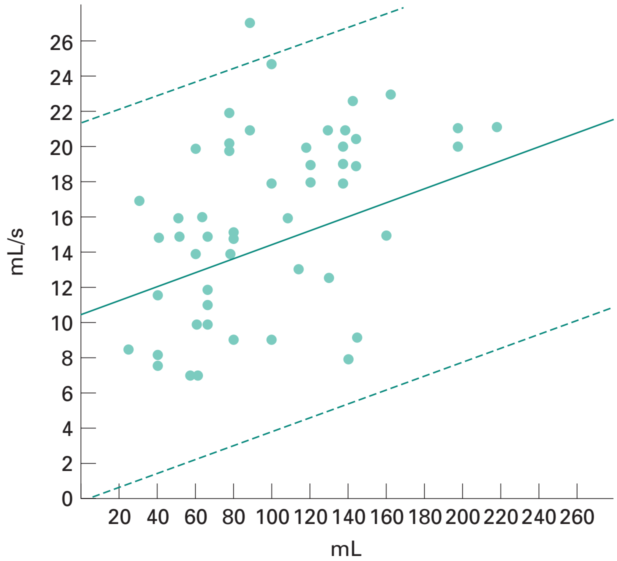

Fig. 4. Fifty consecutive voidings in a healthy 5-year-old boy, plotted as the volume voided against the maximum flow rate. The confidence interval is very wide [12,15,16]; extreme caution must be used in the interpretation of individual single values for Q_{max}. In general, voided volumes of < 50 mL cannot be considered as relevant for interpreting flow rate or flow pattern [12]. It is therefore important to specify whether urinary flow was recorded during voiding on command (small volumes) or during voiding on urge (normal volumes). Reference values on voiding frequency and voided volumes have been published by Mattson [12] and nomograms for Q_{max} have also been published recently [15,16].

Continuous flow

Voided volume is the total volume expelled via the urethra. *Maximum flow rate* is the maximum measured value of the flow rate. *Average flow rate* is voided volume divided by flow time. The calculation of the average flow rate is only meaningful if the flow is continuous and without dribbling. *Flow time* is the time over which measurable flow actually occurs. *Time to maximum flow* is the elapsed time from the onset of flow to the maximum flow. The flow pattern must be described when flow time and average flow rate are measured ((Fig. 5).

Intermittent or fractionated flow

The same variables used to characterize continuous flow may be applicable, if care is exercised, in patients with intermittent, fractionated or staccato flow patterns (Fig. 5b). In measuring flow time, the time intervals between flow episodes are disregarded. Voiding time is the total duration of micturition, including interruptions. When voiding is completed without interruption, voiding time is equal to flow time.

Bladder pressure during micturition: pressure/flow study

Definitions

The specification for patient position, access for pressure measurement, catheter type, and measuring equipment are the same as for cystometry. The terminology referring to bladder pressure during micturition is as follows ((Fig. 6).

Opening time is the elapsed time from the initial rise in detrusor pressure to the onset of flow. This is the initial isovolumetric contraction period of micturition. Time lags should be taken into account. In most urodynamic systems a time lag occurs equal to the time taken for the urine to pass from the point of exit (urethral meatus) to the flow transducer.

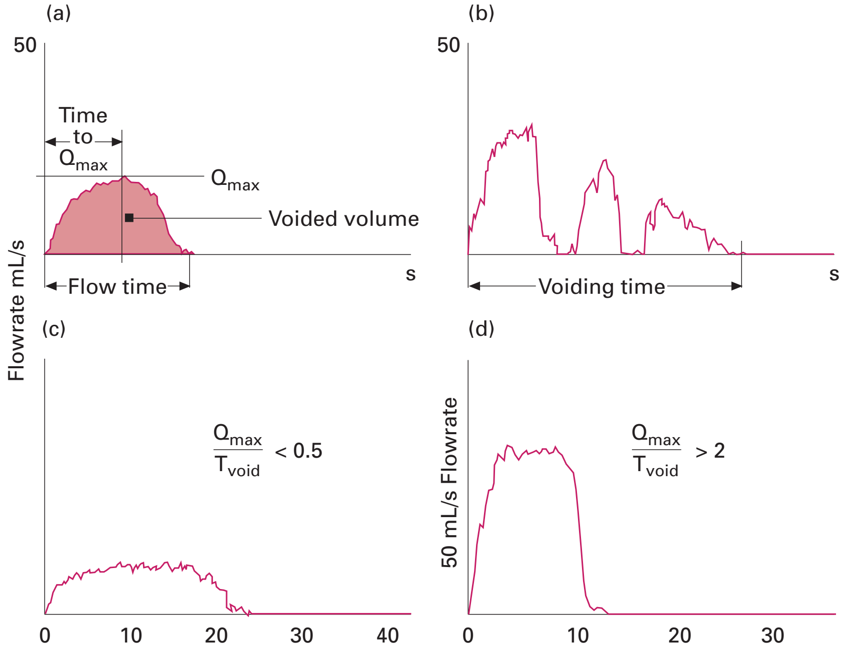

Fig. 5. Flow recordings showing (a) continuous flow and (b) interrupted flow, both using ICS recommended nomenclature. In (c), the 'plateau' flow recording denotes structural obstruction and in (d), a 'tower' flow recording, showing a steep rise and fall in flow rate, with a high Q_{max}.

Opening pressure is the pressure recorded at the onset of measured flow.

Maximum pressure is the maximum value of the measured pressure.

Pressure at maximum flow is the pressure recorded at the maximum measured flow rate.

Contraction pressure at maximum flow is the difference between pressure at maximum flow and premicturition pressure. Postmicturition events (e.g., aftercontraction) are not well understood and so cannot be defined as yet.

Pressure/flow relationships

In the early days of urodynamics the flow rate and voiding pressure were related as a 'urethral resistance factor'. The concept of a resistance factor originates from rigid-tube hydrodynamics. The urethra does not generally behave as a rigid tube; it is an irregular and distensible conduit and its walls and surroundings have active and passive elements which influence the flow through it. Therefore, a resistance factor cannot provide a valid comparison among patients. There are many ways of displaying the relationships between flow and pressure during micturition. An example is suggested in the third ICS report [3]. As yet, available data do not permit a standard presentation of pressure/flow variables. When data from a group of patients are presented, pressure/flow relationships may be shown on a graph, as in Fig. 7. Pressure and flow rate during voiding for an individual patient can also be represented in one continuous diagram, which makes the diagnosis of obstruction less equivocal (Fig. 8).

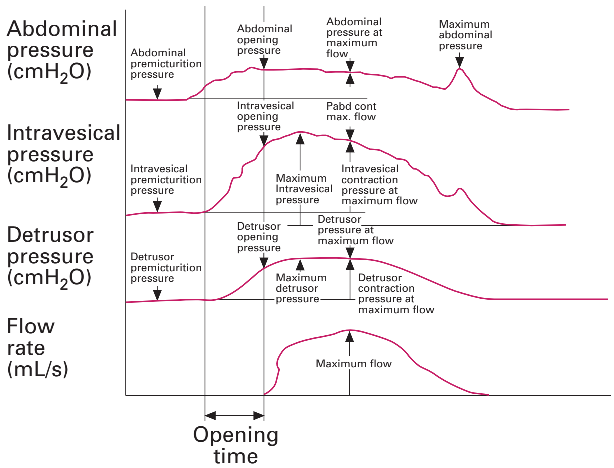

Fig. 6. A pressure/flow/EMG recording of micturition using ICS recommended nomenclature for all variables.

Infravesical obstruction, recorded with a pressure/flow study, may be anatomical or functional. An anatomical obstruction creates a urethral segment with a small and fixed diameter, that does not dilate during voiding. As a result, the flow pattern will become stable, with a low and constant maximum flow rate, despite high detrusor pressure and complete relaxation of the urethral sphincter (Fig. 5c). In a functional obstruction, it is the active contraction of the urethral sphincter during passage of urine that creates the narrow urethral segment, constantly or intermittently. To differentiate anatomical from functional obstruction, information is needed about the activity of the urethral sphincter during voiding.

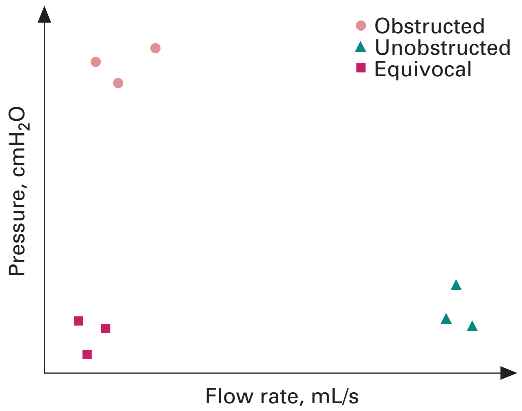

Fig. 7. The pressure data for three groups of patients (obstructed, equivocal and unobstructed). Data are plotted as p_{max} at Q_{max} during voiding at urge for each patient. Equivocal results might include either an unrepresentative micturition in an obstructed or unobstructed patient, or underactive detrusor function with or without obstruction. It is this group which invalidates the use of the term 'urethral resistance factor'.

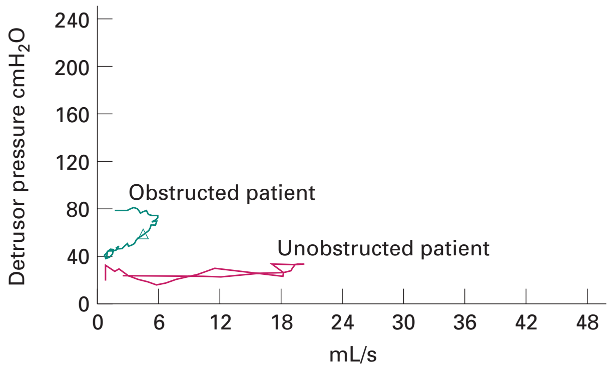

Fig. 8. Continuous registration of flow rate and detrusor pressure during voiding. This simultaneous representation of p/Q during voiding will make the diagnosis of urethral obstruction less equivocal.

This information can be obtained and recorded, together with pressure and flow, by monitoring the urethral pressure at the level of the urethral sphincter, or by recording continuous EMG of the striated urethral sphincter *sensu stricto*. For clinical purposes, in patients where the urethral sphincter is not readily accessible, the EMG of the external anal sphincter is often used to monitor activity of the striated urethral sphincter.

Pressure/flow/EMG study

Continuous EMG, recorded with detrusor pressure and flow rate, is the most widely used urodynamic technique in paediatrics. In the filling phase, the EMG registration is helpful in testing pelvic floor reflexes; in the voiding phase, it is used to monitor urethral activity during voiding. The slow speed of most urodynamic recorders, as well as the inability of pen recorders to follow frequencies above 100 Hz, make it impossible to distinguish electronic 'noise' from true EMG potentials on the recording. It is mandatory to display the EMG signal separately on an oscilloscope (frequency range 50–1000 Hz, time base in milliseconds)

Residual urine

Except in infants, the normal bladder will empty completely, without residual urine, at every micturition. Residual urine is defined as the volume of fluid remaining in the bladder immediately after the completion of micturition. The measurement of residual urine forms an integral part of the study of micturition. However, voiding in unfamiliar surroundings may lead to unrepresentative results, as may voiding on command with a partially filled or overfilled bladder. Residual urine is commonly estimated by (i) catheterization (transurethral, suprapubic), (ii) radiography (excretory urography, micturition cystography), (iii) ultrasonography, or (iv) radioisotopes (clearance, gamma camera). When estimating residual urine, voided volume and the time interval between voiding and residual urine estimation should be recorded. This is particularly important if the patient is in a diuretic phase. In patients with extreme VUR, ureteric urine may enter the bladder immediately after micturition and may falsely be interpreted as residual urine. The absence of residual urine is an observation of clinical value, but does not exclude infravesical obstruction or bladder dysfunction. An isolated finding of residual urine requires confirmation before being considered significant, especially in infants and young children. Residual volumes can be considered clinically significant when they represent, on repeated occasions, volumes of $\geqslant$20 mL, or volumes of $>$10% of the CBC.

Classification of function in the voiding phase

The detrusor during voiding

During micturition, the detrusor may be acontractile, areflexic, underactive, or normal. The acontractile detrusor is one that cannot be shown to contract during urodynamic studies.

Detrusor areflexia is defined as acontractility arising from an abnormality of nervous control and denotes the complete absence of centrally coordinated contraction. In detrusor areflexia caused by a lesion of the conus medullaris or sacral nerve outflow, the detrusor should be described as decentralized, not denervated, as the peripheral neurones remain. In such bladders, pressure fluctuations of low amplitude, sometimes known as 'autonomous' waves, may occasionally occur. The use of terms such as atonic, hypotonic, autonomic and flaccid should be avoided.

Detrusor underactivity is defined as a detrusor contraction of inadequate magnitude and/or duration to effect bladder emptying with a normal time span. The term should be reserved as an expression describing detrusor activity during micturition. Patients may have underactivity during micturition and detrusor overactivity during filling.

Unsustained detrusor contractions are insufficient in duration, not in magnitude, to empty the bladder completely.

Normal detrusor contractility Normal voiding is achieved by a voluntarily initiated detrusor contraction that is sustained and can not usually be suppressed voluntarily, until at least after the age of 4 years.

A normal detrusor contraction will effect complete bladder emptying, in the absence of bladder outlet obstruction. For any given detrusor contraction, the magnitude of the recorded pressure rise will depend on the degree of outlet resistance. In small boys with gross bilateral reflux the detrusor may be overactive during filling and the micturition contraction may give high pressures in the absence of infravesical obstruction.

Urethral function during voiding

During voiding, urethral function may be normal or obstructive. The normal urethra opens to allow the bladder to empty. Obstructive urethral function may be due to urethral overactivity (closure during voiding) or to mechanical causes. Mechanical obstruction is most commonly anatomical, e.g. caused by urethral stricture, or by congenital posterior urethral valves. In infants and small children, occasional urethral overactivity during voiding (with post-void residual urine) is not uncommon; in all probability it is a normal developmental feature. Obstruction caused by urethral overactivity occurs when the urethral and periurethral closure mechanisms contract simultaneously, during voiding, with the detrusor contraction, or fail to open at attempted micturition.

Despite the confusion surrounding sphincter-terminology, the use of certain terms is so widespread that they are retained and defined here.

Detrusor-sphincter dyssynergia (DSD) or *detrusor/external sphincter dyssynergia* describes a detrusor contraction concurrent with an involuntary contraction of the urethral and/or periurethral striated muscle, during micturition; DSD is essentially a common feature of neuropathic bladder/sphincter dysfunction.

(Over)activity of the urethral sphincter may occur during the voiding contraction of the detrusor in neurologically normal children; this set of events is termed *dysfunctional voiding*, as opposed to DSD in neuropathic bladder/sphincter dysfunction. The use of terms such as 'non-neurogenic' or 'occult neuropathic' is to be avoided.

Activity of the striated urethral sphincter also occurs in the absence of detrusor contraction. This is not detrusor/sphincter dyssynergia, but represents the so-called *guarding reflex*, operative, e.g. during coughing.

Procedures related to neurophysiological evaluation

Electromyography

EMG is the study of electrical potentials generated by the depolarization of muscle. The following discussion refers to striated muscle fibres; the functional unit in these fibres is the motor unit, comprising a single motor neurone in the anterior horn of the spinal cord and the muscle fibres it innervates. A motor unit action potential is the recorded depolarization of muscle fibres which results from activation of a single anterior horn cell.

Muscle action potentials may be detected either by needle electrodes or surface electrodes. EMG potentials should be displayed on an oscilloscope screen, to observe single potentials or the full range of interfering frequencies. As an alternative, the frequencies can be monitored as sound, by using an audio amplifier and loudspeaker. A permanent record of EMG potentials can only be made on a chart recorder with a high-frequency response (linear from 1 to 1000 Hz). Computerized urodynamic apparatus often have the same drawback as chart recorders, i.e. the time base is too slow, and because the conversion of analogue EMG frequencies to a digital form is poor, the bandwidth is much too narrow (sampling should be at a rate of at least 1000 Hz).

EMG should be interpreted in the light of the patient's symptoms, physical findings, and urological and urodynamic investigations.

Needle electrodes are placed directly into the muscle mass and permit recording of action potentials from discrete motor units. They are indispensable for studying single unit potentials, but not suited for continuous monitoring during filling and voiding in children.

Surface electrodes are applied to an epithelial surface, as close to the muscle under study as possible. Surface electrodes detect action potentials from groups of adjacent motor units underlying the recording surface. Skin electrodes are strips of silver/silver chloride with a connecting lead, affixed to the skin with adhesive.

Anal and vaginal plug electrodes are generally not well tolerated by children; anal plugs may generate unwanted contraction or relaxation of the pelvic floor. Surface electrodes mounted on a catheter will occlude the urethra, prohibiting pressure/flow/EMG studies. Consequently, these techniques should be avoided.

For clinical purposes, skin electrodes are widely used in children. They are positioned symmetrically left and right from the external anal sphincter. Because of the resistance to electrical current across the skin–electrode interface, the skin should be degreased (alcohol) and desquamated skin removed (abrasive paper) before applying conductive gel and electrodes.

General information

The following details should be given on the EMG; (i) solitary procedure, part of urodynamic or other electrophysiological investigation; (ii) patient position (supine, standing, sitting or other); and (iii) electrode placement (sampling site, recording electrode, reference electrode).
Sampling site, i.e. intrinsic striated muscle of the urethra, periurethral striated muscle, bulbocavernosus muscle, external anal sphincter, pubococcygeus, or other. State whether sites are single or multiple, unilateral or bilateral, and state number of samples per site.

Recording electrode. Define the precise anatomical location of the electrode. For needle electrodes, include the site of needle entry, angle of entry and needle depth. For vaginal or urethral surface electrodes, state the method of determining the position of electrode.

Reference electrode position. Note; ensure that there is no electrical interference with any other machines, e.g. X-ray apparatus.

Technical information

Needle electrodes. Design (concentric, bipolar, monopolar, single fibre, other); dimensions (length, diameter, recording area); electrode material (e.g. platinum).

Surface electrodes. Type (skin, plug, catheter, other); size and shape; electrode material (silver/silver chloride); mode of fixation to recording surface; conducting medium (e.g. saline, jelly).

Amplifier. Make and specifications; sensitivity (mV-mV); filters, low pass (Hz) and high pass (kHz).

Signal processing. Data; raw, averaged, integrated, or other.

Display equipment. Specify make and specifications to include method of calibration, time base, full-scale deflection in microvolts and polarity); oscilloscope, chart recorder, loudspeaker, other.

Storage. Specify make and specifications: paper, magnetic tape recorder, microprocessor, other.

Hard copy production. Specify make and specifications: chart recorder, photographic/video reproduction of oscilloscope screen, other.

EMG findings

Individual motor unit action potentials

Normal motor unit potentials have a characteristic configuration, amplitude and duration. Abnormalities of the motor unit may include an increase in the amplitude, duration and complexity of waveform (polyphasicity) of the potentials. A polyphasic potential is defined as one having more than five deflections. The EMG findings of fibrillations, positive sharp waves, and bizarre high-frequency potentials are thought to be abnormal.

Recruitment patterns

In normal subjects there is a gradual increase in EMG activity from pelvic floor and urethral sphincter during bladder filling. At the onset of micturition there is complete absence of activity. Any EMG activity from the sphincter or pelvic floor during voiding is abnormal unless the patient is attempting to inhibit micturition. In neuropathic bladder/sphincter dysfunction, the finding of increased EMG activity during voiding, accompanied by characteristic simultaneous detrusor pressure and flow changes, is described by the term detrusor-sphincter dyssynergia. In this condition, a detrusor contraction occurs concurrently with an inappropriate contraction of the urethral and/or periurethral striated muscles. In neurologically normal children, this condition is better described as dysfunctional voiding (detrusor/sphincter dyscoordination).

Nerve conduction studies

Nerve conduction studies involve stimulation of a peripheral nerve and recording the time taken for a response to occur in muscle innervated by the nerve under study. The time taken from stimulation of the nerve to the response in the muscle is called the 'latency.' Motor latency is the time taken by the fastest motor fibres in the nerve to conduct impulses to the muscle and it depends on conduction distance and the conduction velocity of the fastest fibres.

Extensive general and technical information can be found in the 6th Report on the standardization of terminology of lower urinary tract function [5] (procedures related to neurophysiological investigations: electromyography, nerve conduction studies, reflex latencies).

Reflex latencies

Reflex latencies require stimulation of a sensory field and recordings from the muscle which contracts reflexively in response to the stimulation. Such responses test reflex arcs, which comprise both afferent and efferent limbs as well as a synaptic region within the CNS. The reflex latency expresses the nerve conduction velocity in both limbs of the arc and the integrity of the CNS at the level of the synapse(s). Increased reflex latency may occur as result of slowed afferent or efferent nerve conduction, or be due to central nervous system conduction delays. Again, General and technical information apply as discussed above under nerve conduction studies.

Evoked responses

Evoked responses are potential changes in CNS neurones resulting from distant stimulation, usually electrical. They are recorded using averaging techniques. Evoked responses may be used to test the integrity of peripheral, spinal, and central nervous pathways. As with nerve conduction studies, the conduction time (latency) may be measured. In addition, information may be gained from the amplitude and configuration of these responses.

Sensory testing

Limited information may be obtained during cystometry by recording such parameters as the first desire to void, urgency or pain. However, sensory function in the lower urinary tract can also be assessed by semi-objective tests, by the measurement of urethral and/or vesical sensory thresholds to a standard applied stimulus such as a known electrical current. These tests can be applied in cooperative children.

General information

Specify; (i) the patient's position (supine, sitting, standing, other); (ii) bladder volume at the time of testing; (iii) the site of applied stimulus (intravesical, intraurethral); (iv) the number of times the stimulus was applied and the response, e.g. the first sensation or the sensation of pulsing; (v) the type of applied stimulus (electrical current or other).

Electrical current. Usually a constant current stimulator is used in urethral sensory measurement. State the electrode characteristics and placement, as in the section on EMG; electrode contact area and distance between electrodes if applicable; impedance characteristics of the system; type of conductive medium used for electrode/epithelial contact. Note that topical anaesthetic agents should not be used. Also state the stimulator make and specifications, and stimulation parameters (pulse width, frequency, pattern, duration, current density).

Other, e.g. mechanical, chemical, physical (temperature).

Definition of sensory thresholds

The vesical/urethral sensory threshold is defined as the least current which consistently produces a sensation perceived by the subject during stimulation at the site under investigation. However, the absolute values vary in relation to the site of the stimulus, the characteristics of the equipment and the stimulation parameters. Normal values should be established for each system.

Bladder cooling test (ice-water test)

The bladder cooling test evaluates a specific bladder reflex that originates from cold receptors in the bladder wall [19]. The reflex is mediated by a sacral pathway separate from the micturition reflex pathway. The bladder cooling test is positive in neurologically normal children up to the age of 4, and negative in children older than 6 years. A negative bladder cooling test in young children indicates a complete lower motor neurone lesion. In older children and adults a positive test indicates damage to the long descending corticospinal tracts.

Units of measurement and symbols

In the urodynamic literature, pressure is measured in centimetres of water pressure, whereas in SI nomenclature the unit is the Pascal (Pa). When Laplace's law is used to calculate tension in the bladder wall, it is often found that pressure is then measured in dyne/cm^2. This lack of uniformity in units leads to confusion when other variables, which are a function of pressure, are computed, e.g. compliance, contraction force, velocity, etc. From these few examples it is evident that standardization is essential for meaningful communication. Many journals now require that the results be given in SI units. Table 1 is designed to guide the application of the SI system to urodynamics and defines the units involved. The SI Unit for pressure is the pascal (Pa), but it is only practical at present to calibrate urodynamic instruments in cmH_2O. One centimetre of water pressure is approximately equal to 100 Pa (1 cmH_2O = 98.07 Pa = 0.098 kPa).

The system in Table 2 has been devised to standardize a code of symbols for use in urodynamic communications. The rationale of the system is to have a basic symbol representing the physical quantity, with qualifying subscripts. The list of basic symbols largely conforms

Table 1 Units and symbols in urodynamics

Quantity	*Acceptable unit*	*Symbol*
Volume	millilitre	mL
Time	second	s
Flow rate	millilitres/second	*mL s^{-1}, mL/s
Pressure	centimetres of water	cmH_2O
Length	metres	m
Velocity	metres/second	*m/s, cm/s, cm s^{-1}
Temperature	degrees Celsius	°C

*depending on the style of the journal, these may be expressed using a solidus or index, and litre may be L or l.

Table 2 List of symbols

Variable	*Symbol*	*Qualifiers (abbr.)*	*Value (abbr.)*
Pressure	p	Bladder (ves)	Maximum (max)
Volume	V	Urethra (ura)	Minimum (min)
Flow rate	Q	Ureter (ure)	Average (ave)
Velocity	v	Detrusor (det)	Isovolumetric (isv)
Time	t	Abdomen (abd)	Isotonic (ist)
Temperature	T	Extern. stream (ext)	Isobaric (isb)
Length	l		Isometric (ism)
Area	A		
Diameter	d		
Force	F		
Energy	E		
Power	P		
Compliance	C		
Work	W		
Energy/volume	e		

Example; $p_{det.max}$ = maximum detrusor pressure; e_{ext} = kinetic energy per unit volume in the external stream.

to international usage. The qualifying subscripts relate to the basic symbols for common urodynamic variables; delimiters for value can be added to the subscripted qualifier.

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